



WORLD-CLASS WAREHOUSING AND MATERIAL HANDLING

Second Edition



EDWARD H. FRAZELLE, PHD.

WORLD-CLASS WAREHOUSING AND MATERIAL HANDLING

SECOND EDITION

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Singapore Sydney Toronto

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This book is dedicated to my Lord, Savior, and Best Friend Jesus Christ,
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CHAPTER ONE

INTRODUCTION TO WAREHOUSING

1.1 Warehousing Through the Years

1.2 Warehousing Fundamentals

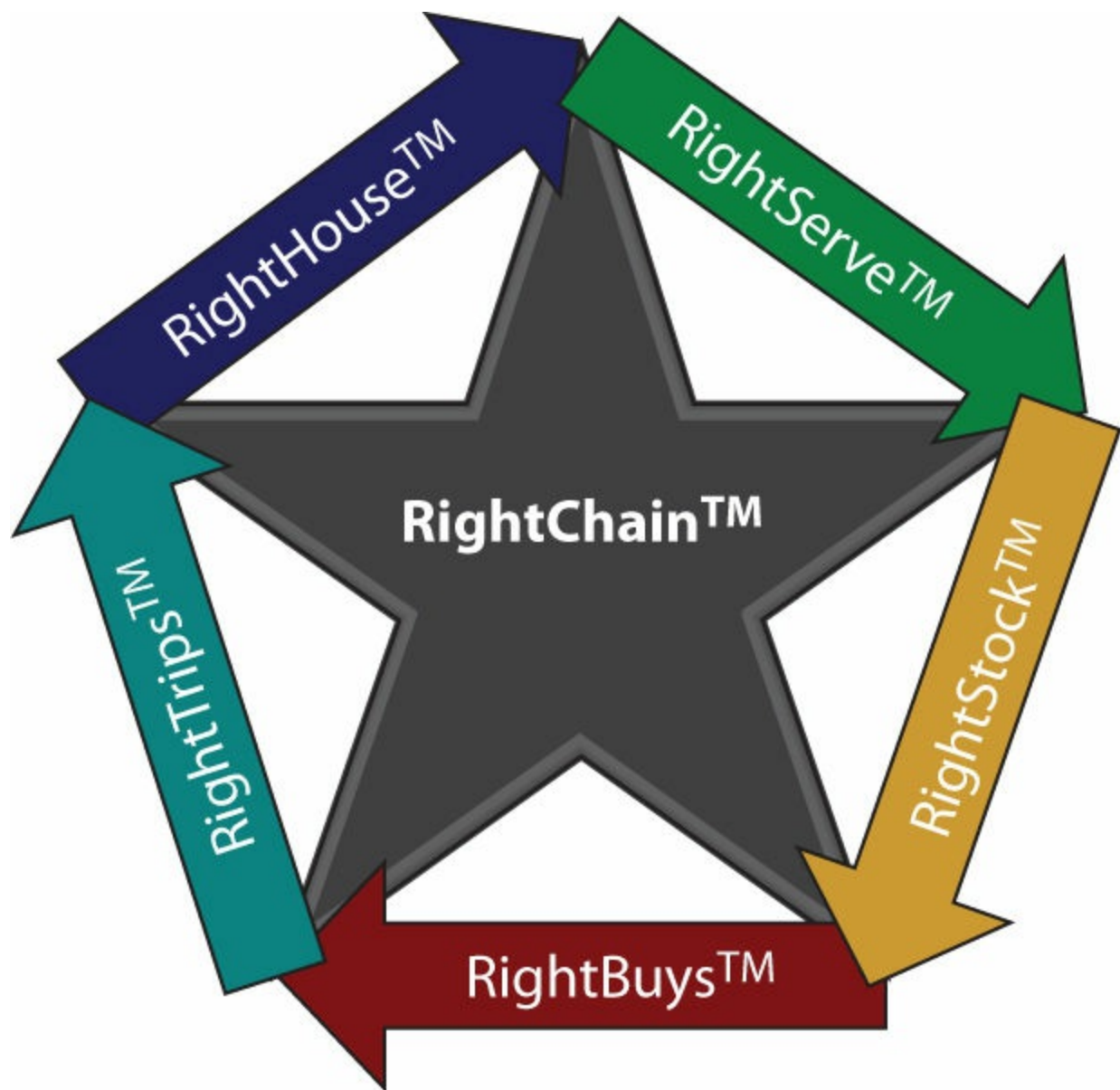
1.3 How to Read This Book

I wrote the first edition of *World-Class Warehousing* in 1995. Back then, people asked me why I was writing a book on warehousing when the just-in-time (JIT) movement was aimed at eliminating warehousing. Today, it's the lean movement. The question is a legitimate one and one I ask seminar attendees every time I teach a warehousing seminar. "Why should we devote our time and energy to studying an activity that every supply-chain professional and the lean literature is trying to eliminate?" A better question might be, "In what ways does warehousing add value in business and in supply chains?" If we can't come up with good answers, then writing this book really was a waste of time, and reading it likewise. As we will see, warehousing plays an indispensable role in business and supply-chain strategy.

Warehousing in the Supply Chain

I developed the RightChain model in the mid-1990s. The model integrates and optimizes walks through the five components of supply chain strategy: customer service, inventory management, supply, transportation, and warehousing. Through those eyes, the value of warehousing is demonstrated in each component clearly visible ([Figure 1.1](#)).

Figure 1.1 RightChain supply-chain logistics model.



Warehousing and Customer Service

Warehousing adds value in customer service, by facilitating high inventory availability, shorter response times, value-added services, returns, customization, and consolidation among others.

Fill rate is the portion of a customer's demand satisfiable from on-hand inventory. In most cases, a significant investment in safety stock is required to provide *high customer fill rates*. That safety stock must be housed somewhere, and that somewhere is typically a warehouse.

Warehouses in close proximity to the customer base and with short internal cycle times help *to reduce response times* to customers. We have one client that provides same-day delivery of critical service parts via a nationwide network of small warehouses with short order cycle times. One of our financial services clients supports its financial analysts with small warehouses located in the centers of major financial districts, serving offices via subway, courier, walking, and bicycles. One of our convenience store clients is improving product freshness by increasing delivery frequencies to its 14,000 stores supported by a major increase in the number and capacity of its warehouses and distribution centers.

Following the mass customization movement, the likelihood that an order will require *customization* in some form is increasing exponentially. The ability to execute the requisite value-added services such as custom labeling, special packaging, monogramming, kitting, coloring, and pricing is and will continue to be a competitive supply-chain differentiator. Warehouses are uniquely equipped with the workforce and equipment to execute these value-added services. In addition, by holding the noncustomized inventory and postponing the customization, overall supply chain inventory levels may be reduced. As the physical facility closest to the customer location, a warehouse is also a natural place to customize, kit, assemble, or countryfy products in accordance with the principle of postponement—minimizing overall inventory investments throughout a logistics network by delaying customization. For example, one of our health and beauty aids clients puts its shampoo in blank bottles for storage. Once an order is confirmed from a specific country, the labeling required for that specific country is applied in line with the picking and shipping process.

One customer service is foundational to our culture's expectations of logistics systems but taken for granted is *consolidation*. For example, if you

order a shirt and a pair of pants from a mail-order company, rarely would you want the shirt showing up one day in one package and the pants showing up another day in another package. For those items to show up at the same time in the same package, they most likely need to be housed under the same roof, that is, in a warehouse.

Returns constitute another customer service facilitated by good warehousing practice. Convenient and inexpensive returns for customers yield higher sales and customer satisfaction ratings. Warehouses and distribution centers are typically already located in close proximity to the customer base and have the workforce and material-handling equipment uniquely suited to handling returns.

Although not directly considered a customer service, in many parts of the world, *physical market presence* is an important cultural competitive differentiator. Warehouses and distribution centers are well-recognized means of establishing physical market presence.

Warehousing and Inventory Management

Because warehouses house inventory (or wares), warehousing adds business and supply-chain value in all the same ways as inventory. Warehouses and their inventory facilitate production economies of scale, optimize factory utilization via seasonal inventory builds, and mitigate supply-chain and business risk by holding contingency and disaster inventory. Despite all efforts to reduce setup and changeover costs and time, there will always remain expensive and time-consuming setups. In those situations, it would be economically foolish to produce short runs. When long production runs are economical, the resulting lot-size inventory must be housed, most effectively in a warehouse. For example, one of our large food and beverage clients was running lot sizes 50 percent below optimal, incurring excessive changeover and production costs as a result. To correct, an additional 150,000 square feet of warehousing space was required, yielding a significant return on investment to their business [Figure 1.2](#).

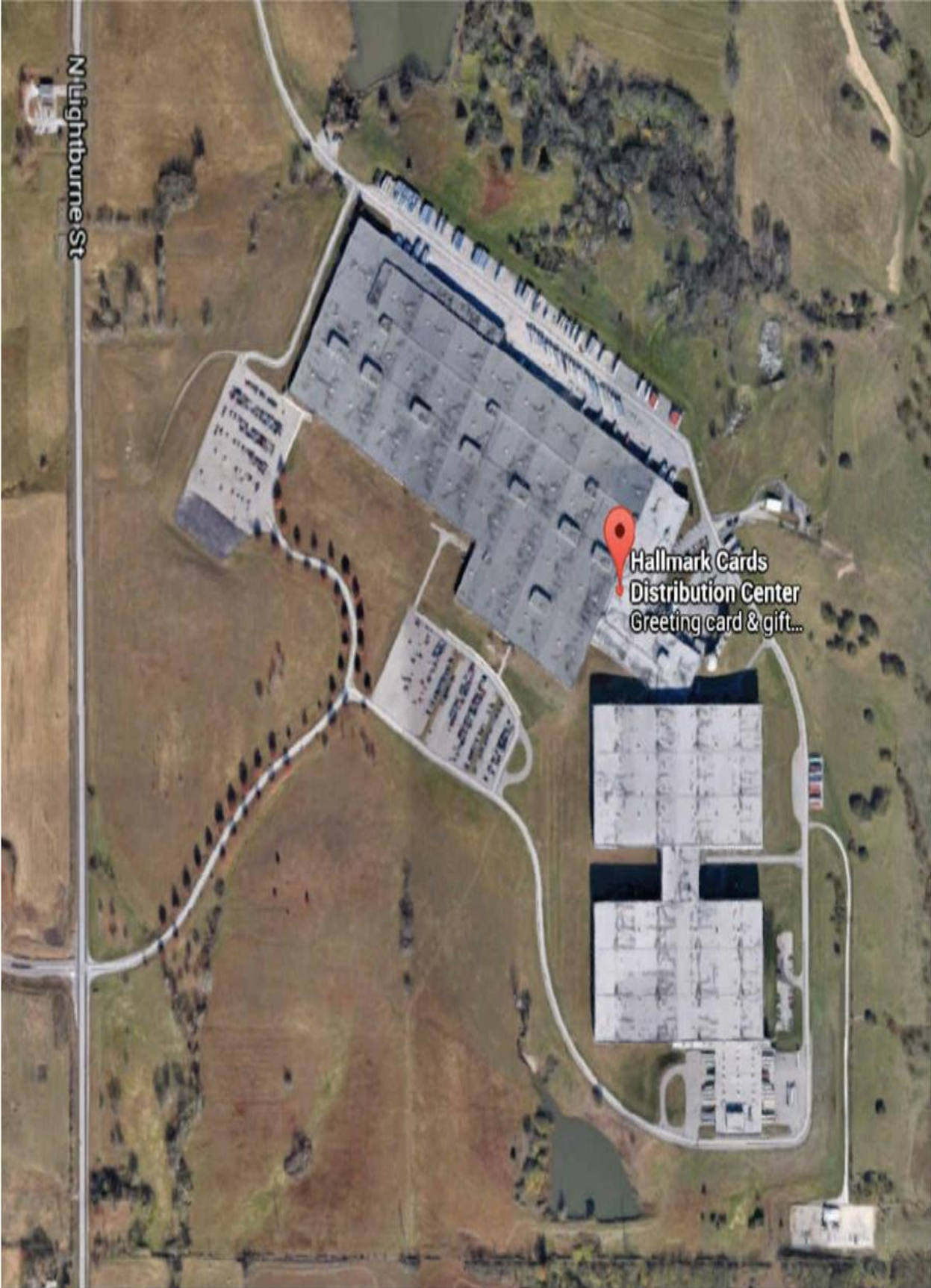
Figure 1.2 Coca-Cola's distribution center near Raleigh, North Carolina, with expanded warehousing square footage to accommodate larger lot sizes and an optimal activity density.



Many corporations have significant peaks and valleys in their demand. One of our clients, Hallmark Cards, is an extreme example. Most of the demand for greeting cards falls in the Christmas and Valentines seasons. If the company's production capacity was designed for those peaks, its production capacity would be cost prohibitively underutilized most of the

year. To balance the production and optimize supply-chain costs, Hallmark produces greeting cards at a fairly balanced pace during the year, resulting in a large storage requirement for most of the year. This *seasonal inventory* is stored in the large warehouse, in [Figure 1.3](#).

Figure 1.3 Hallmark Cards' warehousing complex in Liberty, Missouri. The facility is sized to accommodate inventory buildups in support of extreme seasonal peaks.



The Schwan's Food Company is another one of our clients. One of its flagship products is frozen pie. The company is the world's largest manufacturer of frozen pies, most of which are consumed between Thanksgiving and Christmas. As is the case with Hallmark, to optimize Schwan's supply-chain costs, the company must balance production throughout the year and use third-party frozen warehousing to hold the seasonal buildup in inventory from January through September.

Contingency and disaster inventory insures against unexpected situations outside the realm of those covered by traditional safety-stock inventory. Such situations include natural disasters, labor strikes, and other abnormal supply-chain disruptions. For example, in our work with telecommunications and utilities clients, we often plan for contingency and disaster inventory to maintain service in the increasingly likely event of hurricanes, floods, and snowstorms.

Warehousing and Sourcing

One of our clients is one of the world's largest chocolate candy companies. Of course, the main ingredients are cocoa and sugar. In addition to production, those raw material costs also make up most of the total landed product cost. To help determine the optimal timing of the purchase of sugar and cocoa, the company maintains advanced proprietary weather-forecasting systems and sophisticated predictors of the future price of sugar and cocoa. When our client believes that the price is optimal, it may literally buy boatloads of sugar and cocoa. That sugar and cocoa must be housed somewhere, and that somewhere is a warehouse.

After raw materials, the next most expensive cost component of the company's total landed cost is production. To help keep those costs low, the company operates with extremely long production runs. Because margins are high, inventory carrying rates are low, the risk of obsolescence is low (I have never personally refused a candy bar because of technical or packaging obsolescence), and shelf lives are long, total landed supply-chain costs are optimized with long production runs. Those long production runs create large batches of inventory that must be housed somewhere. That somewhere is a warehouse.

Another means by which companies seek to reduce material cost is low-cost foreign sourcing. The likelihood of an order entering or departing the warehouse from/to another country has never been higher. Warehouses add significant value in the supply chain by facilitating the efficient inbound and outbound processing of international orders. One example is our client, Payless Shoes, one of the world's largest shoe retailers and global importers. Most of the company's shoes are imported from China and arrive in the United States via the Port of Long Beach. Goods arriving there are transloaded into 53-foot containers and trucked to the company's West Coast distribution center in Redlands, California, or the company's East Coast distribution center near Cincinnati, Ohio. Similar West Coast distribution center missions are carried out by the massive concentration of distribution centers in or near Redlands known as the "Inland Empire." A similar empire of distribution centers has grown up around the Port of Savannah, Georgia, where The Home Depot, Ikea, and Pep Boys, among many others, inject imported products into their East Coast logistics networks ([Figures 1.4 through 1.7](#)).

Figure 1.4 The "Inland Empire" is approximately one hour's drive from the ports of Long Beach and Los Angeles, located at the crossroads of major interstates I10, I15, and I215, and is home to a high-quality workforce. It is also home to perhaps the world's largest concentration of warehouses.

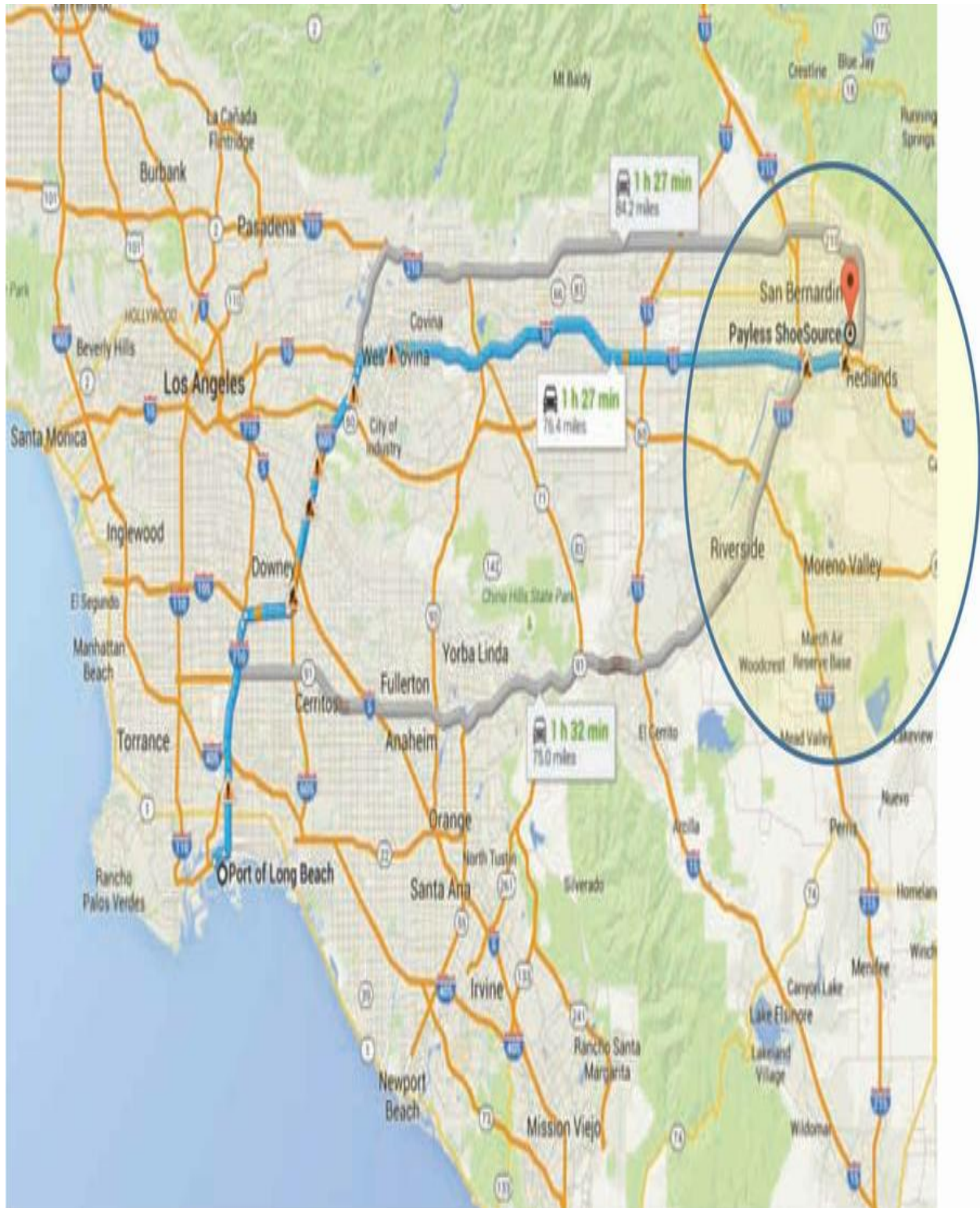


Figure 1.5 Aerial view of a concentration of warehouses and distribution centers in the “Inland Empire”.



Figure 1.6 Aerial view of Payless Shoes' West Coast distribution center (Redlands, California).



Figure 1.7 East Coast “Inland Empire” (Savannah, Georgia).



By postponing title transfer, on-site vendor-managed inventories are another means by which warehousing can add value in business and supply-chain logistics. [Figure 1.8](#) shows one of our mining client's maintenance parts vendor management inventory warehouse locations. The warehouse is located near the large maintenance shops in one of the world's largest copper mines.

Figure 1.8 Rio Tinto's vendor management inventory warehouse in support of maintenance operations for its Kennecott copper mine located outside Salt Lake City, Utah.



Warehousing and Transportation

As supply chains reduce inventory by shipping more frequently in smaller

quantities, warehouses can help to provide transportation economies of scale by working as consolidation points for accumulating and assembling small shipments into larger ones, less-than-truckload shipments into full truckloads, less-than-container-load shipments into full container loads, transloading 40-foot containers to 53-foot containers, and so on ([Figure 1.9](#)).

Figure 1.9 Transloading is the transfer of cargo from 20- or 40-foot ocean containers into domestic 48- or 53-foot trailers. Depicted is Pep Boy's East Coast transload facility located near the Port of Savannah, Georgia.



A frequently overlooked transportation expense is customs duties. Bonded warehouses allow consignees to delay duty payment until their goods are withdrawn from the bonded warehouse. Bonded warehouses located in free-trade zones also permit in-transit goods to pass through without duties being charged at all.

Warehousing and Warehousing

The fifth and last set of RightChain supply chain strategy decisions has to do with warehousing. It's my personal favorite, but I have to admit that it's the last logistics activity that should be considered when developing a supply-chain strategy. First, *a clever trip through the first four RightChain initiatives may eliminate, should minimize, and will correctly determine the need for warehousing as opposed to letting the warehouses play their normal role of being the physical manifestation of the lack of supply-chain coordination, integration, and planning.* Second, the warehouse is like a goalie in a soccer game. Like it or not, it's the last line of defense and needs to be designed accordingly. Third, we need the customer-service, inventory management, supply, and transportation mission requirements from the supply chain strategy to properly plan and operate the warehouse.

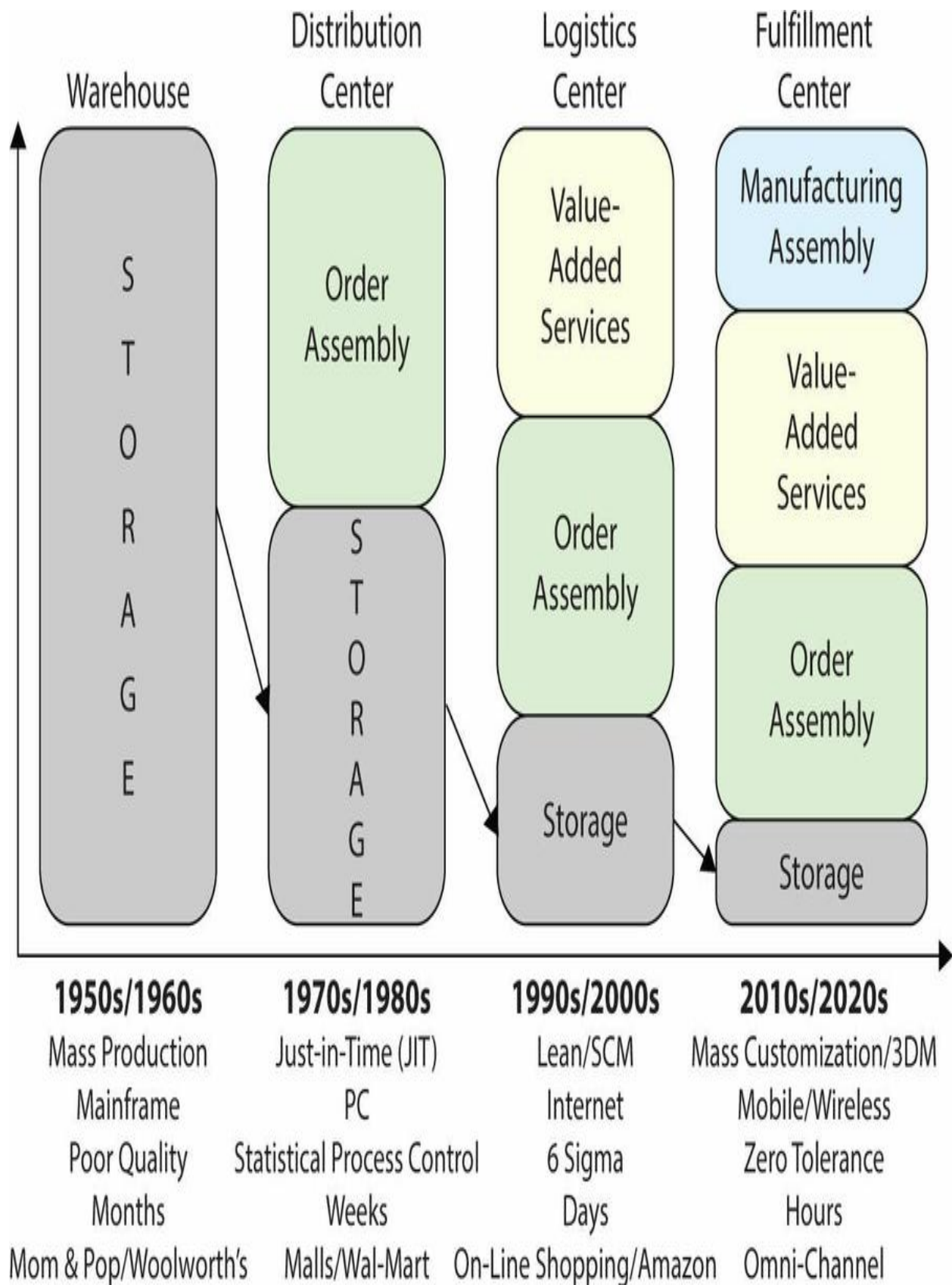
Thus, despite all the initiatives of e-commerce, supply-chain integration, efficient consumer response, quick response, lean Six Sigma, and JIT delivery, the supply chain connecting manufacturing with end consumers will never be so well coordinated that warehousing will be eliminated completely. In fact, the length of supply chains owing to global sourcing and the potential for disruption as a result of increasing numbers and severity of climatic and security incidents are increasing the need for warehousing and the value warehousing adds in businesses and supply chains. As all these disruptions take hold, the role and mission of warehouse operations are changing and will continue to change dramatically.

1.1 Warehousing Through the Years

Warehousing has evolved from a simple activity devoted primarily to material storage in the 1950s and 1960s ([Figure 1.10](#)). With the adoption of

JIT principles in the 1970s and 1980s came smaller order sizes more often, less inventory, and a greater need for order-assembly activities occupying the space made available by inventory reductions. Warehouses were transformed into distribution centers, beginning the reimagining of warehousing from a career-killing profession to a career-making profession. With the adoption of postponement, mass customization, supply chain integration, and global logistics in the 1990s, a number of cross-docking and value-added service activities were added in the warehouse. Logistics centers were created out of distribution centers, combining customized labeling and packaging, kitting, international shipment preparation, customer-dedicated processes, and cross-docking with the traditional activities of storage and order assembly. The distinctions between manufacturing, transportation, and warehousing activities blurred. The margin for error is minimal ([Figure 1.10](#)).

Figure 1.10 Warehousing through the years.



All these changes accumulate to put warehouse managers in duress. Under the influence of e-commerce, supply-chain collaboration, globalization, quick response, and JIT, warehouses today are being asked to

- Execute *more* smaller transactions
- Handle and store *more* items
- Provide *more* product and service customization
- Offer *more* value-added services
- Process *more* returns
- Receive and ship *more* international orders

At the same *time*, warehouses today have

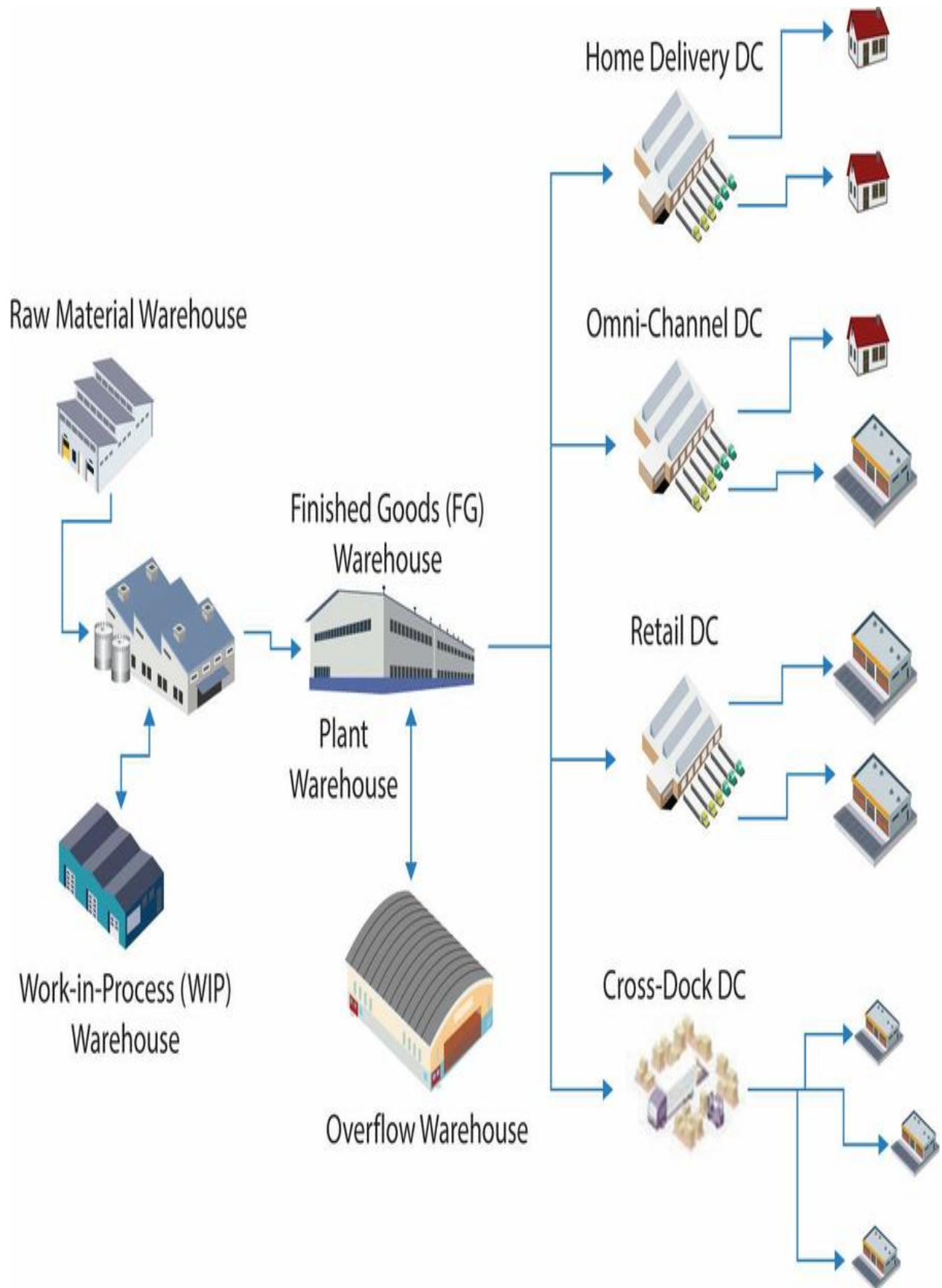
- *Less* time to process an order
- *Less* margin for error
- *Fewer* young, skilled, native-speaking, literate personnel
- *Less* warehouse management system capability (a by-product of Y2K investments in enterprise resource planning systems)

I call this rock-and-a-hard-place scenario the plight of the warehouse manager. Never has the warehouse been asked to do so much and at the same time been so strapped for resources. This makes it even more important to understand the fundamentals and best practices of warehousing. Such an understanding begins with a basic classification of the roles of warehousing in a logistics network.

1.2 Warehousing Fundamentals

Warehouses are not disappearing but continue to play many valuable business and supply chain roles. Those roles have names ([Figure 1.11](#)).

Figure 1.11 The role of the warehouse in the logistics chain.



Raw material warehouses hold inventory near or in factories where the timely support of production and assembly schedules is the key to success.

Work-in-process warehouses hold inventory in or near factories and serve primarily as variation buffers between production schedules and demand.

Finished-goods warehouses (or *plant warehouses*) typically hold large quantities of finished goods awaiting deployment to distribution centers.

Overflow warehouses are typically located near plant warehouses often hold seasonal inventory and are frequently operated by a third party. Nearly two-thirds of all plant warehouses have overflow warehouses.

Distribution center warehouses are located much closer to the customer base than are plant warehouses. Distribution centers typically receive product from many plant warehouses and serve customers with same- or next-day delivery. The delivery point for the distribution center determines its name. Home delivery distribution centers deliver to homes. Retail distribution centers deliver to retail stores. Omni-channel distribution centers deliver to a mix of homes and retail stores. Cross-dock distribution centers do not hold product but simply mix and sort.

Bonded warehouses typically sit inside free-trade zones and facilitate delayed duty payments.

Public warehouses are operated by third parties and are open to the public for what are typically short-term storage agreements.

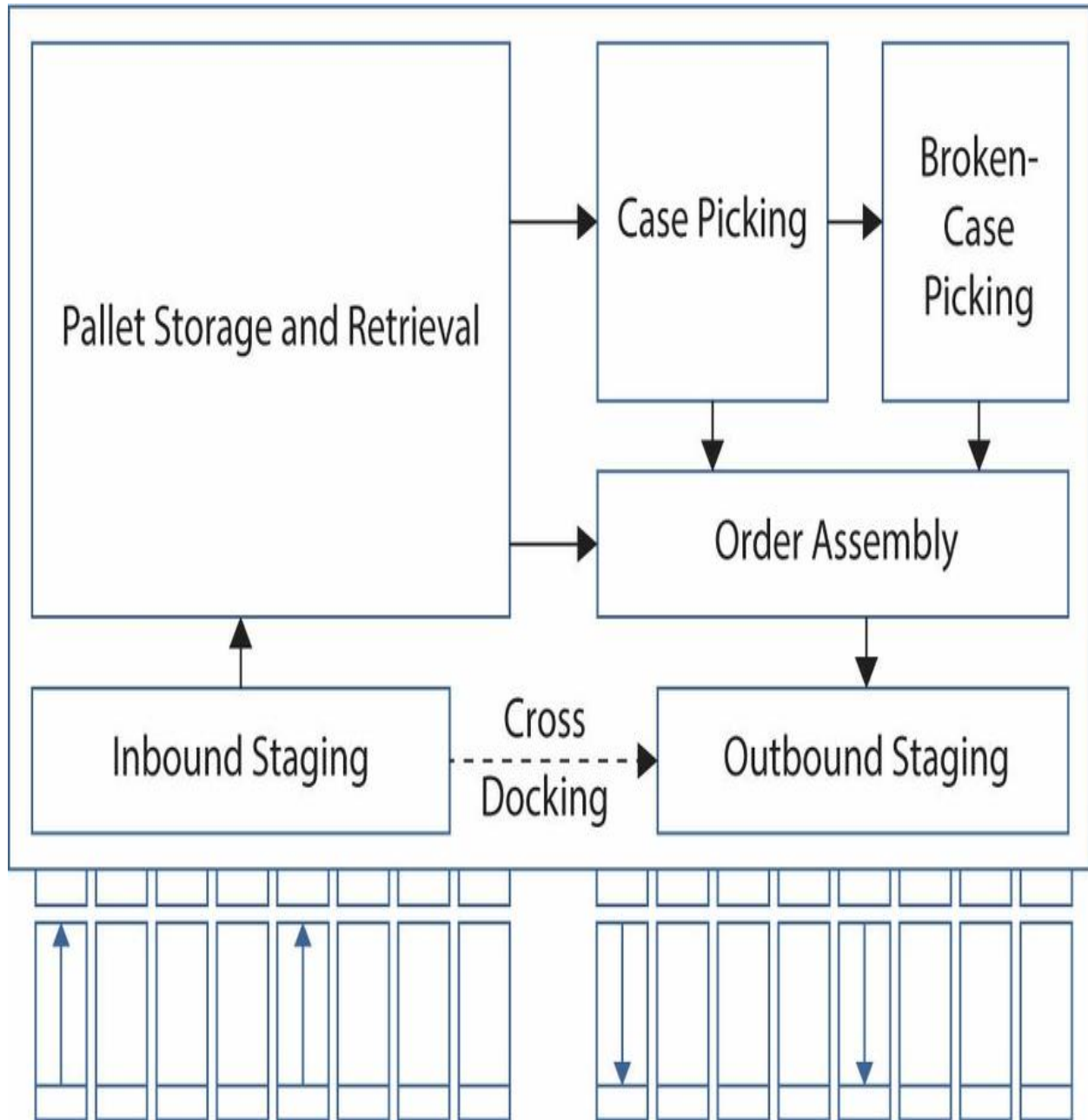
Contract warehouses are operated by third parties and typically are dedicated to single users for extended periods.

Retail back rooms, tool cribs, storerooms, and parts lockers are also forms of warehouses that do not carry the *warehousing* name ([Figures 1.11 through 1.13](#)).

Figure 1.12 Plant finished-goods and raw-materials warehouses supporting H.P. Hood's Winchester dairy plant.



Figure 1.13 Traditional warehouse process flow.



Although the roles and names of warehouses may differ, the internal activities are remarkably similar. Those activities include the following:

1. *Receiving* is the collection of activities involved in (a) the orderly unloading and receipt of all materials coming into the warehouse, in (b) providing the assurance that the quantity and quality of such materials are as ordered, and in (c) disbursing materials to storage or to other organizational functions requiring them. *Prepackaging* is an optional activity that is performed in a warehouse when products are received in bulk from a supplier and subsequently packaged singly, in merchandisable quantities, or in combinations with other parts to form kits or assortments. An entire receipt of merchandise may be processed at once, or a portion may be held in bulk to be processed later. This may be done when packaging greatly increases the storage-cube requirements or when a part is common to several kits or assortments. *Cross-docking* is moving inbound material directly from the receiving dock to the shipping dock, essentially filling orders from receiving.
2. *Put-away* is the act of placing merchandise in storage. It includes moving material to and placing material in assigned put-away locations.
3. *Storage* is the physical containment of merchandise while it is awaiting a demand or until it is released from quarantine. The storage method depends on the size and quantity of the items in inventory and the handling characteristics of the product and/or its container. We characterize storage systems as pallet storage systems, case storage systems, and broken-case storage systems.
4. *Order picking* is the process of removing items from storage to meet a specific demand. Order picking is the basic service a warehouse provides for its customers, and it is the function around which most warehouse designs are based.
5. *Shipping* typically includes
 - a. Sorting batch picks into individual orders and accumulating distributed picks into orders (This must be done when an order has more than one item and the accumulation is not done as the picks are made.)
 - b. Checking orders for completeness and accuracy
 - c. Packaging merchandise in an appropriate shipping container
 - d. Preparing shipping documents, including packing lists, address labels, and/or bills of lading
 - e. Weighing and cubing shipments to determine shipping charges

- f. Accumulating orders by outbound carrier
- g. Loading trucks

1.3 How to Read This Book

World-Class Warehousing and Material Handling is a journey through our RightHouse principles and practices required to execute each warehouse activity at a world-class level. First is RightViews, warehouse activity profiling, the data and pattern recognition required to quickly and objectively reveal opportunities for simplification, process integration, and process automation. Second is RightScores, warehouse performance, cost, and value measures, where we will consider financial, productivity, utilization, quality, and cycle-time metrics and how to use them in justifying new warehouse projects. Third are RightIns and RightPuts, aimed at optimizing receiving and put-away. There we will study cross-docking, direct put-away, directed put-away, dock optimization, prereceiving, and interleaving. RightStore, discussed in [Chapters 5, 6, and 7](#), presents systems and best practices for optimizing pallet storage and retrieval, case storage and picking, and broken-case storage and picking. RightPick and RightShip present principles and practices to optimize order picking and shipping. RightPaths presents our seven-step methodology for optimizing warehouse layout and material flow. RightComms concludes the book with a presentation of the latest warehouse communication systems.

Our RightHouse principles were developed during a retrospective review of hundreds of warehousing projects, including greenfield warehouse designs, warehouse layout designs, warehouse operations benchmarking, warehouse process improvement, and warehouse management systems design and implementation in literally every part of the world. The common denominator in those breakthrough process improvements is the elimination and simplification of work content. To the extent to which you can eliminate and simplify that work content, you will be successful in your pursuit of world-class warehousing.

CHAPTER TWO

WAREHOUSE ACTIVITY PROFILING, DATA MINING, AND PATTERN RECOGNITION

2.1 The P's and P's of Profiling

2.2 Warehouse Activity Profiles

2.3 Calendar-Clock Profiles

2.4 Item Activity Profiling

2.5 Inventory Profile

Imagine that you were sick and went to a doctor for a diagnosis and prescription. When you arrived at the doctor's office, he already had a prescription waiting for you, without even talking to you, let alone looking at you, examining you, or doing blood work. In effect, he wrote your prescription with his eyes closed and a random prescription generator. Needless to say, you would not be going back to that doctor for treatment.

Unfortunately, the prescriptions for many sick warehouses are written and

implemented without much examination either. For lack of knowledge, lack of tools, and/or lack of time, many warehouse projects launch without any understanding of the root cause of the problems and without exploration of the real opportunities for improvement.

Warehouse activity profiling and data mining is the systematic analysis of item and order activity, seeking to identify and take advantage of patterns of opportunity. Our pattern recognition algorithms highlight the root cause of material and information flow problems, pinpoint major opportunities for process improvements, and provide an objective basis for project-team decision making.

I will start with some of the major motivations and potential roadblocks to successful profiling. Then I will review a full set of example profiles and their interpretations. The examples will serve to teach the principles of profiling and as an outline for the full set of profiles required for warehouse reengineering.

2.1 The P's and P's of Profiling

I have been leading, facilitating, researching, and teaching activity profiling and data mining for more than 20 years. I recently summarized our lessons learned as the *P's and P's of profiling*.

The Preparation of Profiling

The first thing I do before writing a new article is to read what others have written about the topic. If I am preparing to teach a class or a seminar, I do the same thing: I review what others have prepared on the topic to stimulate my thinking. Reviewing activity profiles works the same way; it is like reading an illustrated journal of the warehouse activity. As you study the profiles of customer orders, purchase orders, item activity, inventory levels, and so on, the creative juices should begin to flow as your understanding of underlying activity improves.

The Power of Profiling

Done properly, the patterns in profiling quickly reveal a small set of candidate process flows and material handling equipment types for each warehouse activity. Conversely, profiling quickly eliminates process and equipment options that really do not warrant consideration. Many warehouse reengineering projects go awry because we waste valuable resources analyzing concepts that were doomed from the start.

The Participation of Profiling

Profiling involves key stakeholders. During the profiling process, it is natural to ask people from many affected groups to provide data, to verify and rationalize data, and to help interpret results. To the extent those stakeholders have been involved, they have helped with the design process.

The Probity of Profiling

Profiling supports and promotes objective decisions. I worked with one client whose team leader we somewhat affectionately called “Captain Carousels.” No matter what the data said, no matter what the order and profiles looked like, no matter what the company could afford, he was going to have carousels in the new design.

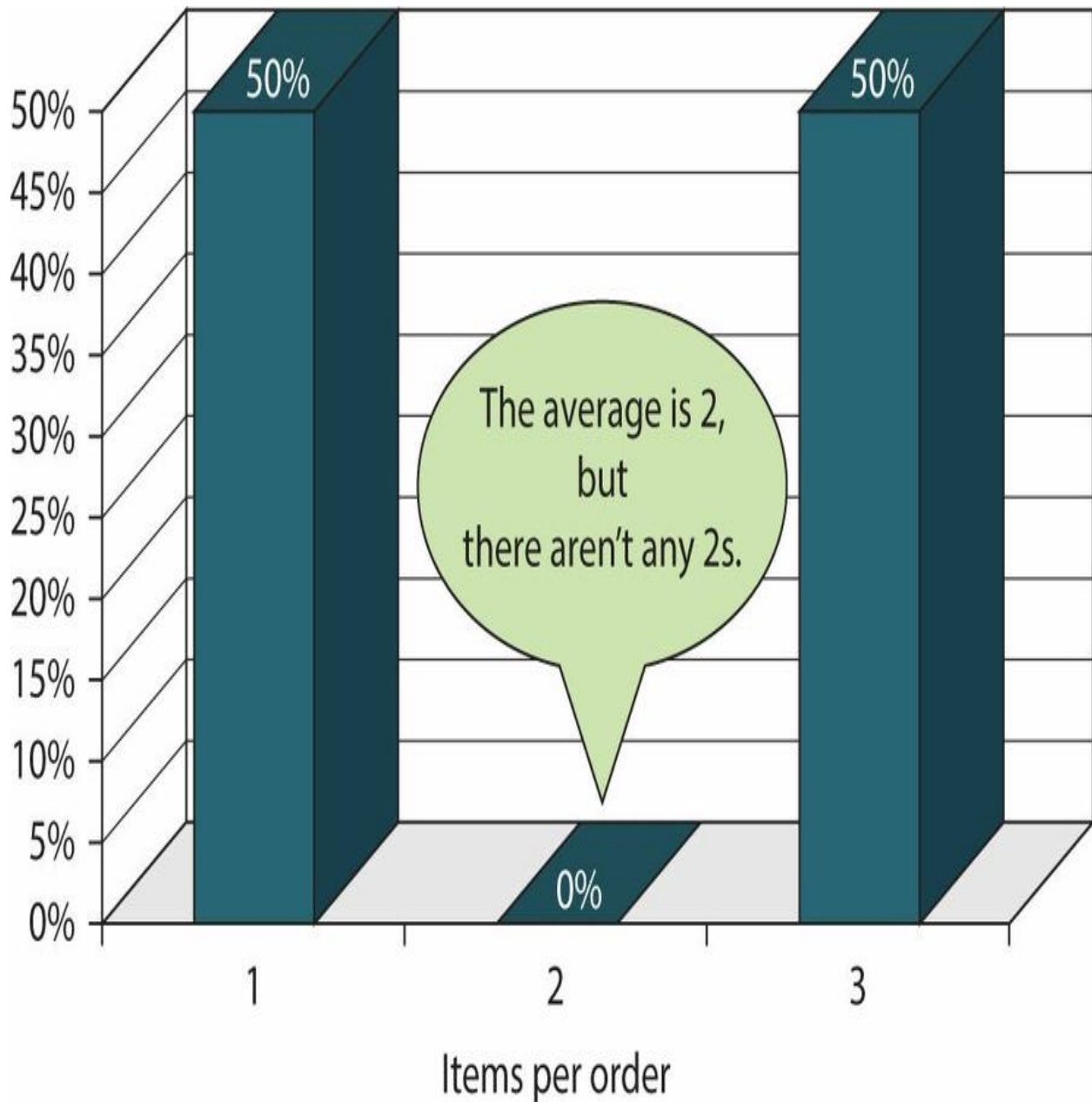
The Purpose of Profiling

You will see myriad complex statistical distributions in our journey through warehouse activity profiling. Why go to all the trouble?

Suppose that we are trying to determine the average number of items on an order. [Figure 2.1](#) shows that 50 orders are for one item, 0 are for two items, and 50 are for three items. What is the average number of items per order? It’s two. How often does that happen? It never happens! If we are not careful to plan and design based on distributions as opposed to averages, our plans and designs will be flawed.

Figure 2.1 Items per order distribution completed for a small mail-order

company. The average is two lines per order, but the average never happens.



The Principal and Principle of Profiling

Vilfredo Pareto was an Italian economist and gardener. Pareto's law stems from his observation that 80 percent of the land was owned by 20 percent of

the population and that 20 percent of the peapods in his garden yielded 80 percent of the peas. Joseph Juran called this principle the “separation of the vital few from the trivial many.” Activity profiling and data mining are essentially the repeated and logical application of *Pareto’s law*, sometimes referred to as the *80/20 principle* or *ABC analysis*. Examples of Pareto’s law working in warehousing include

- A minority of the items generate a majority of the activity.
- A minority of the items are responsible for a majority of the inventory.
- A minority of the customers generate a majority of the picking and shipping activity.

The Pictures of Profiling

When you see a picture you experience a thousand simultaneous thoughts. We are aiming for the same effect in warehouse activity profiling as we paint a representative picture of warehouse activity. In profiling, we capture the activity of the warehouse in pictorial form so that we can quickly develop wise, data driven, consensus decisions.

The Perspectives of Profiling

If a picture is worth a thousand words, then a video is worth a thousand pictures. Interactive data visualization, simulation, and animation are the closest media we have to video for activity profiling. Interactive data visualization ([Figure 2.2](#)) is simply dynamic charting controlled by the user. Simulation ([Figure 2.3](#)) is typically a two-dimensional representation of the physical warehouse with the activity profiles moving warehouse objects according to the profiles. Animation ([Figure 2.4](#)) is three-dimensional simulation.

Figure 2.2 Interactive warehouse data visualization for a large consumer products company.

RightSpace™ | Space Requirements Simulation

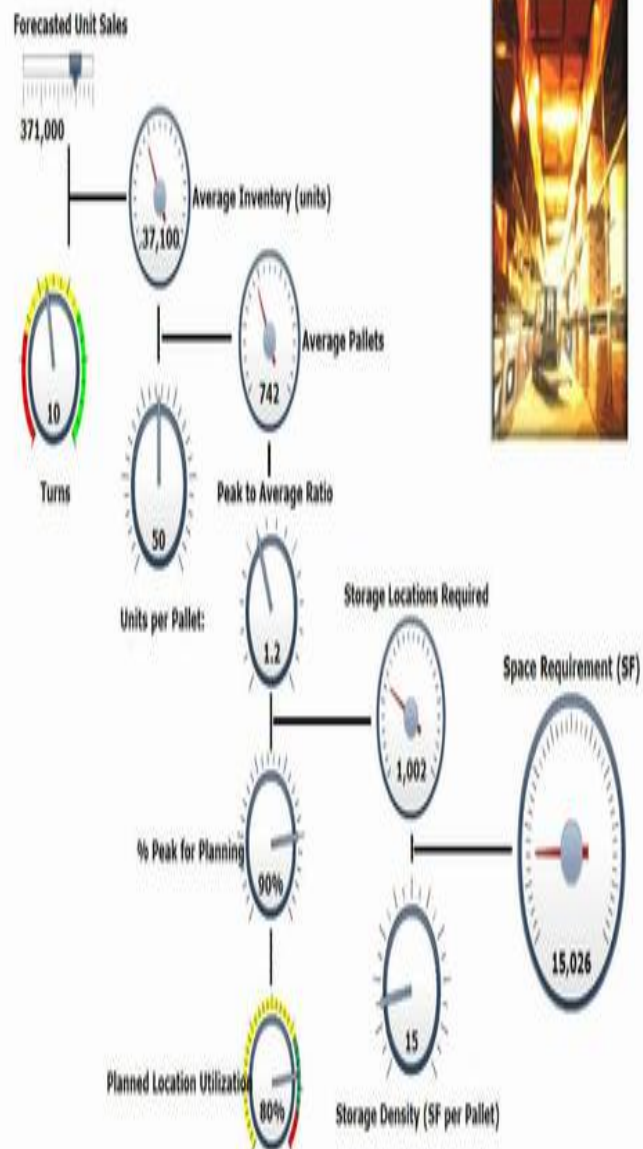


Figure 2.3 Two-dimensional warehouse simulation for a large pharmaceutical company.

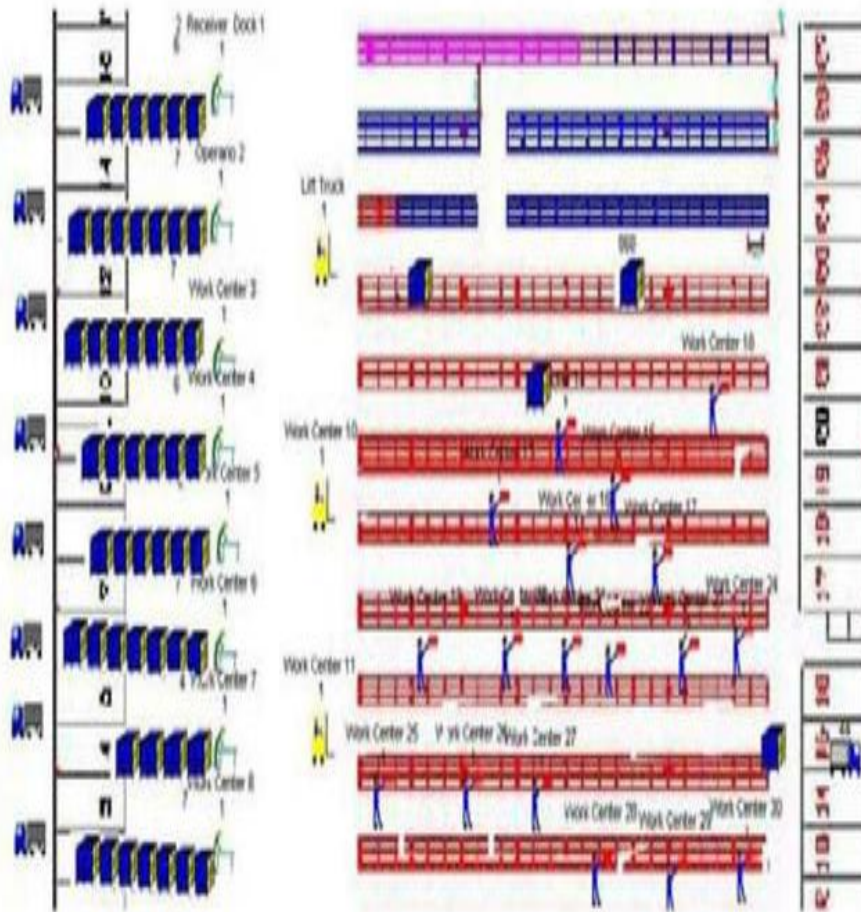
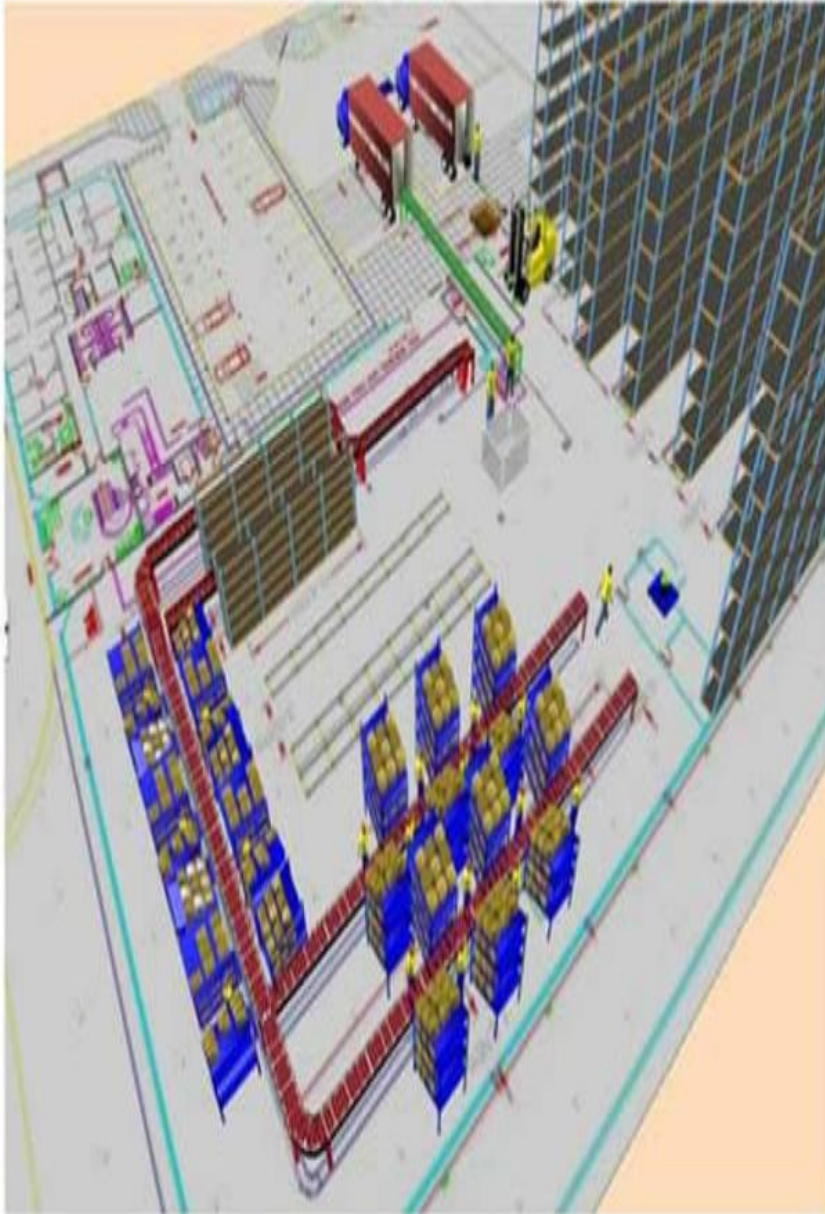


Figure 2.4 3D animation model of a large cosmetics distribution center.



AVON DC SIMULATION | ORDER PICKING

The Pitfalls of Profiling

One warning before we begin to profile the warehouse (as an engineer and logistics nerd, I fall into this trap a lot): We can drown in our own profiles. Some people call this *paralysis of analysis*! If we are not careful, we can get so caught up in profiling itself that we forget to solve the problem.

2.2 Warehouse Activity Profiles

Over the years we have developed a structured and comprehensive suite of activity profiles to address the major planning, design, and management decisions in a supply chain strategy. The profiles are constructed with our proprietary pattern recognition algorithms and are fed from a supply chain data warehouse ([Figure 2.5](#)). The warehouse activity profiles are organized according to [Figure 2.6](#).

Figure 2.5 RightChain™ Decision Support Suite.

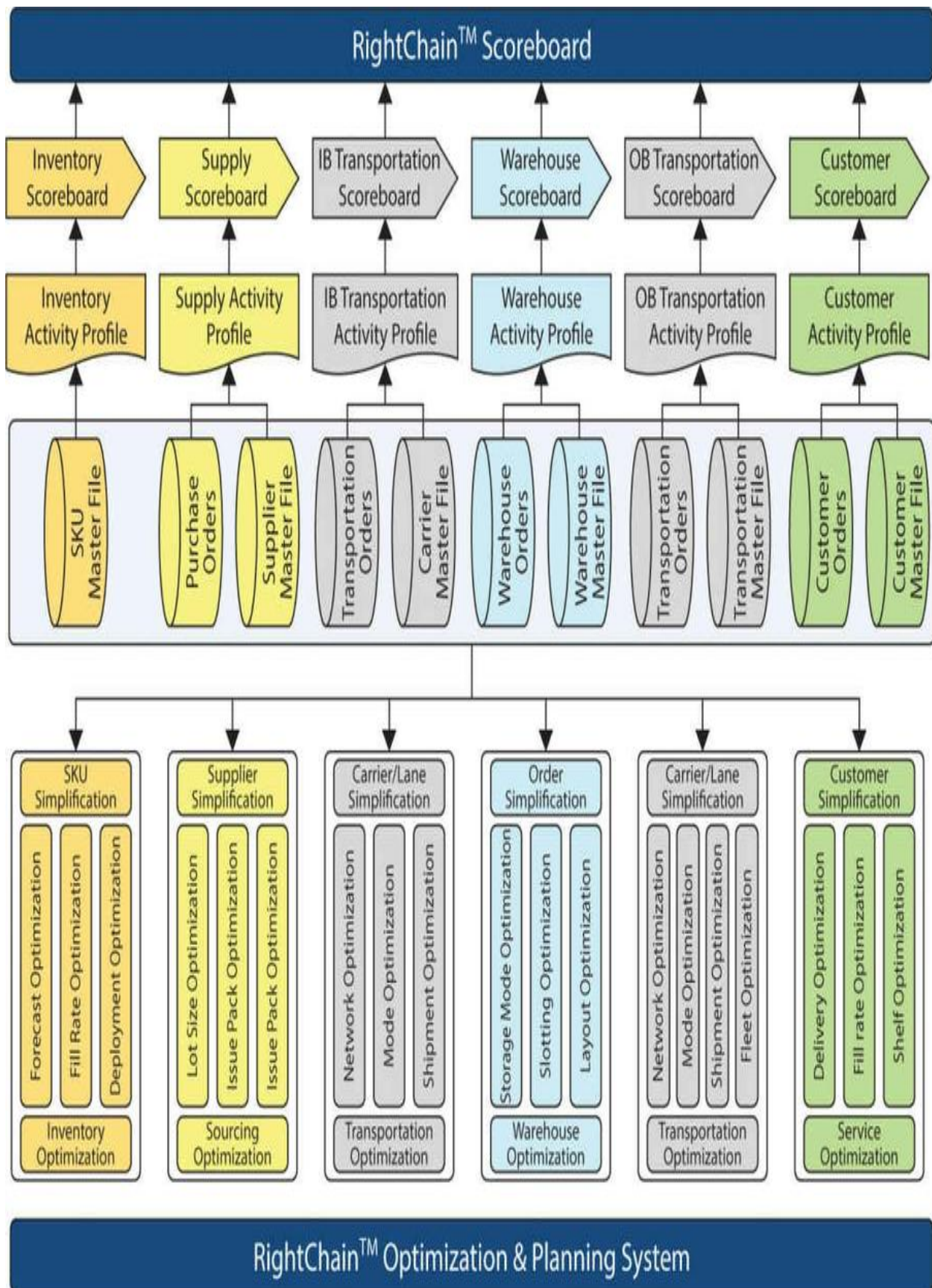
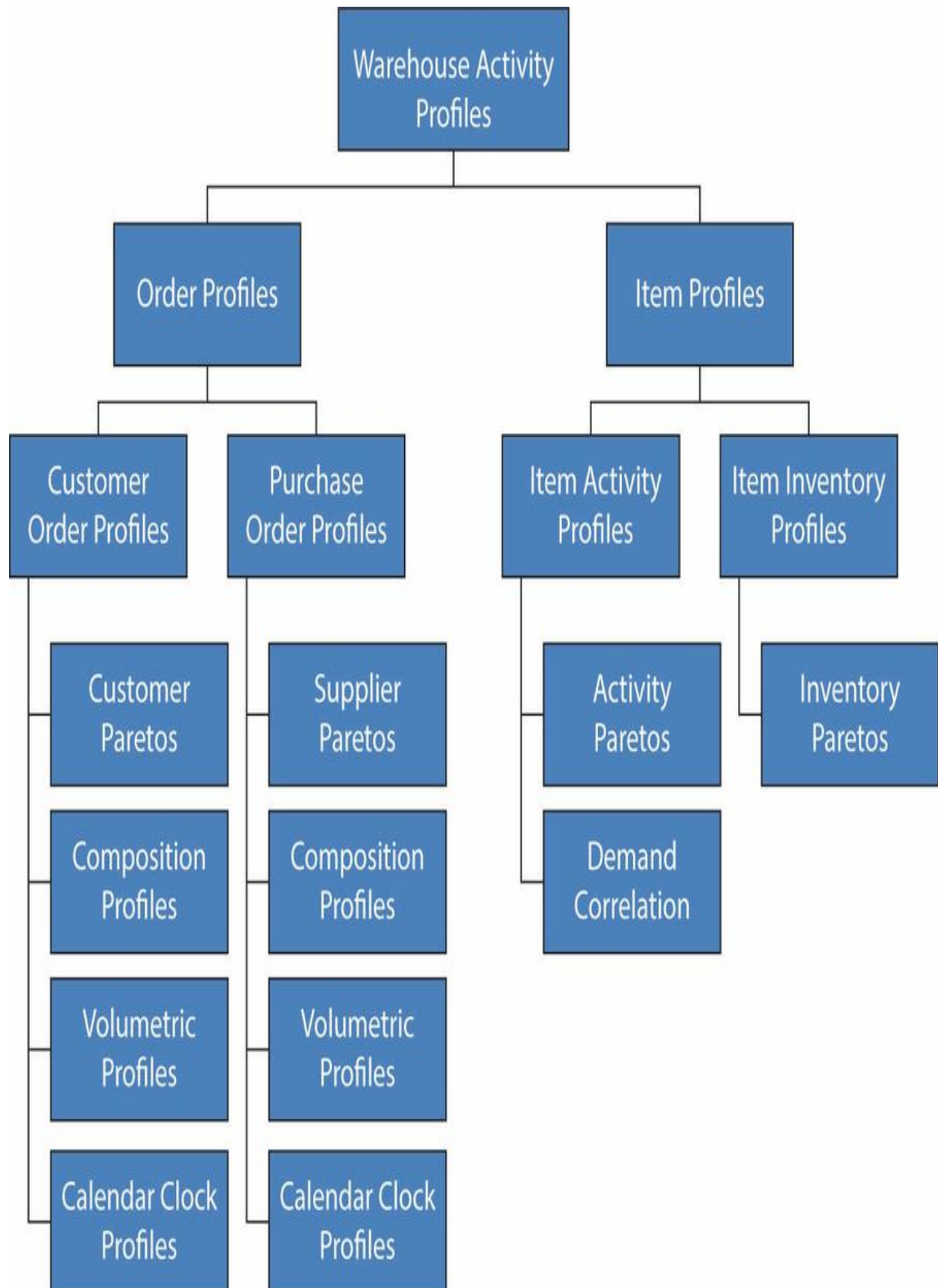


Figure 2.6 Warehouse activity profiles.



Order Profiles

Order profiles include customer order profiles, purchase order profiles, and inbound/outbound transportation order profiles. They jointly portray the major patterns of warehouse activity. Time and space do not permit a full description of each of the four major profiles. I selected customer order profiles as the context for our presentation on order profiles.

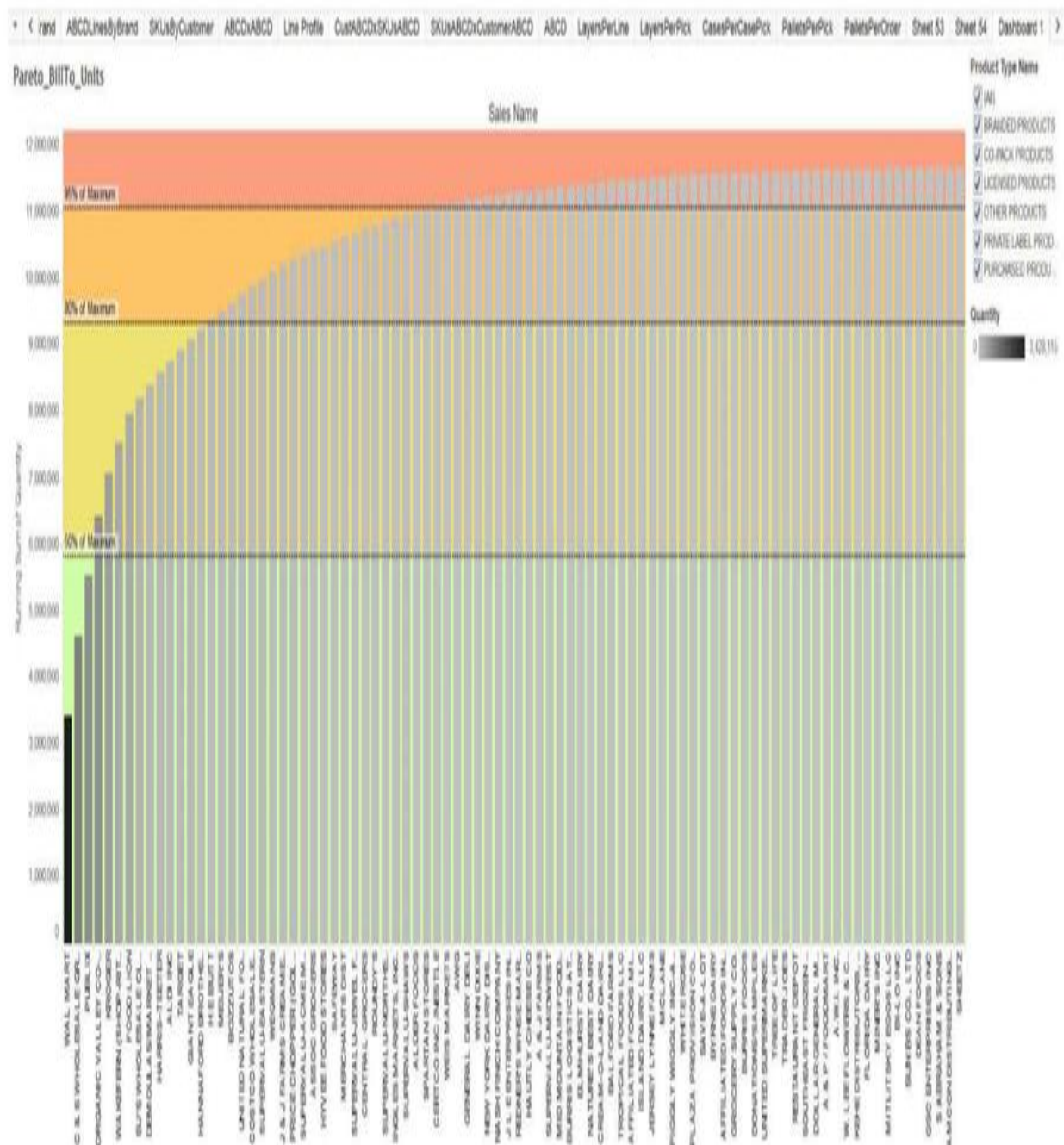
Material and information should flow through a warehouse to facilitate excellent customer service. What do customers really want from a warehouse? They want their orders filled in an accurate, timely, and cost-effective manner. Accordingly, the first thing we must understand to plan and design warehouse operations is the profile of customers and their orders.

Customer Paretos

Some customers place such high demands on a warehouse, represent such a large portion of the activity of the warehouse, and have such demanding customer-service requirements that it may make sense to establish a separate area within the warehouse for those customers. For example, one of our apparel manufacturing clients does so much business with JC Penney that they have a JC Penney warehouse within their warehouse. It is not uncommon for consumer products and food manufacturing companies to have areas within their warehousing dedicated to Wal-Mart activity.

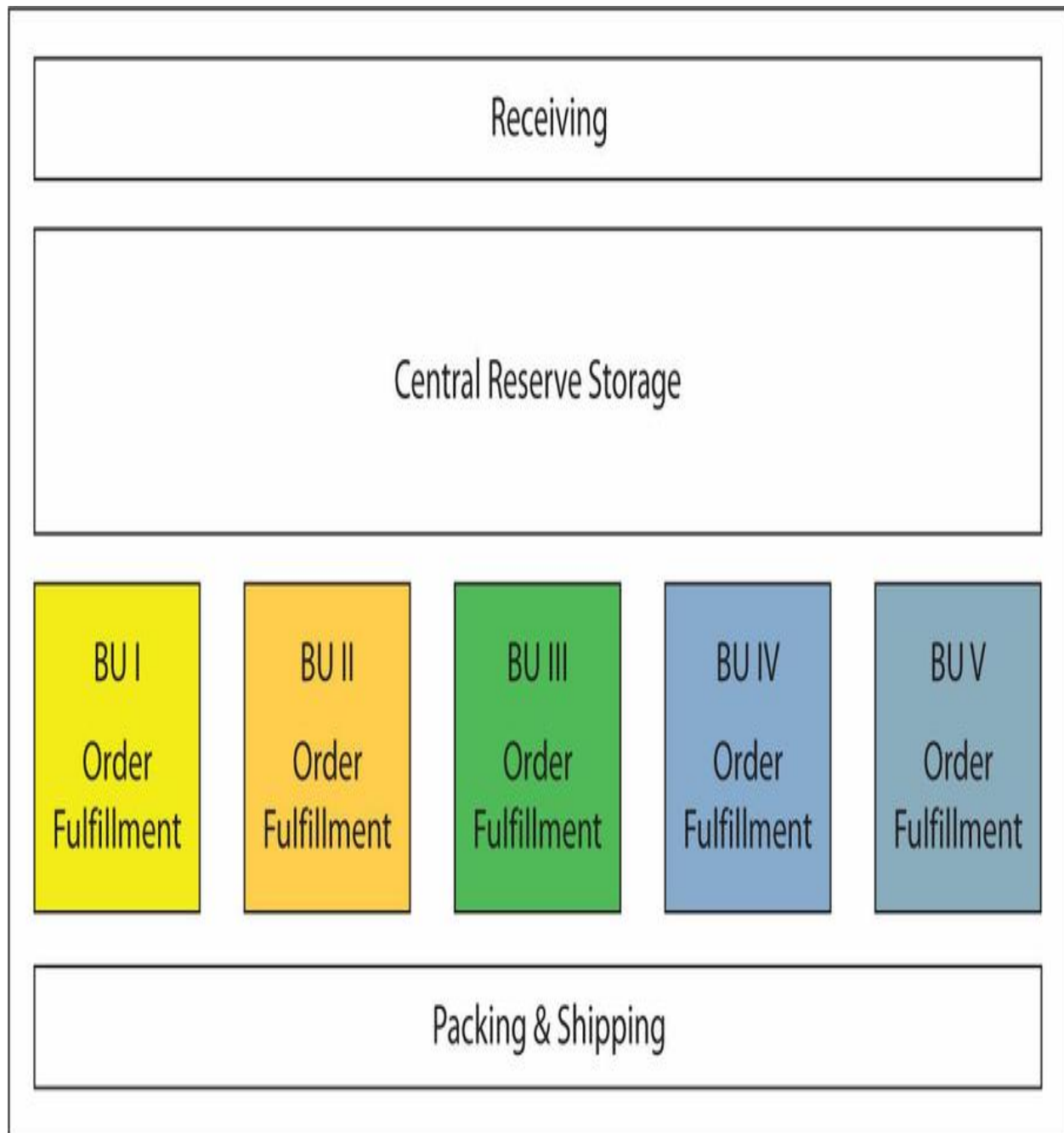
The customer pareto in [Figure 2.7](#) is from one of our food and beverage clients. Note that just three customers make up 50 percent of our client's distribution center activity. Accordingly, we assigned each of those customers their own zones in the warehouse to reduce travel time and improve customer service.

Figure 2.7 A small minority of customers generate a large majority of picking and shipping activity.



In another example ([Figure 2.8](#)), in a large publisher's distribution center, a central pool of reserve stock is used to support three distinct internal customers/business units—retail, trade, and periodicals. We designed the central, shared warehouse with allocated, random storage and the forward picking areas with dedicated, distinct forward picking zones. The manager of each forward picking zone has a dotted-line reporting relationship with the business unit to which his or her picking zone reports. The solid-line reporting relationship is to the director of distribution. This warehouse-within-a-warehouse design yielded the best of both worlds—shared receiving resources, efficient handling of central inventory, dedicated forward picking lines, shared shipping resources, and business unit accountability.

Figure 2.8 Warehouse-within-a-warehouse concept developed for a large publishing company.



The warehouse-within-a-warehouse design philosophy works because small warehouses, in general, have higher productivity, response time, and accuracy performance than large warehouses. Many of the customer-order and item-activity profiles identify opportunities to subdivide a warehouse operation into self-contained warehouse processing cells, virtual warehouses, or warehouses within the warehouse. A warehouse within a warehouse is similar to a flexible manufacturing cell in a factory, where the productivity,

quality, and cycle time are much better than in the factory as a whole.

Composition Profiles

Customer order composition profiles include the following:

- Family-mix profiles
- Handling-mix profiles
- Order-increment profiles

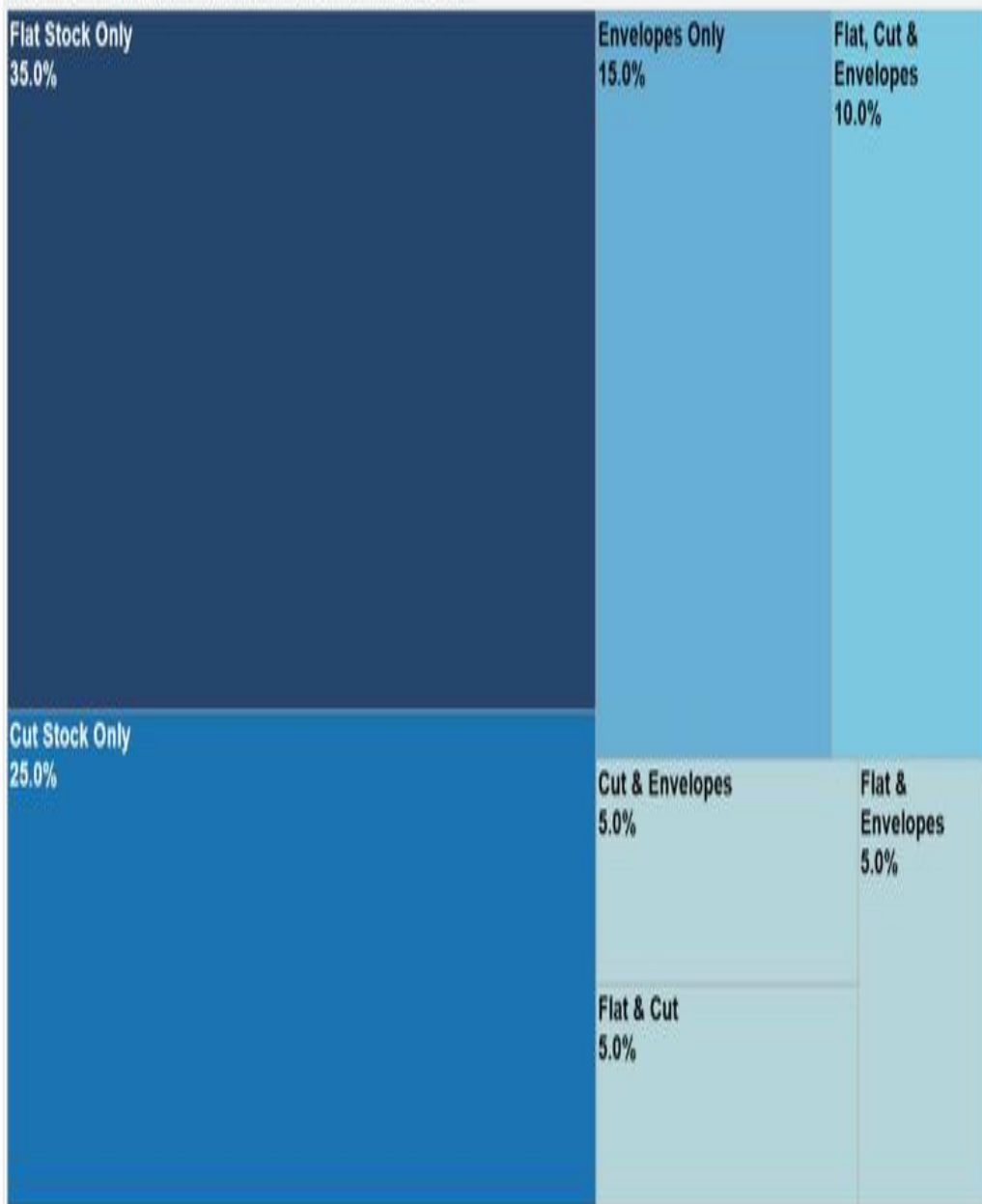
Family-Mix Profiles The overall operating strategy of a warehouse should be influenced by the extent to which orders require items from multiple families. If the majority of the orders are *pure*, drawing from a single product family, then zoning the warehouse on that basis could create virtual warehouses within the warehouse.

For example, the family-mix profile in [Figure 2.9](#) was developed for a wholesale distributor of fine papers, copy/laser paper, and envelopes. Printers make high-quality brochures from *flat stocks* of fine papers. A carton of flat stock is 30 inches long, 24 inches wide, and 9 inches deep. A carton weighs 80 pounds. *Cut stock* is basic 8½- by 11-inch copier and laser printer paper. A carton of cut stock is 24 inches long, 10 inches wide, and 10 inches deep. A carton weighs 20 pounds. The third product family is *envelopes*—extremely small and lightweight merchandise.

Figure 2.9 Family-mix profile for a large paper distributor.

RightViews™ | Order Profiles | Customer Orders | Family Mix

RightViews™ | Warehouse | Sales Order Profile | Families per Order



In this example (Figure 2.9), we are evaluating the merits of zoning based on those three product families—flat stock, cut stock, and envelopes. If the orders are *mixed*—that is, flat stock, cut stock, and envelopes tend to appear together on customer orders—then in pallet building, we would start with flat stock, put cut stock on top of that, and put envelopes on top of that. If we zone the warehouse that way, we may pay a big travel-time penalty passing pallets between those zones. However, if the orders are *pure*—that is, they tend to be “complete-able” out of a single product family—then zoning the warehouse by product family will establish efficient warehouse processing cells, especially since inbound loads already arrive in those same product families.

In Figure 2.9, 35 percent of the orders can be completed solely from flat stock items, 25 percent can be completed solely from cut stock items, and 15 percent can be completed solely envelope items. The good news is that 75 percent of the orders (35 percent + 25 percent + 15 percent) can be completed within a single product family. Zoning the warehouse based upon those families yielded a 38 percent increase in overall operating productivity.

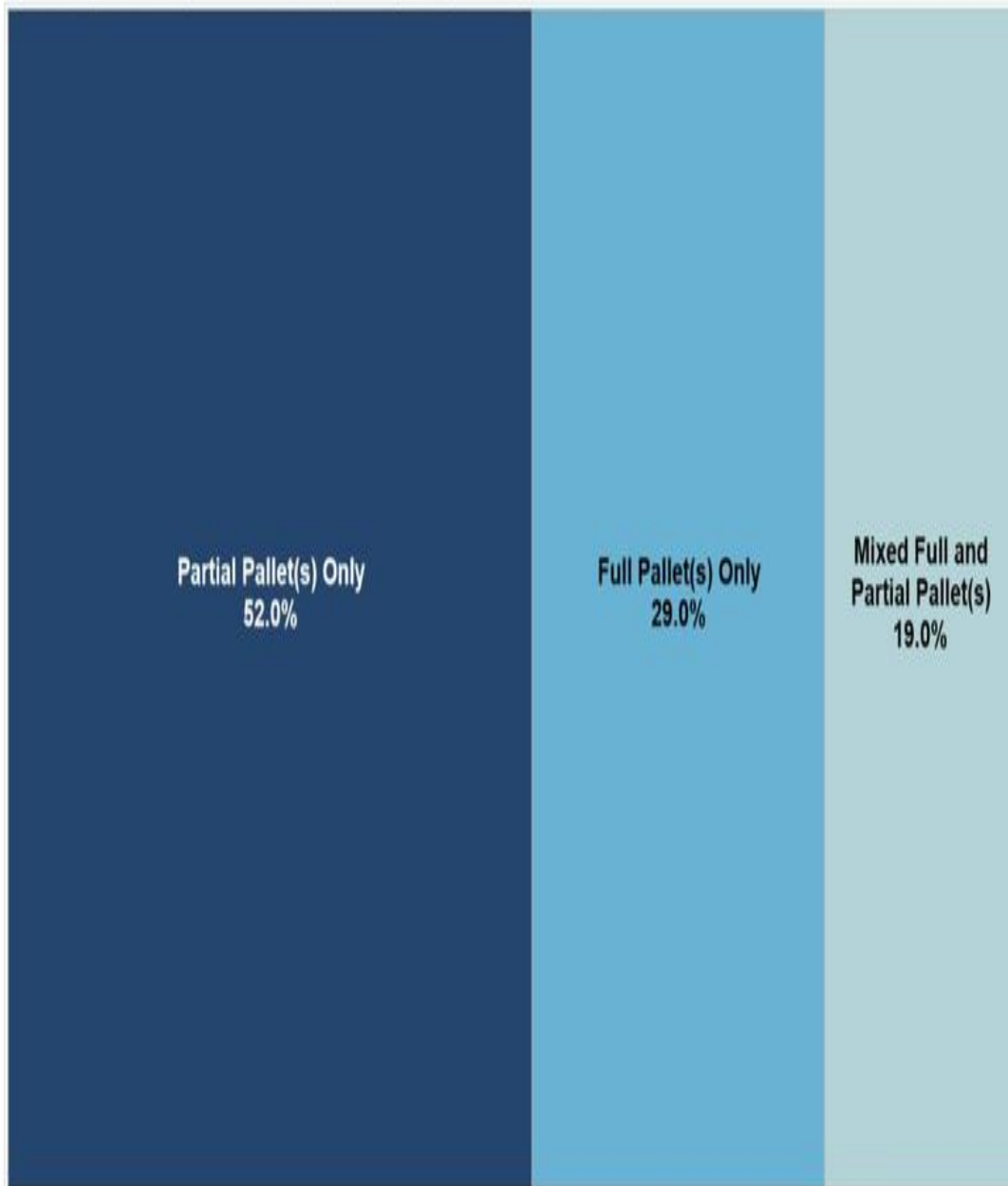
Handling-Mix Profiles The full/partial-pallet mix profile and the full/broken-case mix profile are two handling-unit mix profiles.

Full/Partial-Pallet Mix Profile With a full/partial-pallet mix profile, we determine whether full and partial pallet picking should take place in the same or separate areas. For example, in Figure 2.10, 52 percent of the orders are “complete-able” out of partial-pallet quantities, that is, just case picks; 29 percent of the orders are “complete-able” from full-pallet quantities, and the remaining 19 percent of the orders require both partial- and full-pallet quantities. The profile strongly suggests that separate areas for full and partial picking should be established.

Figure 2.10 Full/partial-pallet mix profile for a large office supplies company.

RightViews™ | Order Profiles | Customer Orders | Composition | Handling Unit Mix | Pallets

RightViews™ | Warehouse | Sales Order Profile | Handling Units per Order | Pallet Mix



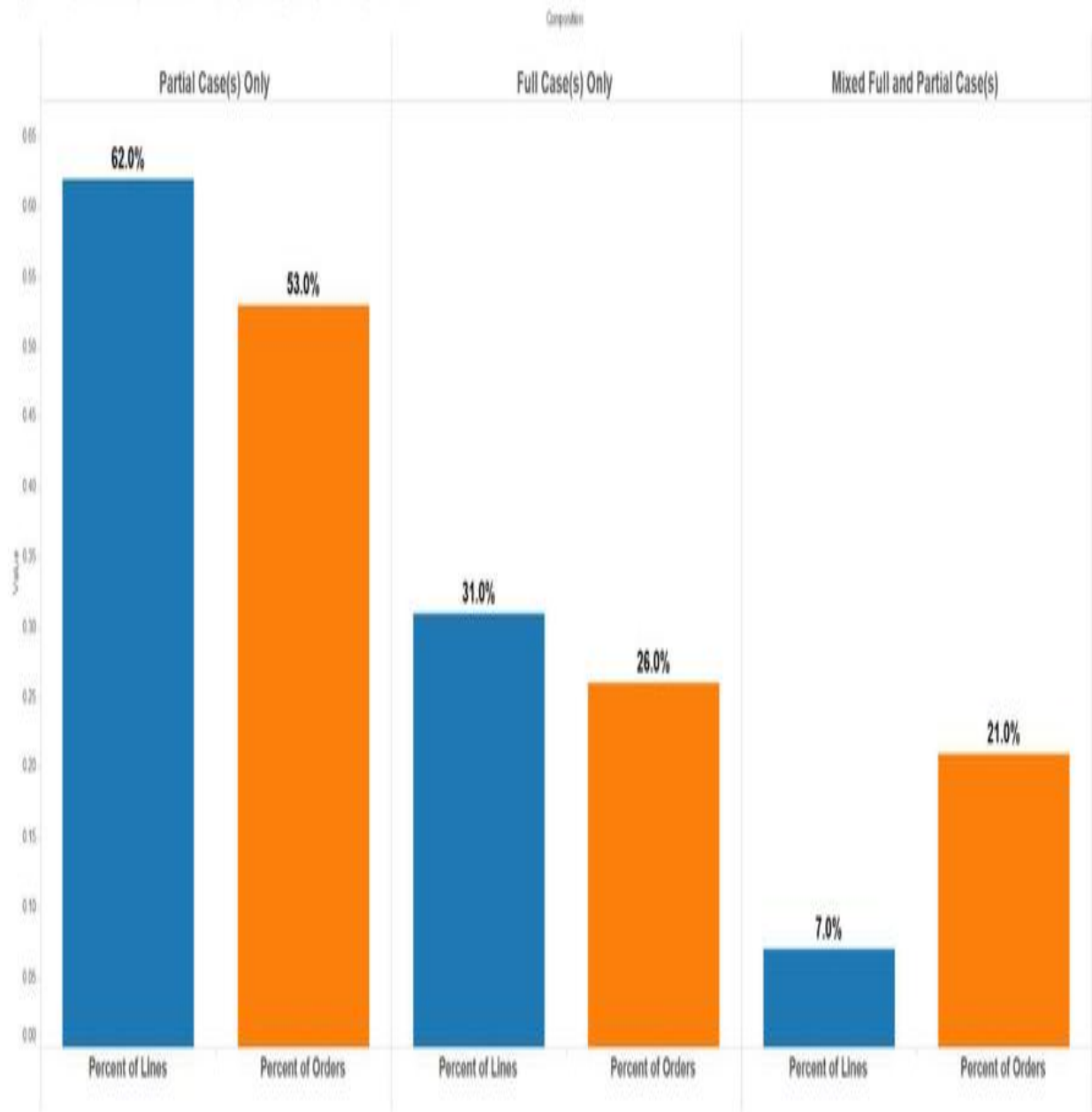
Should we have separate case picking and pallet picking areas? If so, would we pay a big penalty for mixed orders that require merging of the partial- and full-pallet portions of the order? No, only a small minority of the orders are mixed. For 81 percent of the orders, zoning based on pallet/case picking creates warehouses within-the-warehouse. When the orders are released into the warehouse management system, it should classify them immediately as pallet pick orders, carton pick orders, or mixed orders. For mixed orders, the warehouse management system should create a pallet portion and a case pick portion and either pass the full-pallet portion to the case pick area or merge the case pick and pallet portions downstream from picking.

Full/Broken-Case Mix Profile The full/broken-case mix profile helps us determine whether we should create separate areas for full- and broken-case picking. As was the case with the pallet/case-mix profile, the profile in [Figure 2.11](#) indicates that only a small portion of the orders requires both a full- and broken-case quantity. Hence, creating separate areas for full- and broken-case picking will yield two order-completion zones with very little mixing between them.

Figure 2.11 Full/broken-case mix profile.

RightViews™ | Order Profiles | Customer Orders | Composition | Handling Unit Mix | Cases

RightViews™ | Warehouse | Sales Order Profile | Handling Units per Order | Case Mix

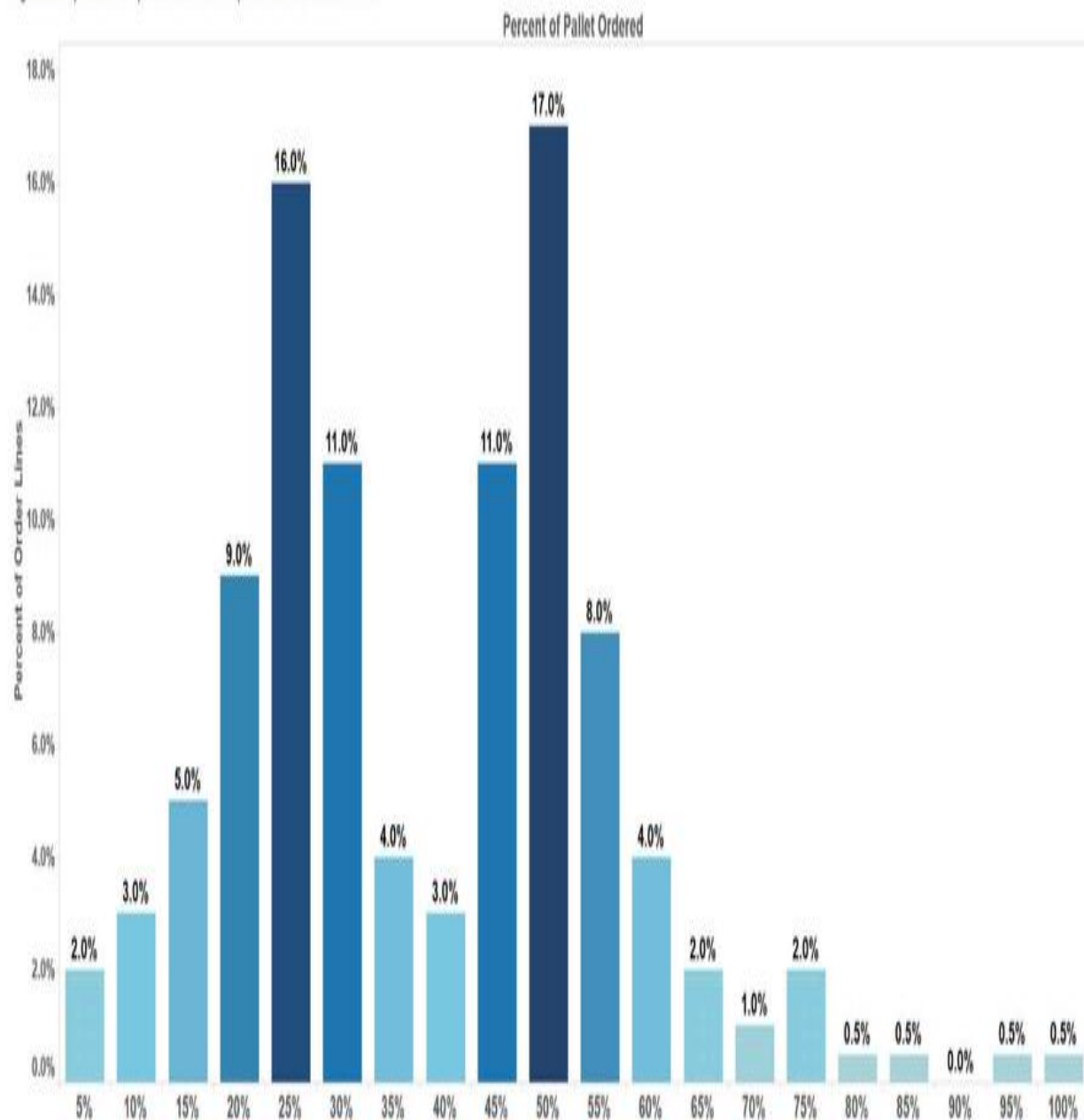


Order-Increment Profiles Order-increment profiles ([Figure 2.12](#)), illustrate the portion of a unit load (in this situation, a pallet) requested on a customer order. For example, suppose that there are 100 cartons on a pallet and a customer orders 50 cartons. In this case, the customer ordered 50 percent of the pallet. If there are 80 cartons on a pallet and that customer orders 20, they ordered 25 percent of the pallet.

Figure 2.12 Pallet order-increment distribution for a large office supplies distributor.

RightViews™ | Order Profiles | Customer Orders | Composition | Order Increments | Pallets

RightViews™ | Warehouse | Sales Order Profile | Order Increment Distribution



What do you notice that is unusual about this distribution? (In almost all these distributions, the key insights are in the peaks and valleys). Where are the peaks? The peaks are around 25 and 50 percent of a pallet.

Suppose that there are 100 cartons on a pallet and a customer places an order for 100 cartons. Would you rather pick a full pallet or 100 individual cartons? You did not have to read this book to figure out that you would prefer to pick a whole pallet at a time. In addition, a customer would rather receive a full-pallet quantity that they can handle in one unit load as opposed to having to handle 100 loose cartons.

How can we build half- and quarter-pallet unit loads? In this particular case, the manufacturing facility is attached to the warehouse. There is a palletizer that sits on the border, and all we have to do is set the palletizer to put a pallet in place about four times as often as it builds quarter pallets and twice as often as it builds half pallets. If the warehouse is not attached to a manufacturing facility, the next-best scenario is to have the supplier build the quarter- and half-pallet loads. And if not the supplier, then we can preconfigure the unit loads at receiving.

Can we influence customers to order in half-, quarter-, and/or layer-quantity increments? Absolutely! In many cases, simply by making the pallet/layer quantities accurate and visible to the customer and the order-entry personnel, we can encourage the practice of ordering in preconfigured-unit loads. We can further encourage the practice by offering price discounts designed around efficient handling increments. In this case, there was a representative from the sales organization on the cross-functional team who literally reset the price breaks on the quarter- and half-pallet quantities the next day. Picking productivity increased by 68%.

The two potential downsides of preconfiguring sub-pallet unit loads are (1) the complications of strict product rotation requirements and (2) loss of storage density. I believe that in many industries first in, first out FIFO requirements are exaggerated. For example, I recently worked with a candy company that continued to hold out FIFO as a barrier to productivity improvements. *I can remember a design meeting on Valentine's Day when our client was receiving product for the Halloween season. There can be some large time windows within FIFO requirements.*

There will be some loss in storage density because a pallet worth of

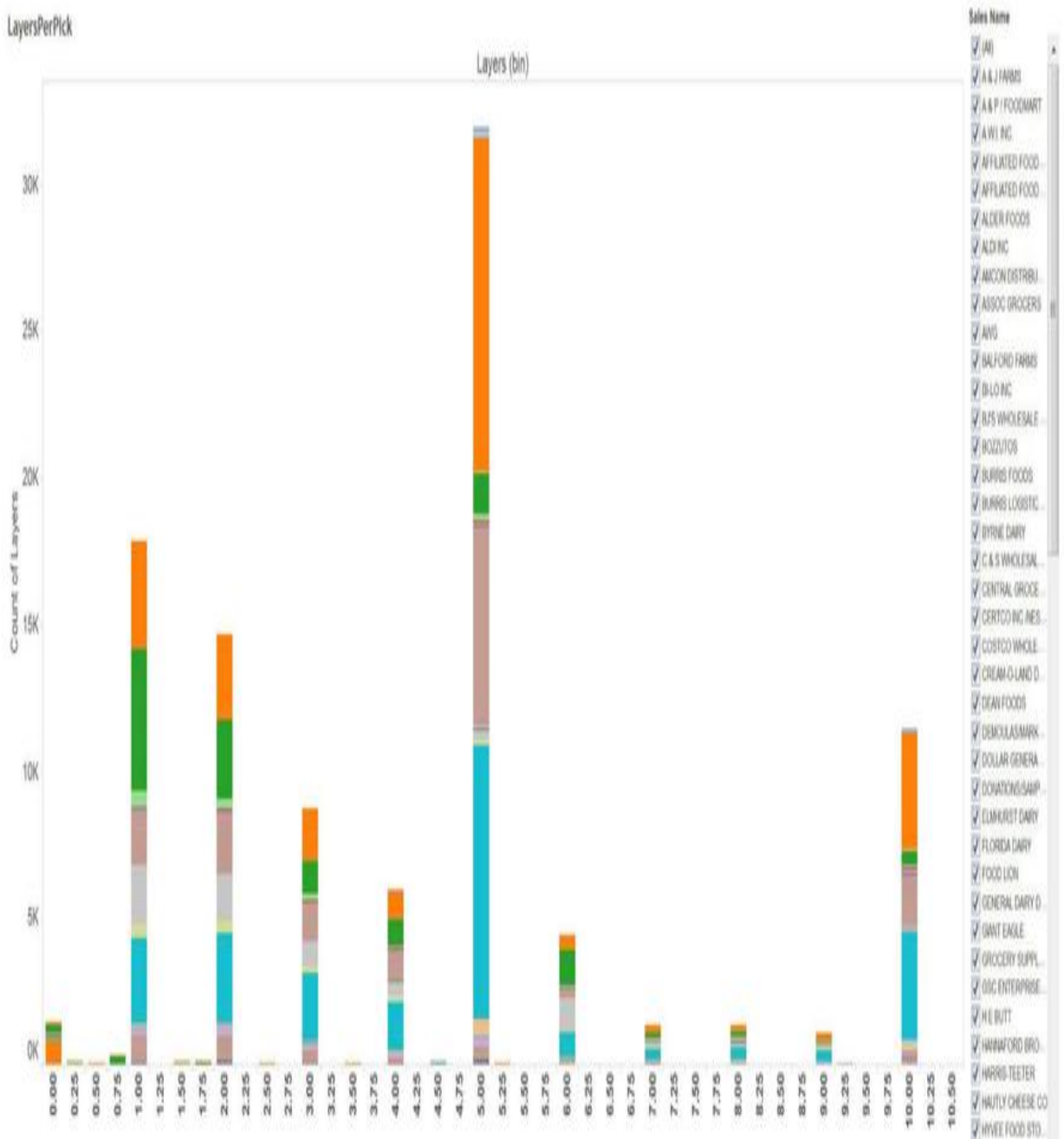
cartons may now have two or four pallets supporting it. For half-pallet quantities, we should be able to stack two halves in a full opening. For quarter-pallet quantities, we may need a row of openings that are 15 percent taller than the opening for singles. As a result, the loss in storage density should be less than 5 percent for the entire warehouse.

Layer Picking Customers often order in full layer quantities. An example from a food and beverage client is illustrated in [Figure 2.13](#). Note that 80 percent of the order lines are for full-layer increments, leading to our strong recommendation that layer picking be implemented to dramatically increase the productivity and throughput capacity. (A variety of layer picking systems are described in [Chapter 6](#).)

Figure 2.13 Layer picking profile for a large food and beverage company.

RightViews™ | Order Profiles | Customer Orders | Composition | Order Increments | Layers

LayersPerPick

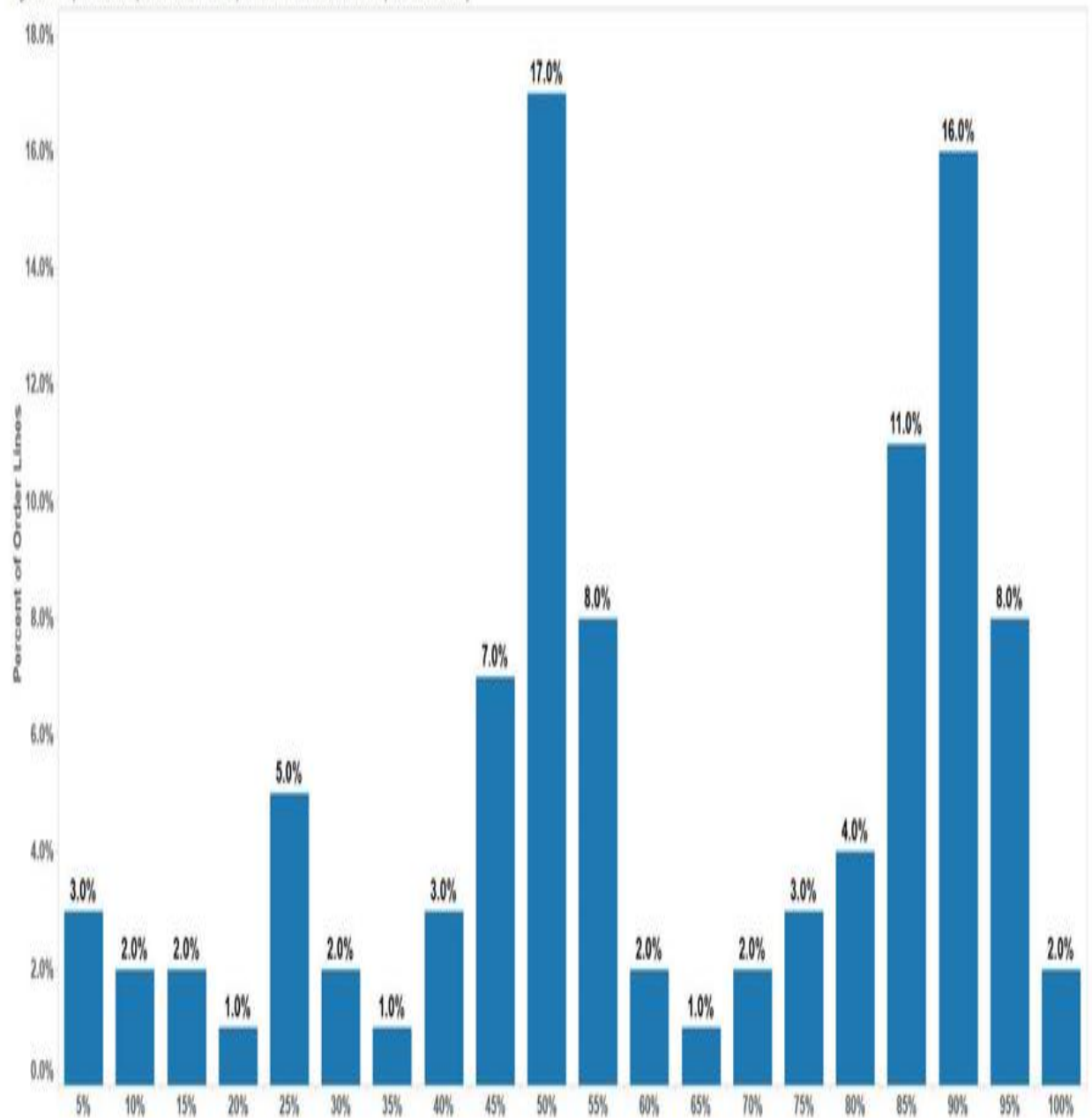


Split Case Inner Packs The case order-increment profile ([Figure 2.14](#)), determines the portion of a full carton that is requested on customer orders. For example, if there are 100 pieces in a carton and a customer orders 50, the customer ordered half the carton. What do you notice that is unusual about this profile? In this example, customers tend to order around half a carton and a quantity close to a full carton. As a result, we would like to set price breaks at a half carton (and create an inner pack for a half carton) and at a full carton to encourage customers who are almost ordering that quantity to order in full-carton increments.

Figure 2.14 Case order-increment distribution for a large pharmaceuticals firm.

RightViews™ | Order Profiles | Customer Orders | Composition | Order Increments | Cases

RightViews™ | Warehouse | Sales Order Profile | Order Increment Distribution | Case Portionality



The general principle is to prepackage in increments that customers are likely to order in and to encourage customers to order in those increments. Ideally the supplier should do as much as possible to help prepare the product for picking and shipping. Then we should do as much as possible at the receiving dock to prepare product for shipping immediately upon receipt as we have the longest time window available for picking/shipping preparation. As soon as an order drops for that product, the handling and preparation of the product for shipping should be minimized.

Customer Order Volumetric Profiles Our customer order volumetrics include lines-; units-; cube-; and weight-per-order profiles; and joint profiles comprised of the same. Some sample profiles are provided below.

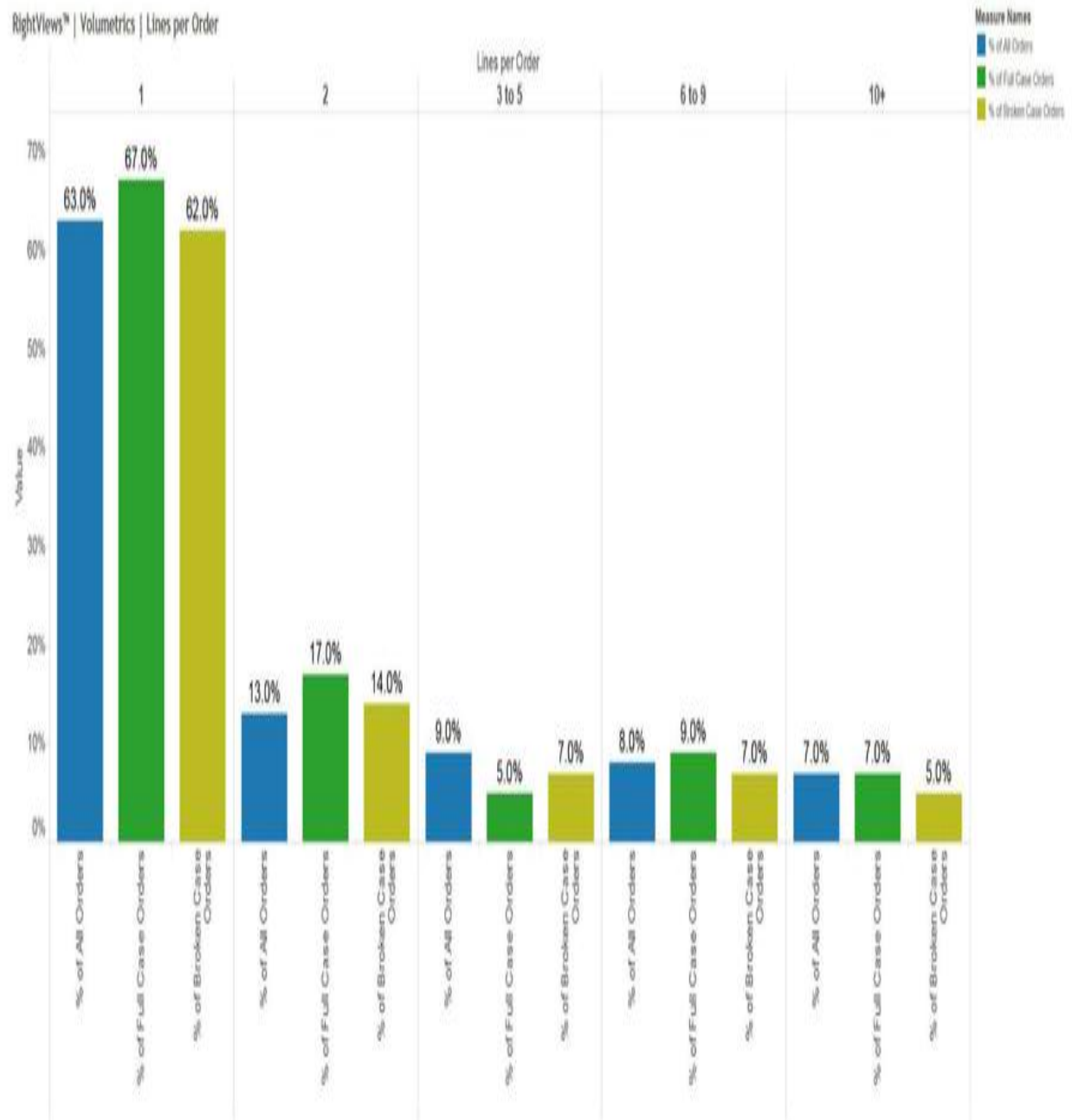
Lines-per-Order Profile The lines-per-order profile portrays the number of unique stock-keeping units (SKUs) on an order. It is one of the most important profiles because each unique SKU or line on an order represents a visit to the unique location for that SKU. Location visits are the majority of the workload in any warehouse. Consequently, managing location visits is perhaps the master key to maximizing warehouse productivity.

The lines-per-order profile in [Figure 2.15](#) indicates that 63 percent of the orders in the warehouse are for one line item, 13 percent for two, 9 percent for three to five, 8 percent for six to nine, and 7 percent for 10 or more. Where is the peak? It is around single-line orders. This distribution is common in the mail-order industry or when individual consumers or technicians order directly for a warehouse. We now need to consider the operating strategies that take advantage of this order profile.

Figure 2.15 Lines-per-order distribution for a large mail-order company.

RightViews™ | Volumetrics | Lines per Order

RightViews™ | Volumetrics | Lines per Order



Singles may be back orders. Back orders are an excellent opportunity for cross-docking. Singles may be batched together for picking on single-line picking tours. By presenting single-line orders in location sequence, we create very efficient picking tours. In addition, the single-line order batches naturally break the warehouse into zones defined by the length of the picking tour. Single-line orders also may represent an opportunity to create a dynamic forward pick line. In this operating scenario, an automated look-ahead into the day's or shift's orders may yield a number of SKUs for which there is at least a full carton's worth of single-line orders. Those SKUs can be batch picked and set up along fast pick-pack lines.

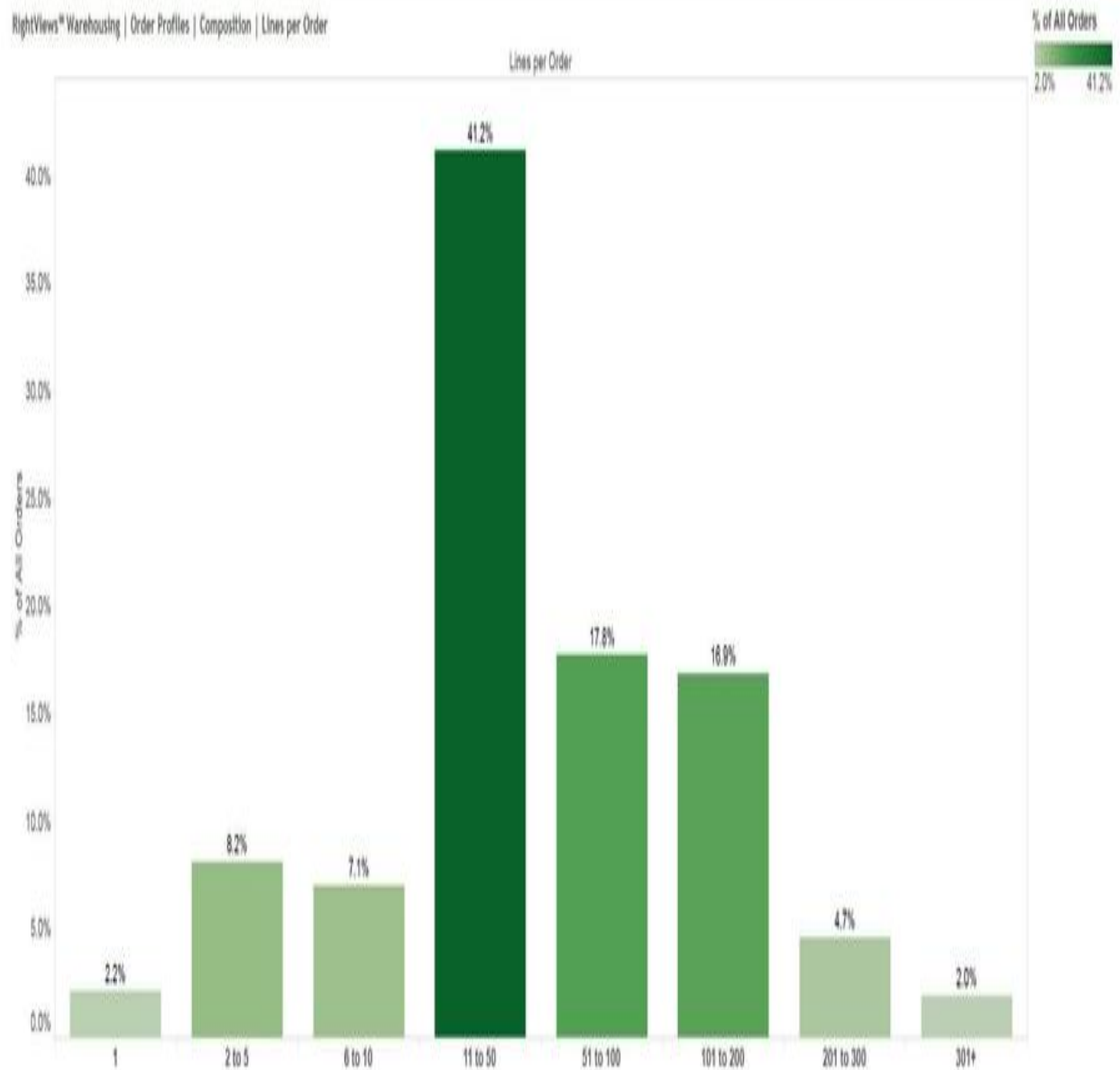
Another common lines-per-order profile is illustrated in [Figure 2.16](#). The peak is around 10+ lines per order. This profile is common in retail/grocery/dealer distribution, where the customer is a retail store/grocery store/dealership. In this case, there is typically enough work to do within an order that the order itself represents an efficient work set. Or the order may be so large that it may be split across multiple order fillers for zone-wave picking.

Figure 2.16 Retail lines-per-order profile for a large convenience store chain.

RightViews™ | Warehousing | Order Profiles | Volumetrics | Lines per Order Retail

RightViews™ Warehousing | Order Profiles | Composition | Lines per Order Dashboard 1

RightViews™ Warehousing | Order Profiles | Composition | Lines per Order

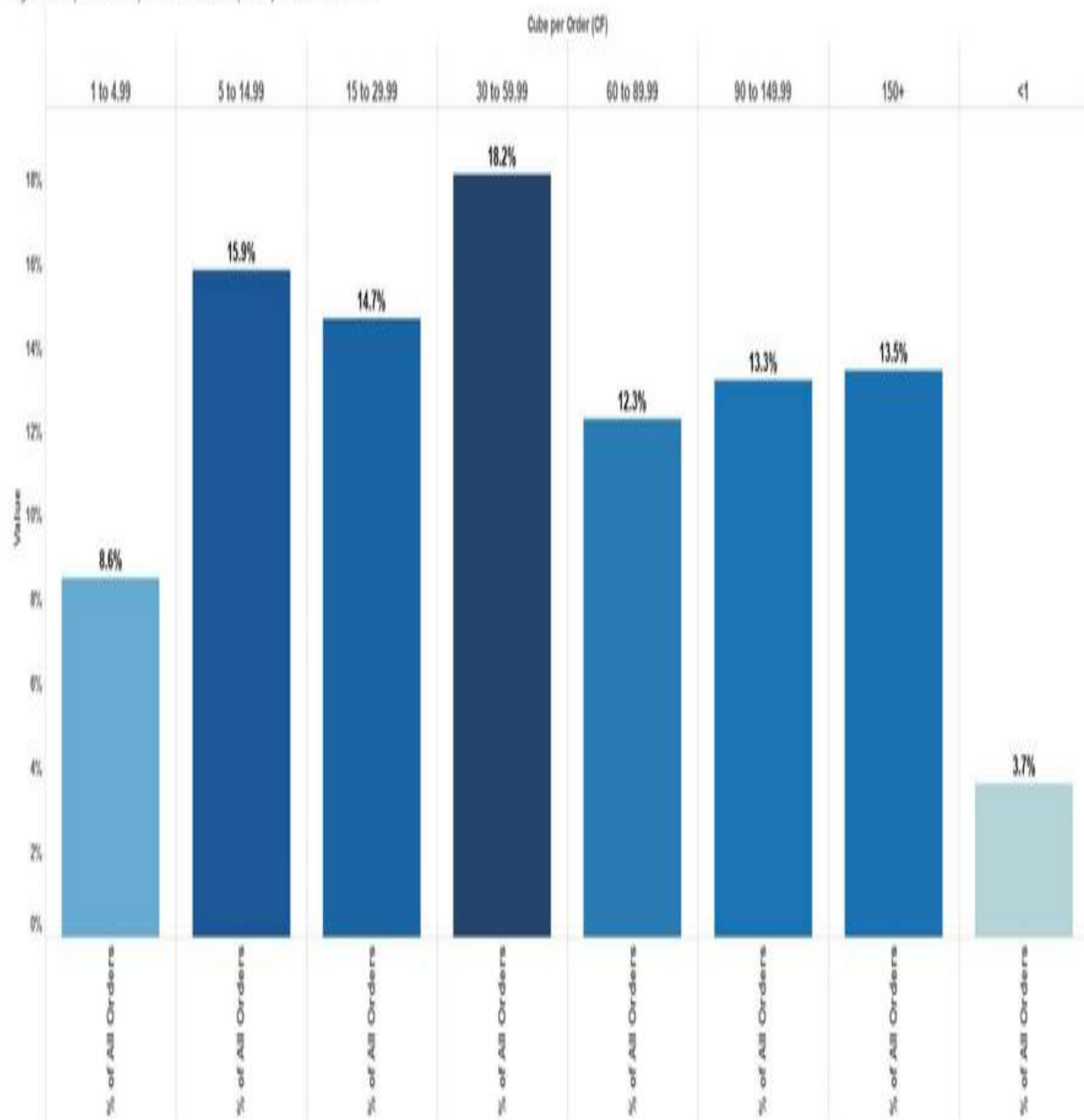


Cube-per-Order Profile The cube-per-order distribution ([Figure 2.17](#)) illustrates the portion of outbound orders falling into pre-defined cube classifications. It may suggest alternative sizes for shipping containers, alternative picking methods, alternative transportation modes, and requirements for staging space. The figure depicts a cube-per-order distribution for a large toy company client. We use the profile to help select picking methods and container sizes for their mix of picking tours.

Figure 2.17 Cube-per-order profile for a large toy company.

RightViews™ | Order Profiles | Customer Orders | Volumetrics | Cube per Order

RightViews™ | Warehouse | Sales Order Profile | Cube per Order Distribution

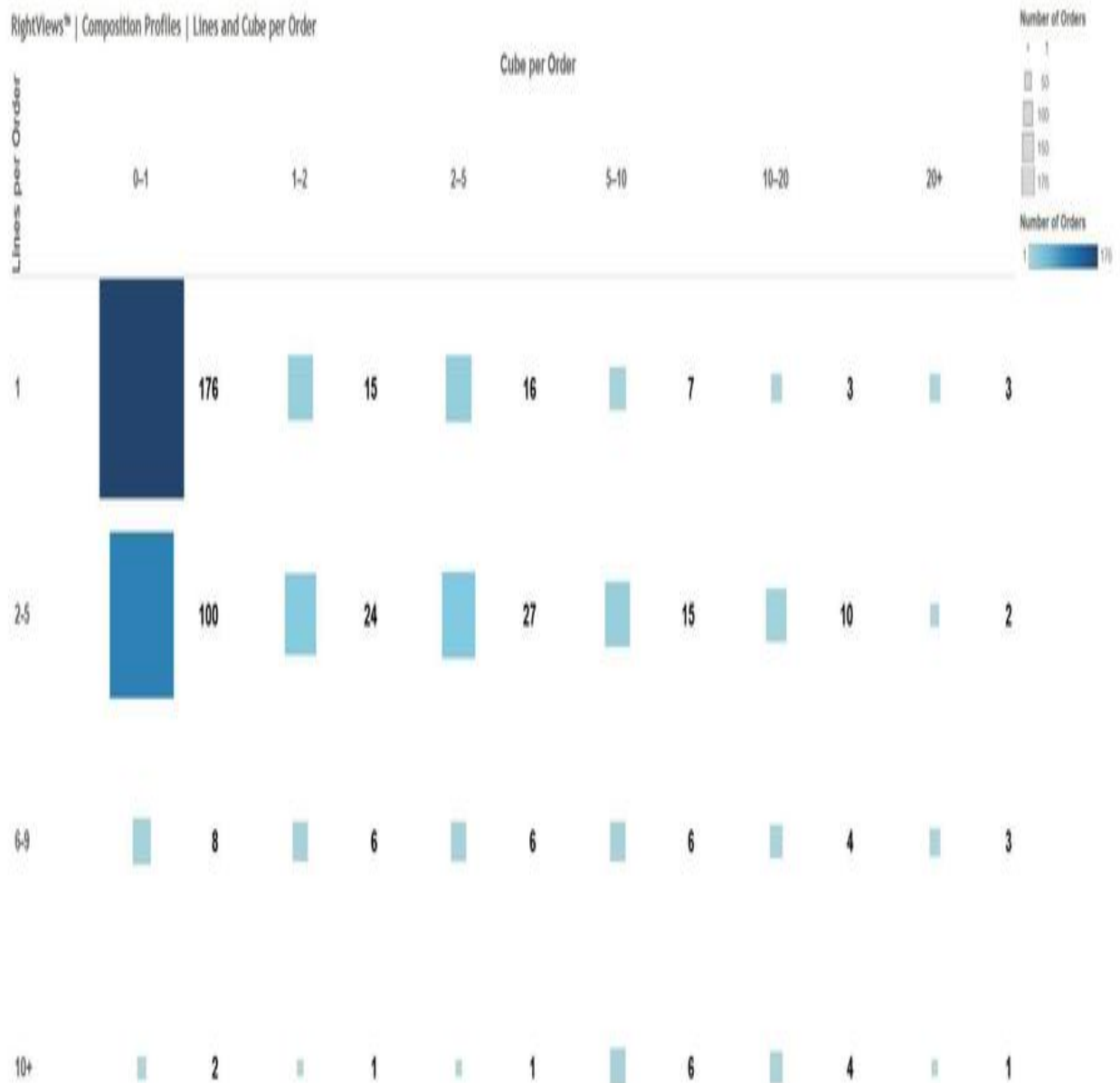


Lines- and Cube-per-Order Profile The lines- and cube-per-order profile (Figure 2.18) brings together in one profile the critical information needed to define order picking strategy. It is a joint distribution that classifies all orders into *lines-per and cube-per families*. In this example, there are 176 orders with one line item and that occupy less than a cubic foot of space. These orders are probably candidates for a single operator to batch together for picking into compartmentalized picking carts, totes, or shipping containers. There is one order with more than 10 line items that occupies more than 20 cubic feet, about a third of a pallet. That order is a candidate for a single operator to pick to a pallet.

Figure 2.18 Lines- and cube-per-order grid analysis.

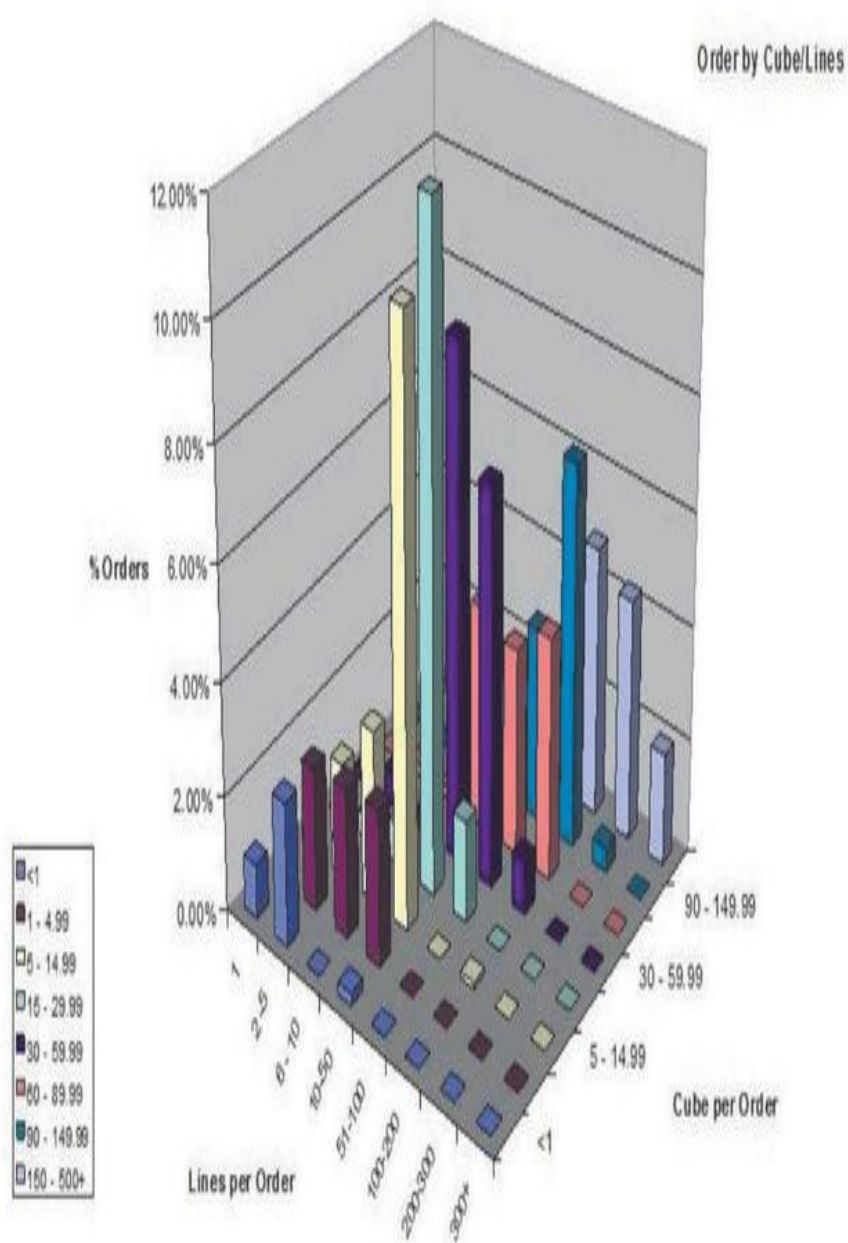
RightViews™ | Order Profiles | Customer Orders | Volumetrics | Lines and Cube per Order

RightViews™ | Composition Profiles | Lines and Cube per Order



The example in [Figure 2.19](#) is a lines- and cube-per-order distribution from a major retail client. Note that the orders tend to fall into one small one medium and one large group. In the example, small orders are picked via special pick-pack carts holding 10 to 20 orders per cart. Medium-sized orders are picked with medium-sized carts holding two to five orders per cart. Large orders are picked one at a time in large-order carts holding a single order per tour.

Figure 2.19 Lines- and cube-per-order distribution for a large retailer.



2.3 Calendar-Clock Profiles

Calendar-clock profiles reveal peaks and valleys in warehouse activity so that all the elements of the warehouse infrastructure—workforce, material-handling systems, storage systems, and dock doors—can be sized optimally. Calendar-clock profiles include the following:

- Month-of-year (MoY) activity profile
- Week-of-month (WoM) activity profile
- Day-of-week (DoW) activity profile
- Hour-of-day (HoD) activity profile

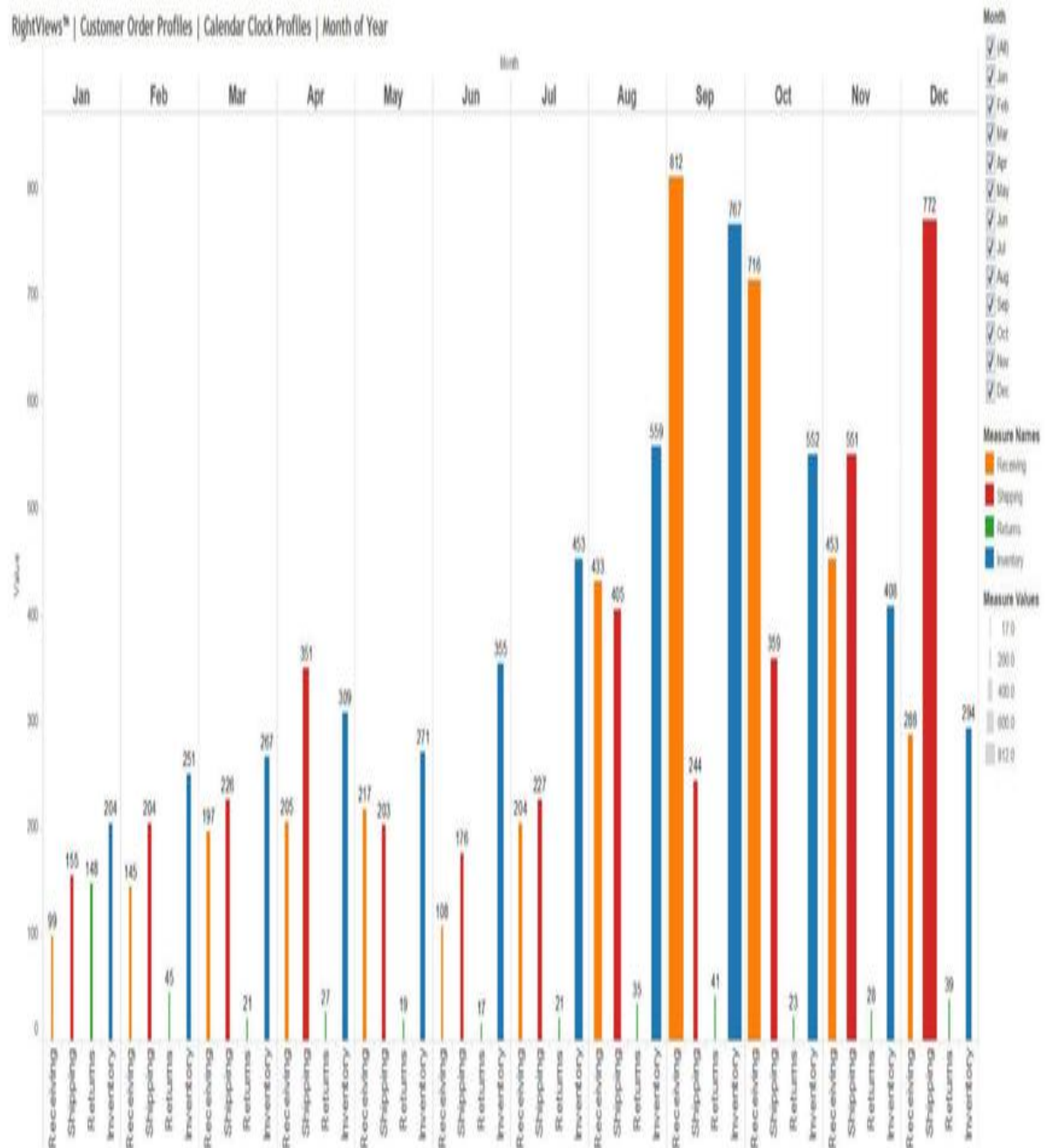
Month-of-Year Activity Profile

The month-of-year activity profile is sometimes referred to as the *seasonality activity distribution* because it typically portrays the impact of seasons such as Christmas, back to school, fall, winter, spring, and so forth on warehouse activity. An example month-of-year activity profile for a large retailer is illustrated in [Figure 2.20](#).

Figure 2.20 Month-of-year profile for a large retailer.

RightViews™ | Order Profiles | Customer Orders | Calendar Clocks | Month of Year

RightViews™ | Customer Order Profiles | Calendar Clock Profiles | Month of Year



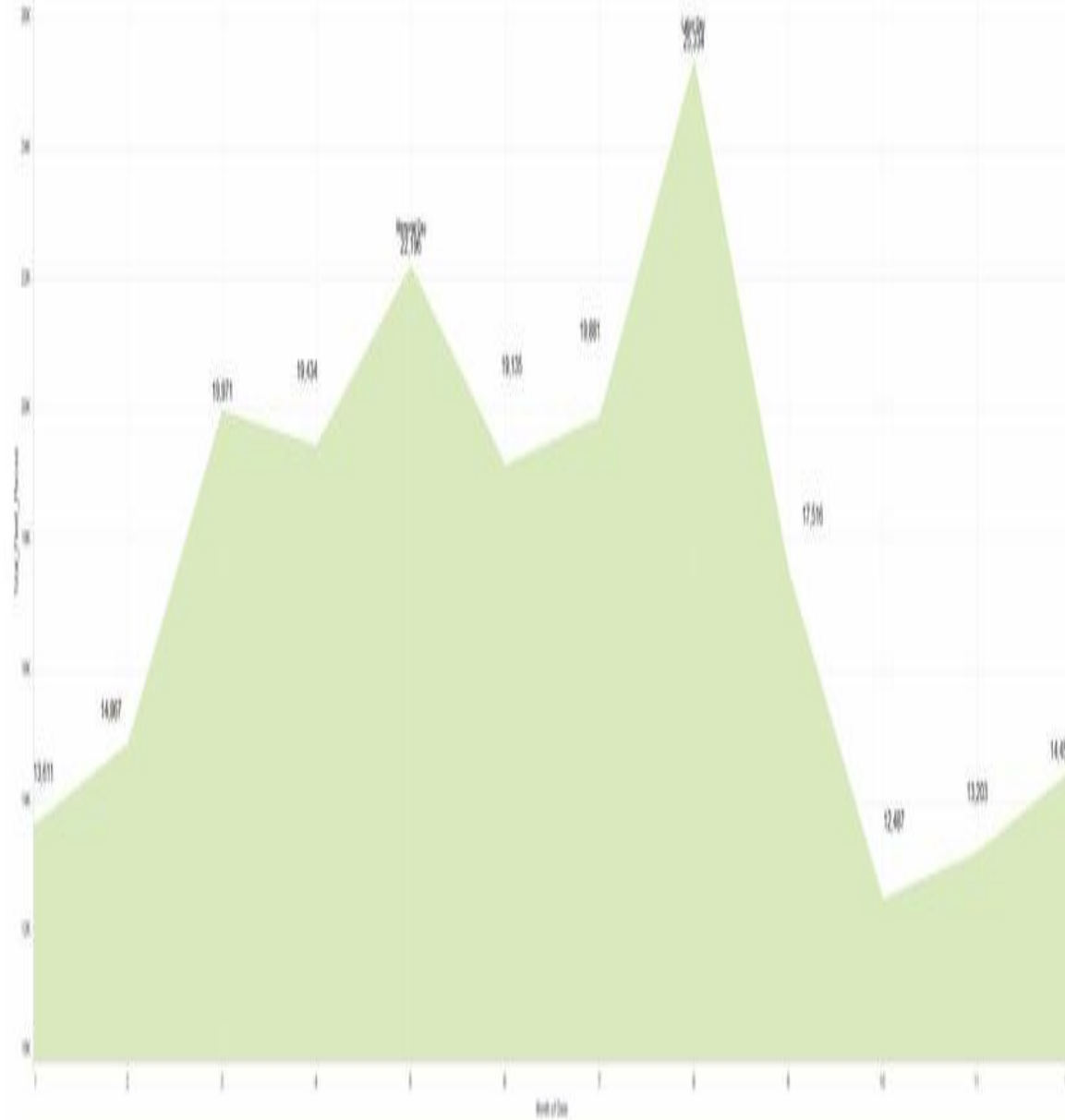
The seasonality profile indicates the peaks and valleys in inventory levels, as well as receiving, shipping, and returns activity. Because storage systems need to be sized to accommodate near-peak inventory levels and material-handling systems need to be sized to accommodate near-peak activity levels, it is critical to identify peak inventory and activity levels. The example is typical of retail distribution, with receipts peaking in August/September, inventory peaking in September/October, shipping peaking in October/November, and returns peaking in January. A distribution presents an opportunity to shift the extra staff required for receiving in August/September to shipping in October/November to returns handling in January.

One of our furniture clients experiences the same volatility but in different seasons ([Figure 2.21](#)). As we learned from our work with them, summer is their busiest season based upon their major sales during the Memorial Day and Labor Day holidays.

Figure 2.21 Seasonality distribution for a large furniture company.

RightViews® | Customer Order Profiles | Calendar Clock Profiles | Month of Year

Total Feet, Poles
0.40 0.14



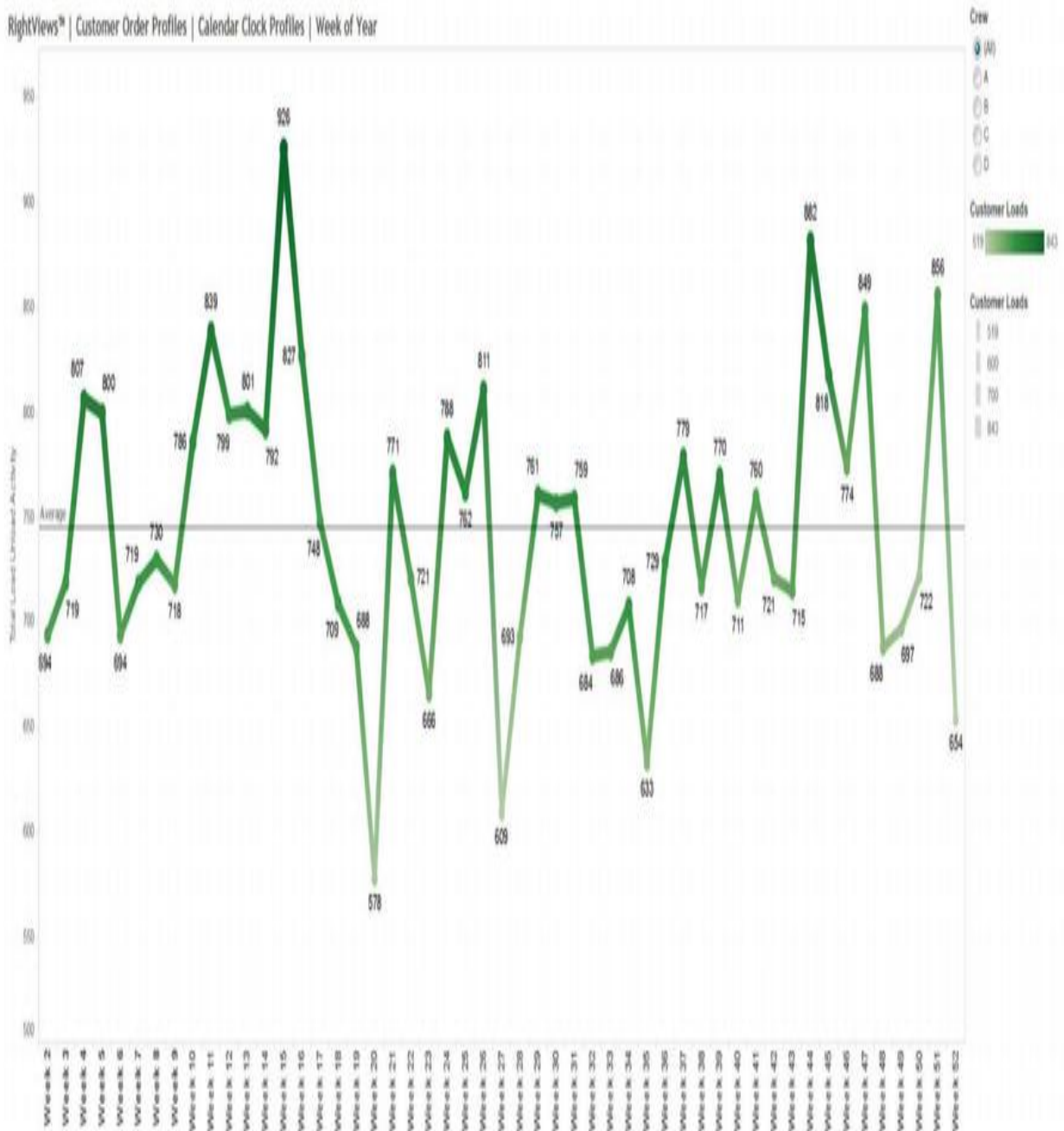
Week-of-Month Activity Distribution

Most shipping activity occurs during the last week of the month, especially during the last month of a quarter ([Figure 2.22](#)). Conversely, most receiving activity occurs during the first week of the month, especially during the first month of a quarter.

Figure 2.22 Week-of-month activity profile.

RightViews™ | Order Profiles | Customer Orders | Calendar Clocks | Week of Year

RightViews™ | Customer Order Profiles | Calendar Clock Profiles | Week of Year

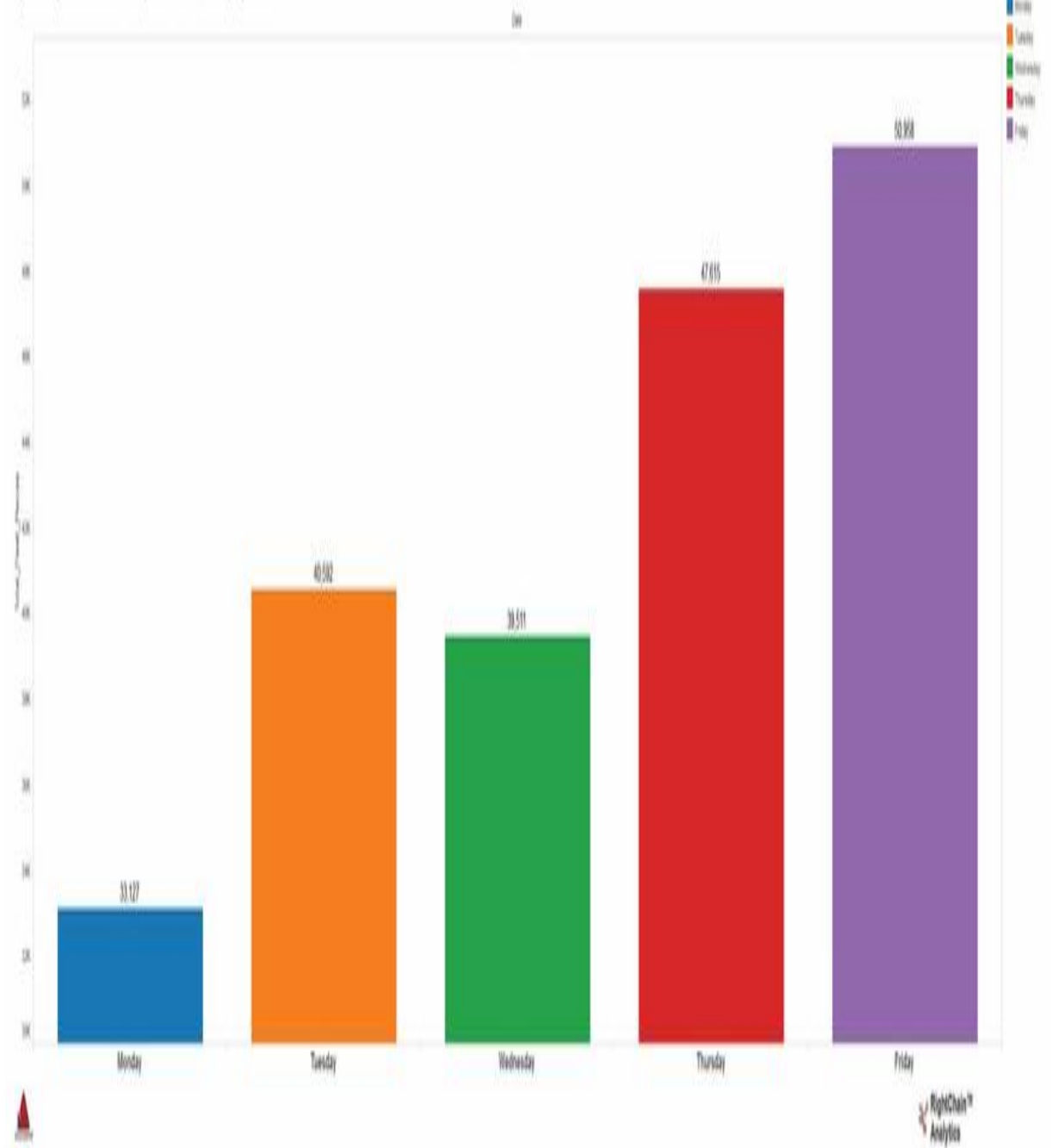


Day-of-Week Activity Distribution

The day of the week is another driving force in many warehouse activity peaks and valleys. We recently completed a supply chain strategy project for one of the world's largest bedding manufacturers ([Figure 2.23](#)). Most of the mattresses purchased in the world are purchased on Saturday, with deliveries scheduled for the following Friday. Needless to say, Thursday and Friday are very busy days in their warehouses.

Figure 2.23 Day-of-Week activity profile for a large bedding company.

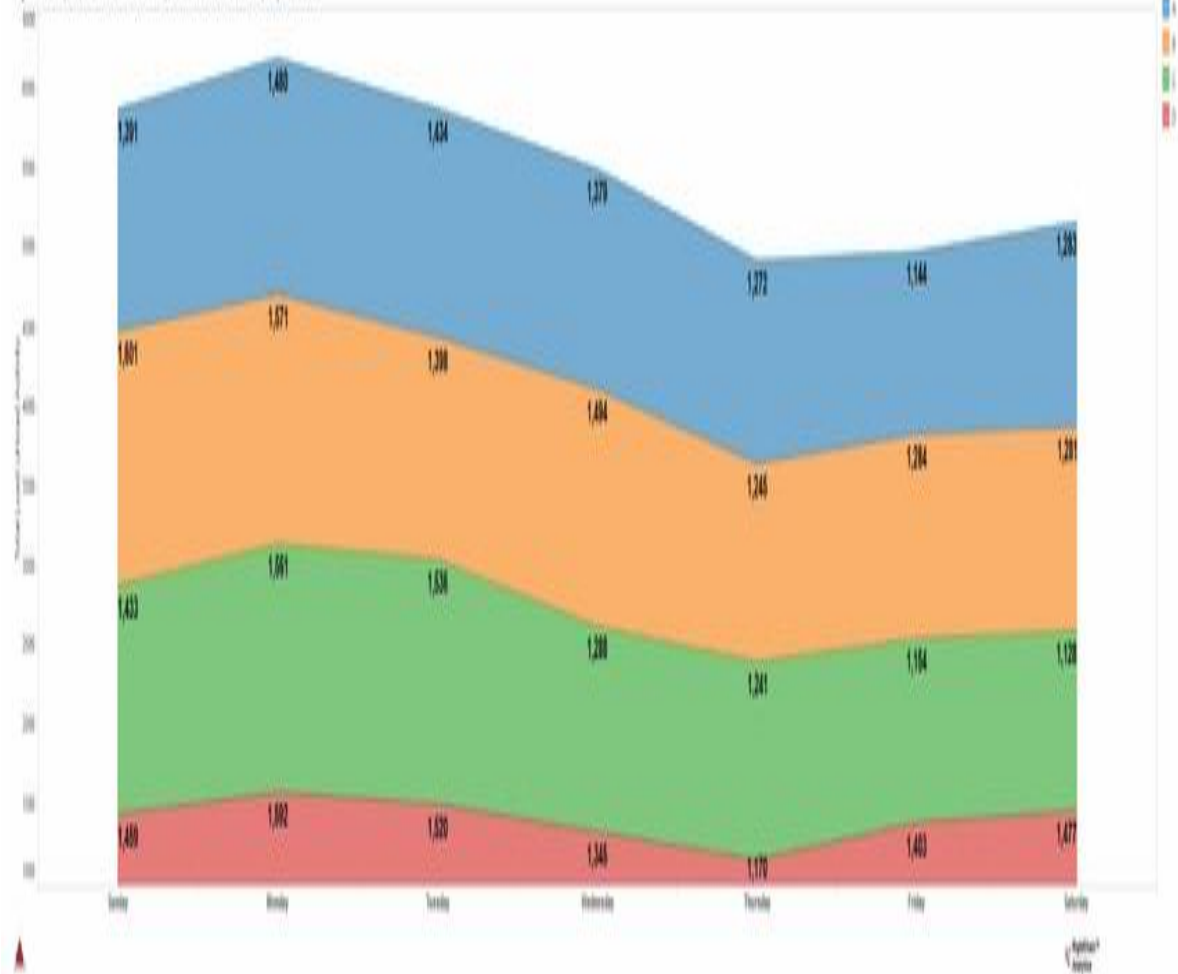
RightView® | Customer Order Profiles | Calendar Clock Profiles | Day of Week



In recent project in the food and beverage industry, two retailers comprised nearly 50 percent of their outbound volume. Unfortunately, each wanted deliveries executed on the same two days of each week. Needless to say, the two days before were overwhelming peaks for the warehouse operations ([Figure 2.24](#)).

Figure 2.24 Day-of-Week activity profile for a food and beverage company

RightView® | Customer Order Profiles | Calendar Clock Profiles | Day of Week



Hour of Day Activity Distribution

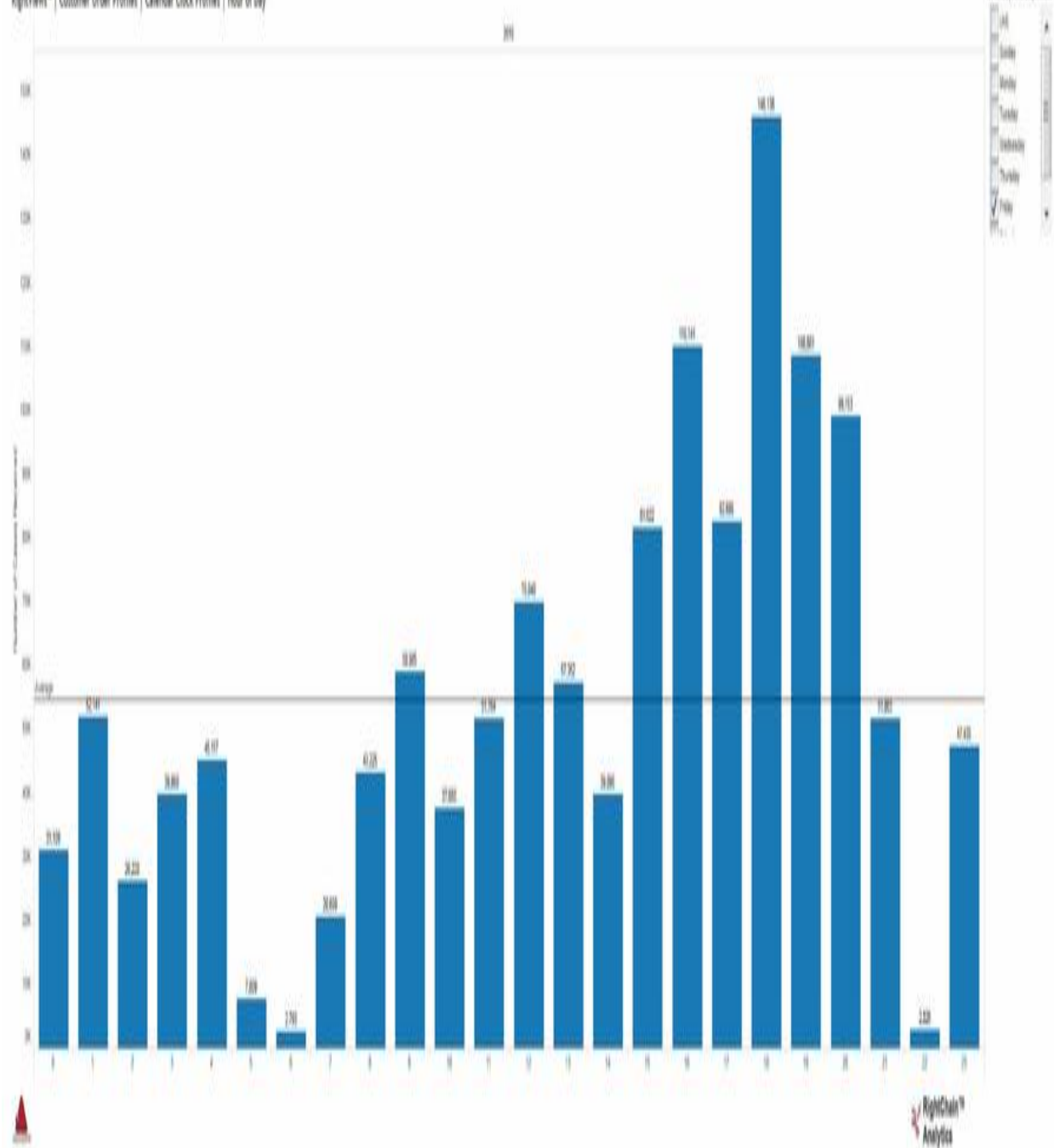
As the name suggests, the Hour-of-Day profile indicates (Figure 2.25) the receiving, putaway, picking, and shipping activity by hour of the day. Material handling systems should be designed for peak activity periods. Offsetting peaks represent opportunities for shift staggering and inter-department workforce shifting.

Figure 2.25 Hour-of-Day distribution for dock door receiving activity.

RightViews® | [Customer Order Profiles](#) | [Calendar Clock Profiles](#) | [Hour of Day](#)

2019

Weekday of Receipt Bell



2.4 Item Activity Profiling

The item activity profile is used primarily to slot the warehouse, to decide for each item (1) what storage mode the item should be assigned to, (2) how much space the item should be allocated in the storage mode, and (3) where in the storage mode the item should be located. The item activity profile includes the following activity profiles:

- Popularity profile
- Cube–movement profile
- Popularity-cube–movement profile
- Order-completion profile
- Demand-correlation profile
- Demand-variability profile

Item Popularity Profile

As mentioned earlier, a minority of the items in a warehouse typically generates a majority of the picking activity. The *popularity profile* (sometimes called an *ABC curve* or a *Pareto distribution*) indicates the x percent of picks associated with y percent of the SKUs (ranked by descending popularity). [Figure 2.26](#) is a classic popularity profile indicating that the 10 percent most popular items yield 70 percent of the picking activity, the 50 percent most popular items yield 90 percent of the picking activity, and so on. Key breakpoints in the distribution suggest delineations between item popularity families. For example, the top 5 percent of items (Family A) may make up 50 percent of the picking activity, the next 15 percent of items (Family B) may take us to 80 percent of the picking activity, and the remaining 80 percent of items (Family C) cover the remaining picking activity. These families, in turn, may suggest three alternative storage modes—Family A in an automated, highly productive storage mode; Family B in a semi-automated, moderately productive picking mode; and Family C in a manual picking mode that offers high storage density. The family breakpoints also may suggest the location of the items within a storage mode—A items located in the golden zone (close to a travel aisle and/or at or near waist

level), B items in the silver zone, and C items in the remaining spaces. The overriding principle is to assign the most popular items to the most accessible warehouse locations.

Figure 2.26 Item popularity profile for a large service parts company.

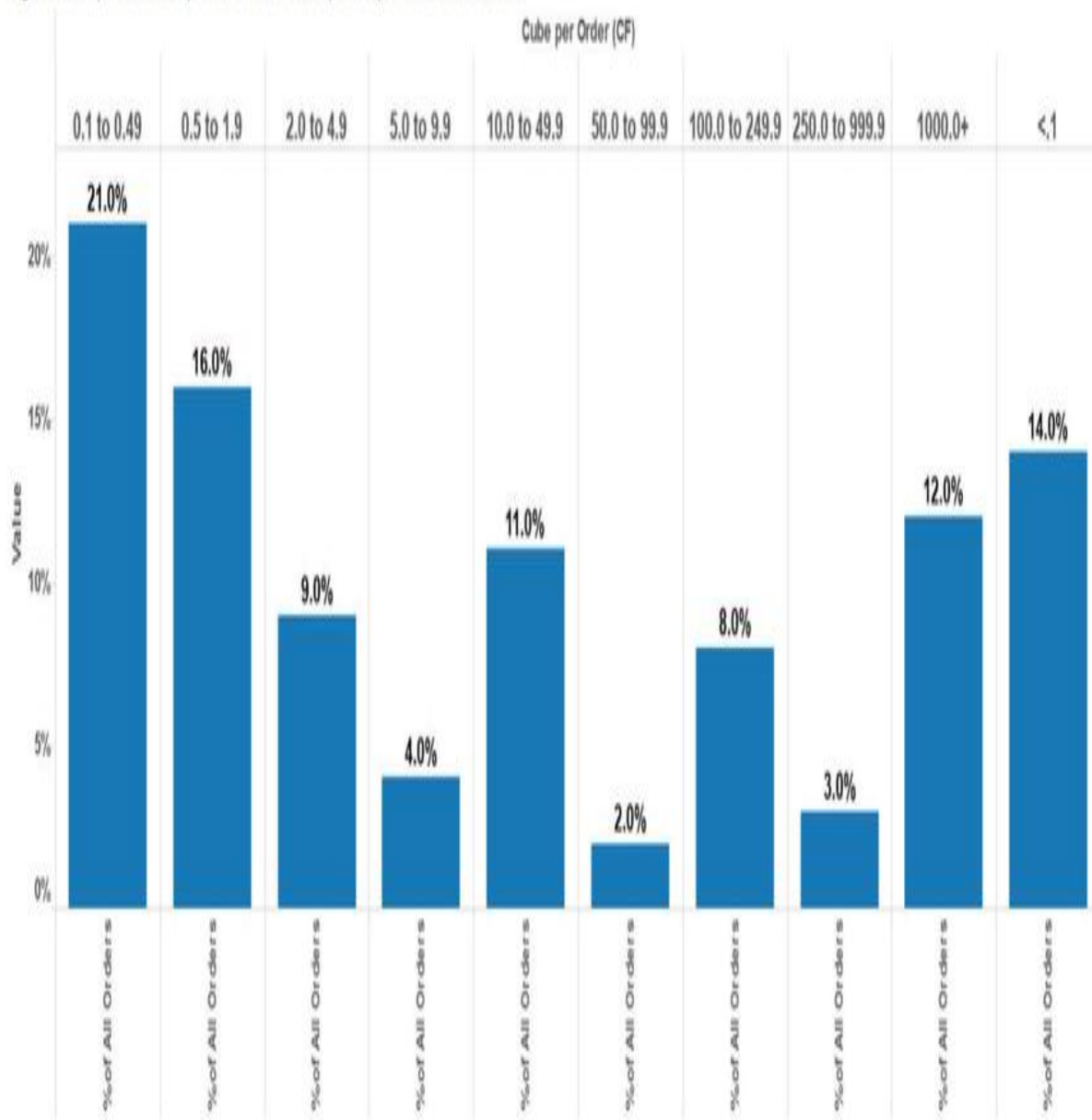


Cube-Movement Profile

The cube-movement profile is used primarily for making storage-mode and space-allocation decisions. The cube-movement profile indicates the portion of items that falls into pre-specified cube-movement ranges. If the pre-specified ranges correspond to storage-mode alternatives, then the cube-movement profile will essentially solve the storage-mode assignment problem. For example, in [Figure 2.27](#), 15 percent of the items ship less than 0.1 cubic feet per month. Those items may be good candidates for storage drawers or bin shelving. At the other end of the distribution, we find 12 percent of the items that move more than 1,000 cubic feet (nearly 20 pallets) per month. Those items may be candidates for block stacking, double-deep rack, push-back rack, and/or pallet flow lanes.

Figure 2.27 Cube-movement profile for a large valves and fittings company.

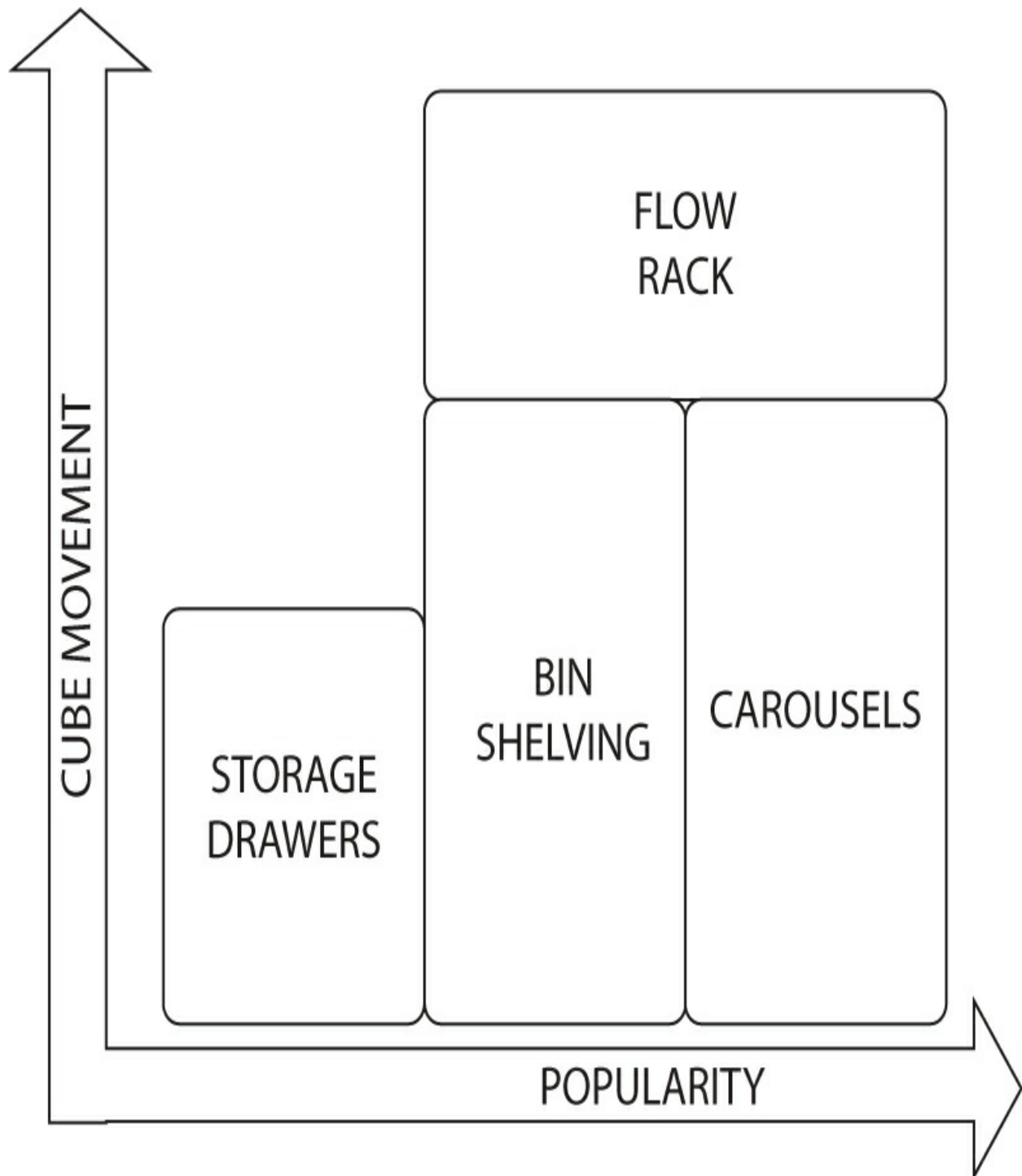
RightViews™ | Warehouse | Sales Order Profile | Lines per Order Distribution



Popularity–Cube-Movement Profile

Done properly, slotting takes into account both the item popularity and cube-movement. An example popularity–cube-movement profile for broken-case picking is presented in [Figure 2.28](#).

Figure 2.28 Popularity–Cube-Movement Profile



In this example, those items exceeding a certain cube-movement threshold are assigned to a carton flow rack. Items with high cube-movement need to be restocked frequently and need a larger storage location compared to items with medium and low cube movement. Hence they need to be

assigned to a storage mode that facilitates restocking and condenses large storage locations along the pick line—carton flow rack. Items with low cube movement and high popularity generate many picks per unit of space that they occupy and do not occupy much space along the pick line. They need to be in a highly productive picking mode. In this case, light directed carousels are recommended because the picking productivity is high, and we can afford the carousels for items that do not need large storage housings on the pick line and do not need to be restocked frequently. (Carousels do not lend themselves to restocking and are expensive per cubic foot of space.)

Items with low popularity and low cube movement cannot be justifiably housed in an expensive storage mode. Hence they are candidates for bin shelving and modular storage drawers.

Items in the bottom right-hand quadrant of each preference region generate the most picking activity per unit of space they occupy in the storage mode. Hence they should be assigned to positions in the golden zone (most accessible pick locations) of their storage mode. Items in the upper right-hand and lower left-hand quadrants generate a moderate number of picks per unit of space they occupy in the storage mode. Hence they should be assigned to positions in the silver zone. Finally, items in the upper left-hand quadrant of the distribution generate the fewest picks per unit of space they occupy and they should be assigned positions in the bronze (least accessible) zone.

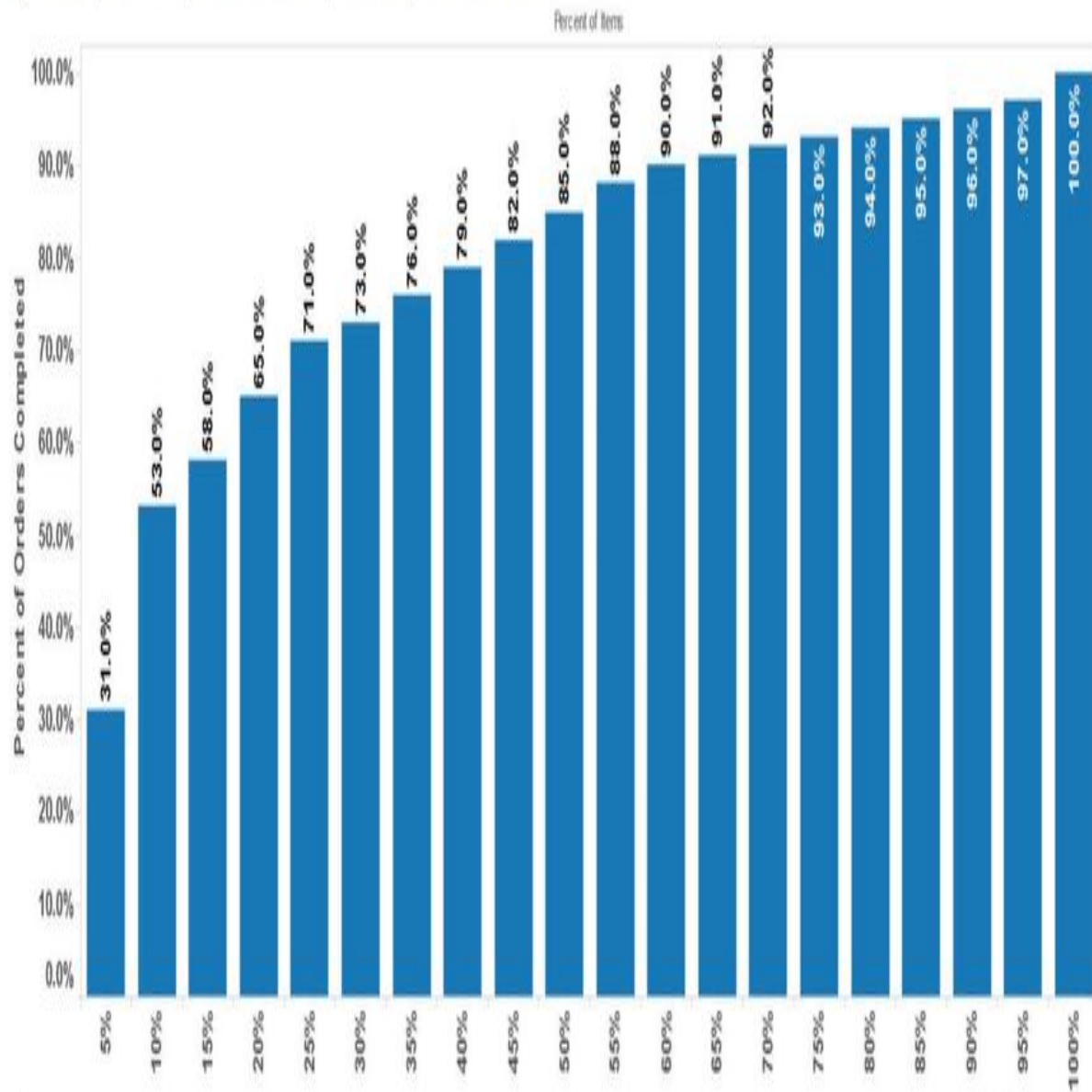
This example is not an end-all recommendation for slotting broken-case picking systems. This depends on many other factors, including the wage rate, the cost of space, the cost of capital, the planning horizon, and so on. Instead, this example is presented to illustrate how the popularity–cube-movement distribution is used in slotting.

Item-Order-Completion Profile

The item-order-completion profile ([Figure 2.29](#)) identifies small groups of items that can fill large groups of orders. Those small groups of items often can be assigned to small *order-completion zones* in which the productivity, processing rate, and processing quality are two to five times better than those found in the general warehouse.

Figure 2.29 Item-order-completion profile.

RightViews™ | Warehouse | Sales Order Profile | Order Completion Distribution



The item-order-completion profile is constructed by ranking items from most to least popular. Beginning with the most popular item, then the two most popular items, then the three most popular items, and so on, the items are compared with the order pool to determine what portion of the orders a given subset of the items can complete. In this example, 10 percent of the items can complete 50 percent of the orders. Suppose that I walk into your warehouse and identify 10 percent of the items that can completely fill 50 percent of the orders. What would you do with those 10 percent of the items? I hope that you would create a warehouse within the warehouse or order-completion zone for those 10 percent.

The design principle is similar to that used in agile manufacturing, where we look for small groups of parts that have similar machine routings. Those machines and those parts make up a small-group technology cell wherein the manufacturing efficiency, quality, and cycle time are dramatically improved over those found in the factory as a whole.

We recently worked with a large media (i.e., compact discs, cassettes, videos, etc.) distributor and helped to identify 5 percent of its 4,000 SKUs that could complete 35 percent of its orders. We assigned those 5 percent to carton flow-rack pods (three flow-rack bays per pod, one operator per pod) at the front of the distribution center. Operators could pick/pack orders from the flow rack at nearly six times the overall rate of the distribution center. The distribution center has won its industry's productivity award each of the last two years.

Very frequently, there is a driving force behind order completion. Examples could include customers ordering within a brand ([Figure 2.30](#)) or, as depicted in [Figure 2.31](#), a product group, a supplier, a size, a color, a kit, and so on. Our pattern-recognition algorithms seek and surface those patterns in an attempt to identify order-completion zoning opportunities within the warehouse.

Figure 2.30 Item-order-completion profile from a large food and beverage company.

RightViews® | Item Activity Profiles | Demand Correlation Profile

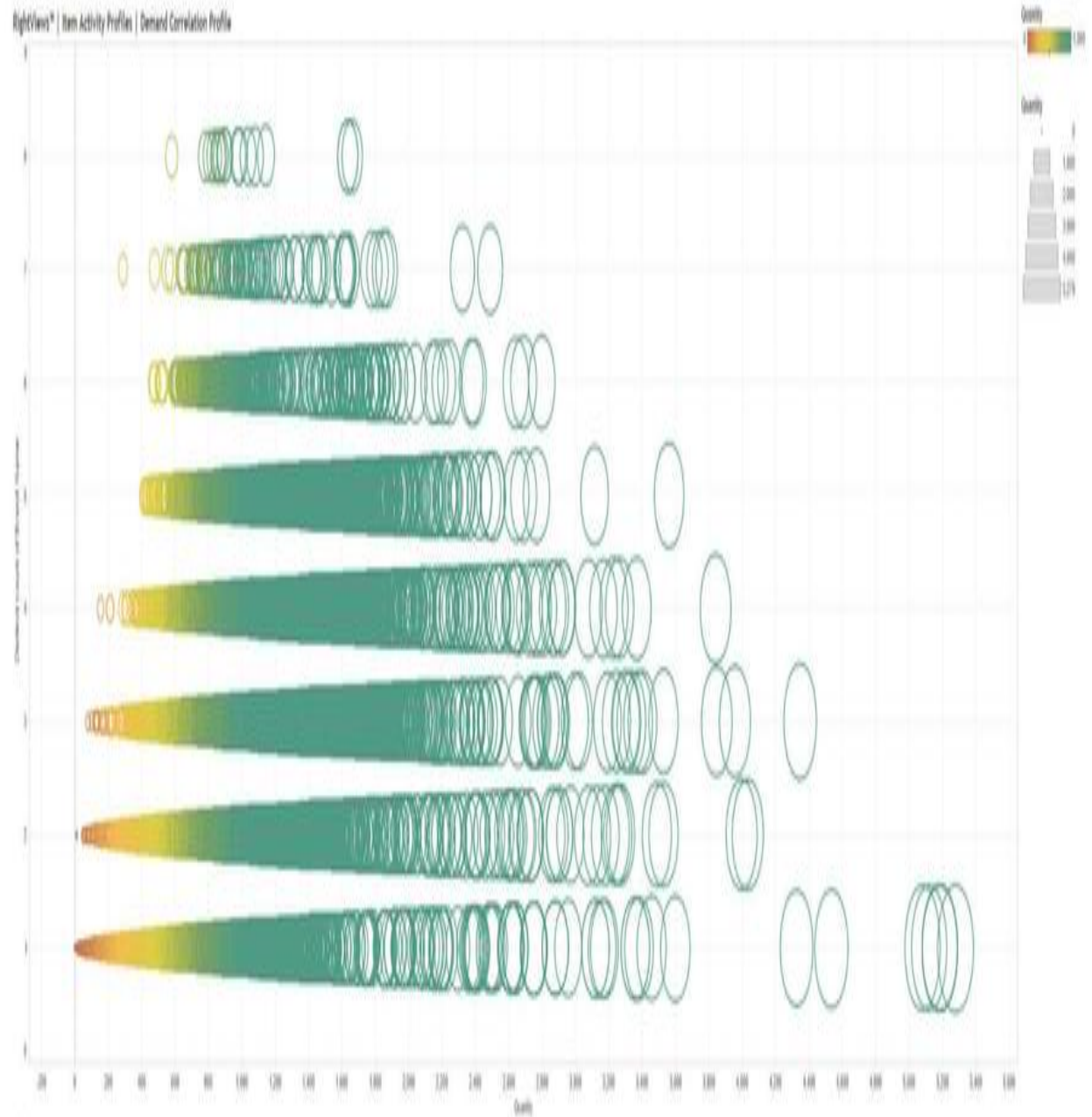
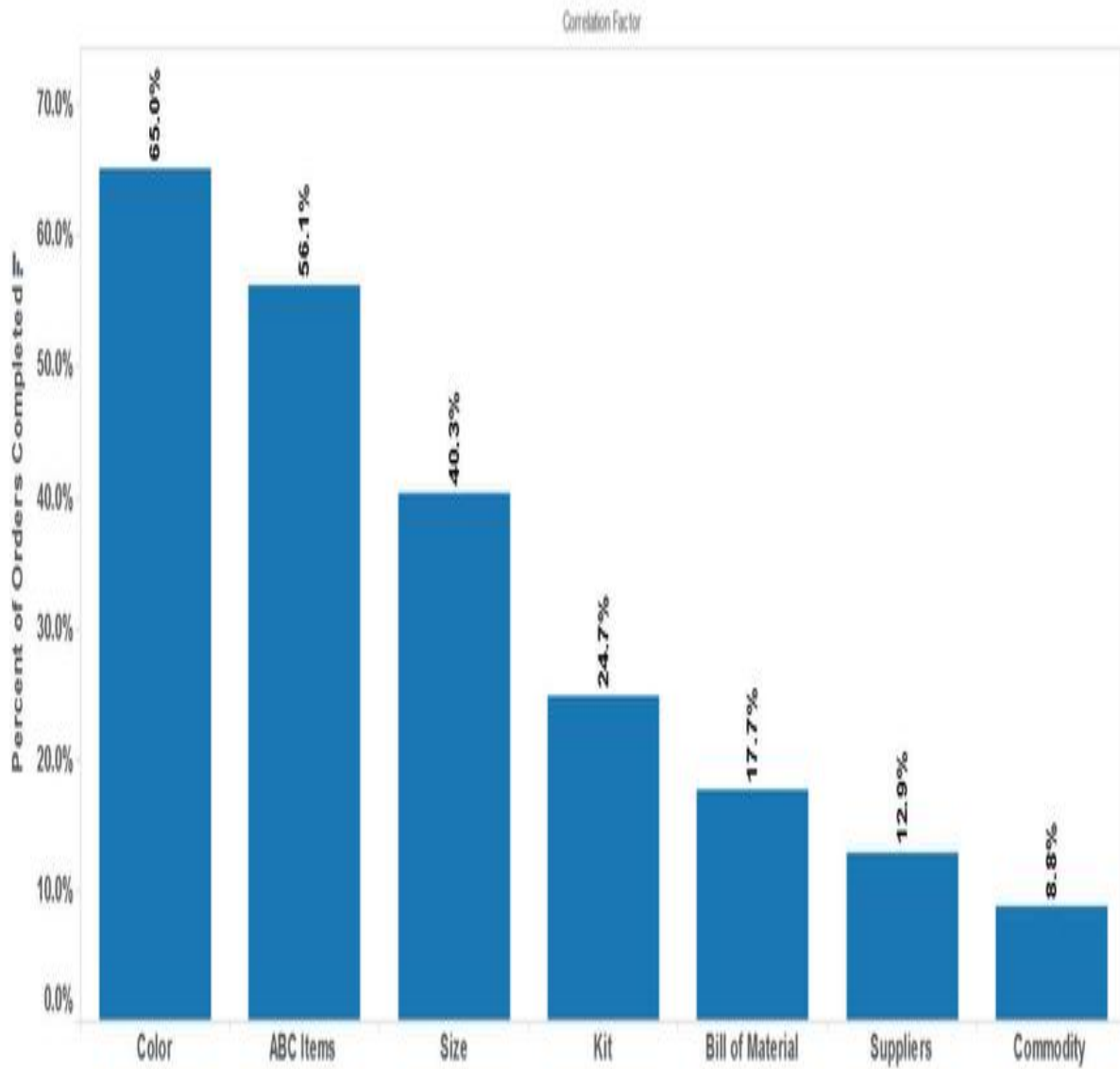


Figure 2.31 Order-completion profile for a large industrial supplies company.

RightViews™ | Warehouse | Sales Order Profile | Demand Correlation Distribution



Demand-Correlation Profile

Just as a minority of the items in a warehouse makes up a majority of the picking activity, *certain items in the warehouse tend to be requested together*. In the example ([Figure 2.32](#)), pairs of items are ranked based on their frequency of appearing together on orders. In this case, we are examining data from a mail-order apparel company. The first three digits represent the style of the item (i.e., crew-neck sweater, V-neck sweater, turtle-neck shirt, pleated pants, etc.), the middle digit represents the size of the item (i.e., 1 = small, 2 = medium, 3 = large, and 4 = extra large), and the last digit represents the color (i.e., 1 = white, 2 = black, 3 = red, 4 = blue, 5 = green, etc.).

Figure 2.32 Demand-correlation distribution (style-size-color) for a large omni-channel retailer.

Item Number	Item Number	Pair Frequency
189-2-4	189-2-1	58
493-2-1	493-2-8	45
007-3-3	007-3-2	36
119-2-1	119-2-7	30
999-1-8	999-1-6	22
207-4-2	207-4-4	15
662-1-9	662-1-1	12
339-7-4	879-2-8	9
112-3-8	112-3-4	6

What do you think people tend to order together from this mail-order company? (I thought it would be shirts and pants that looked good together in the catalog.) What does the profile in [Figure 2.32](#) suggest? In this case, customers tend to order items of the same style and size together. The explanation is that customers tend to get comfortable with a certain style and tend to order in multiple colors to add variety to their wardrobes. Of course, they order the same size unless they will return one for fitting. This pattern was a surprise to me. It was also a surprise to the marketing people. Surfacing truth is the crucial benefits of profiling process. (The myriad SKUs, order patterns, suppliers, and interdependent decisions make it difficult to form a reliable intuition about logistics operations.)

How do we take advantage of this demand-correlation information in slotting a warehouse? We zone the warehouse by item size first, creating a

zone for the smalls, mediums, larges, and extra larges of all styles ([Figure 2.33](#)). Within each size area, we store items of the same style together, mixing colors within a style. This zoning strategy allows us to create picking tours based on size and style. As a result, order pickers pick many items on short-distance picking tours. Simultaneously, we manage congestion by spreading out the sizes. Golden zoning is used to slot the most popular color for each style at or near waist level.

Figure 2.33 Slotting optimization for a large omni-channel apparel retailer.

	A	B	C	D	E	F	G	H	I
1	Accessories	Sweaters			Sweaters		Accessories		Small
2									Medium
3									Large
4									X Large
5	Pants	Shirts			Shirts		Pants		
6									
7									
8									
9	Pants	Shirts			Shirts		Pants		
10									
11									
12									
13	Pants	Shirts			Shirts		Pants		
14									
15									
16									
17	Accessories	Sweaters			Sweaters		Accessories		
18									
19									
20									
21	Accessories	Sweaters			Sweaters		Accessories		
22									
23									
24									
25	Accessories	Sweaters			Sweaters		Accessories		
26									
27									
28									

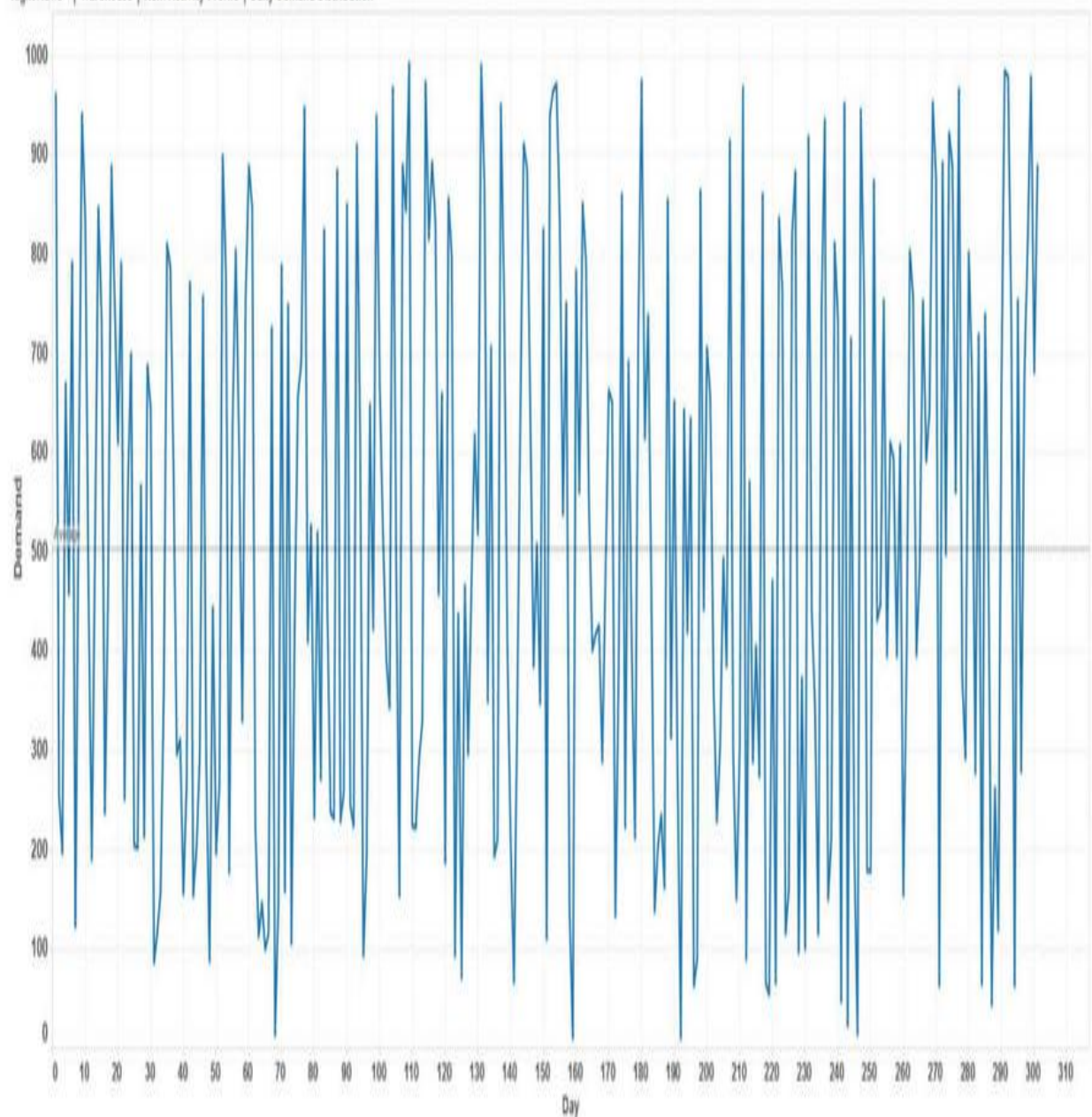
Demand-Variability Profile

The demand-variability profile ([Figure 2.34](#)) indicates the standard deviation of daily demand for each item. Unfortunately, an item's daily demand is not predictable. During a recent project, we were trying to size the pick faces along a case picking line such that each pick face held a day's worth of stock. The motivation was to make sure that we did not need to restock a location during the day. The current design had the pick faces sized for an average day's demand, and the client could not figure out why it had to restock so many locations during the course of a day. You can probably see why. If the pick face is sized for the average day, unless the same quantity is picked every single day, there will be many days when the pick face is oversized and many days when the pick face is undersized. Once the pick faces were resized to accommodate this variability in demand, the restocking during the pick shift was virtually eliminated.

Figure 2.34 Demand-variability profile for a large textile company.

RightViews™ | Item Profiles | Demand Variability | Daily | Units

RightViews™ | Warehouse | Item Activity Profile | Daily Demand Distribution



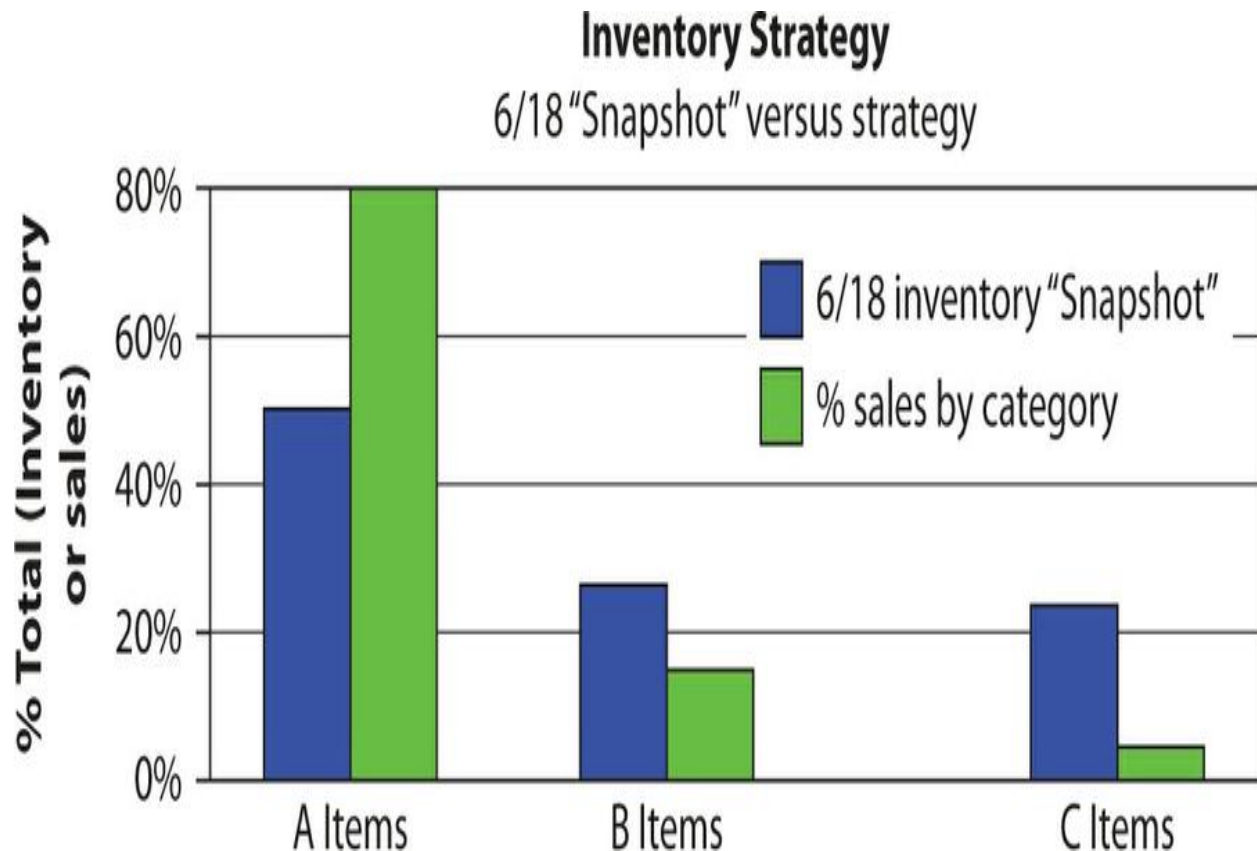
2.5 Inventory Profile

The inventory profile includes the item-family inventory profile used to reveal opportunities for improved inventory management practices and the handling-unit inventory profile used in storage systems planning.

On-Hand Inventory Profile

I receive a lot of phone calls that begin with clients complaining about the lack of space in their warehouse. *More often than not, the problem is not too little space, but too much inventory.* This profile ([Figure 2.35](#)) helps us identify the source of the inventory problem. As is true in the example, most companies have too little type A inventory (back orders and customers screaming for those products) and too much type C inventory (obsolete stock that nobody wants and nobody has the courage to discard). By drawing the picture, we can at least illustrate the magnitude of the problem to management and present a list of “problem items” for their review.

Figure 2.35 Item-family inventory distribution.



In some cases, C items should be removed from inventory. However, in many cases, warehouses are required to house the C items. One example is in the service parts business, where you may be required to support a certain model number in the field for up to 5, 10, even 20 years. Another example is in retailing when some key type C items protect the sales of items A and B. On a recent project in the grocery industry, the chairman of the company was presented with a recommendation to eliminate the C items from inventory. Let's pause and consider the consequences. How many items do you buy on your weekly trip to the grocery store to restock the kitchen cabinets? Say it's 50 items. In this case, there is at least a 70 percent chance that one of those 50 items is a C item. Why did you go to that grocery store? In the case of this grocery chain, it was probably because it stocked that C item. Otherwise, you could and would shop at a warehouse store.

Even though you may not be able to eliminate the C item inventory you can at least efficiently store and pick the items. To conserve space, you can store the C item inventory in dense, high-rise racking or on the second or third level of a mezzanine. To achieve high productivity at the same time,

you can batch-pick the C item pick line and locate the batch in a dedicated location along the forward pick line or introduce the batch into an automated sorting system.

Handling Unit Inventory Profile

The item-family inventory profile is not very useful for storage systems design because the information is not presented in material-handling terms (i.e., pallets, cases, eaches, etc.). This is a common problem with most corporate data used in planning warehouse operations—the data are expressed in terms of dollars, pounds, pieces, days of supply, turns, and so on. Although this is useful for business planning purposes, the data are not very helpful for planning and managing warehouse operations. This is another motivation for the profiling exercise—to give managers and designers of the warehouse operations a presentation of the activity of the warehouse in their terminology.

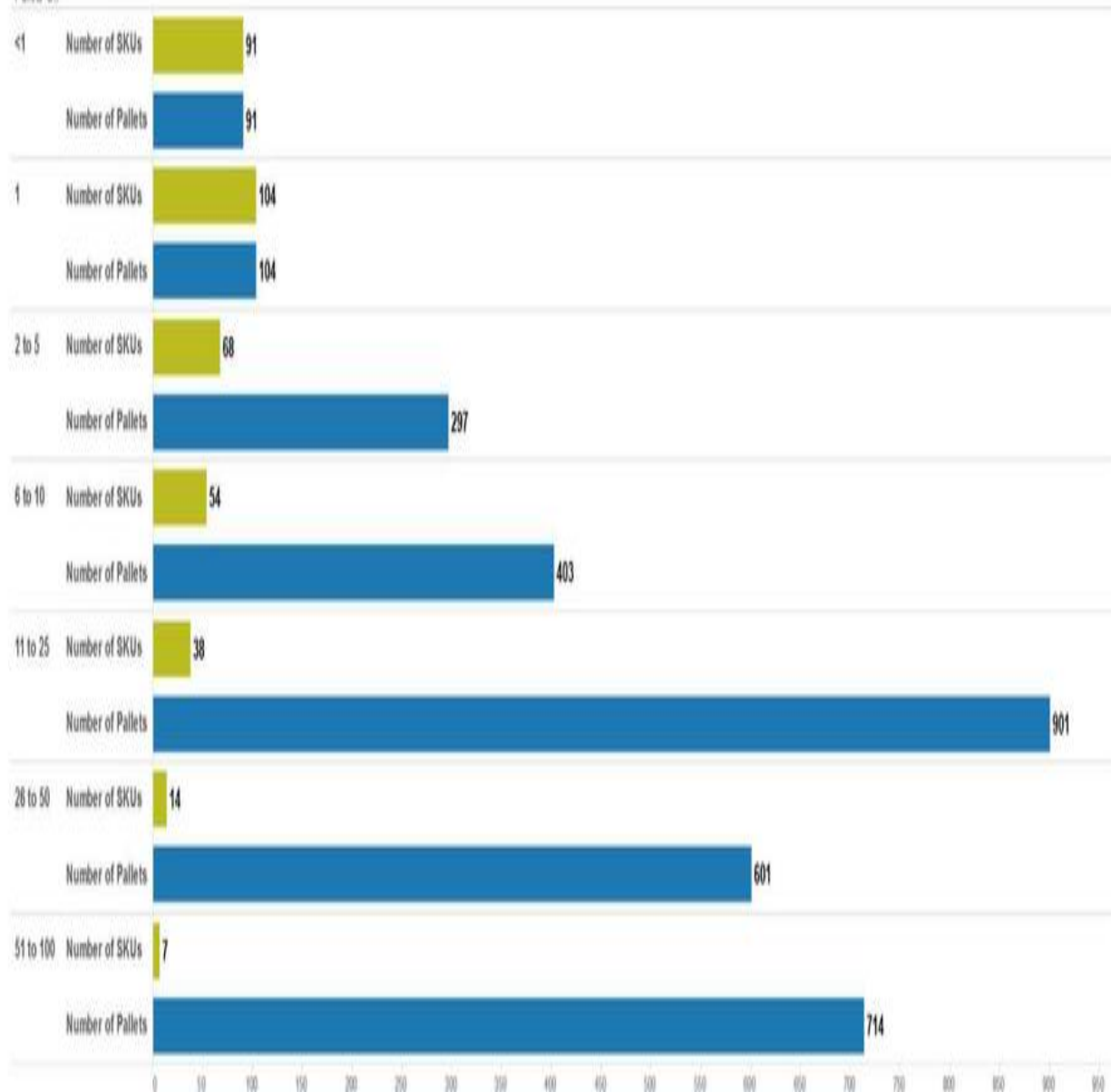
In this example ([Figure 2.36](#)), we convert the item-family inventory distribution into a distribution describing on-hand inventory in terms of pallets of merchandise on hand. As a result, we can recommend the appropriate mix of pallet storage modes. For example, the 91 SKUs with less than a pallet of inventory on hand probably should be stored in shelving or decked racking. The 104 SKUs that have one or two pallets on hand probably should be stored in single-deep pallet racks. The 68 SKUs that have three to five pallets on hand probably should be stored in double-deep and/or push-back racks. The remaining SKUs, those with more than 10 pallets on hand, probably should be stored on the floor in deep block stacking lanes, in drive-in/through racks, and/or in pallet flow lanes.

Figure 2.36 Handling-unit inventory distribution for a large healthcare company.

RightViews™ | Item Profiles | Inventory Profile | Handling Units

RightViews™ | Warehouse | Item Activity Profile | Pallets on Hand

Pallets On



CHAPTER THREE

WAREHOUSE PERFORMANCE, COST, AND VALUE MEASURES

3.1 RightScores Principles

3.2 Workforce Facing Metrics: A Great Place to Work

3.3 Customer-Facing Metrics

3.4 Shareholder-Facing Metrics

3.5 Warehouse Performance Gap Analysis

3.6 Practice Makes Perfect

In our RightScores methodology, we treat the warehouse like a business. Businesses compete on the basis of financial, productivity, utilization, quality, and cycle-time performance. They are also accountable to serve their employees with a great place to work, their customers with excellent customer service, and their shareholders with excellent returns relative to risk. Accordingly, this chapter on warehouse performance measurement shares guiding measurement principles, workforce metrics, customer service metrics, shareholder performance metrics, and techniques for utilizing those

performance metrics in warehouse project justification.

3.1 RightScores Principles

RightScores is our performance-measurement model. The model is based on seven key principles of performance measurement. I will explain these principles briefly and then apply them to warehousing.

1. *Servant leadership.* The heart of the RightScores model is service. Our model encourages serving employees with a great place to work, serving customers with excellent customer service, and serving shareholders with excellent financial performance. Accordingly, RightScores' metrics face three way: Employee-facing metrics include safety and turnover. Customer-facing metrics include accuracy, cycle time, and on-time performance. Shareholder-facing metrics include cost, productivity, and utilization.
2. *Span the flow.* In a supply chain, the flow of materials, information, and money connects suppliers and customers through production, purchasing, inbound transportation, warehousing, outbound transportation, and customer delivery ([Figure 3.1](#)). In warehousing, the flow typically moves from receiving, to put-away, to storage, to picking, to shipping. This flow of connected activities organizes the columns of metrics on our RightHouse Scoreboard ([Figure 3.2](#)).

Figure 3.1 RightChain™ Scoreboard.

	Category	Sub-Cat	Selling	Merchandising	Inventory	Manufacturing	Sourcing	Transportation	Warehousing	Delivery	SUPPLY CHAIN	
WORKFORCE	Workforce	GPTW	↓ 81.0% % yes	↑ 98.0% % yes	→ 91.0% % yes	↗ 93.0% % yes	↘ 94.0% % yes	↗ 91.0% % yes	↓ 81.0% % yes	↓ 79.0% % yes	↗ 85.0% % yes	
		Safety	↓ 4,250.0 MH/I	↑ 8,998.0 MH/I	↗ 7,653.0 MH/I	↓ 3,822.0 MH/I	↑ 8,788.0 MH/I	↑ 9,145.0 MH/I	↑ 9,987.0 MH/I	↑ 9,650.0 MH/I	↑ 9,001.0 MH/I	
Customer Service		Quality	↑ 94.0% PSO	↑ 93.0% PMCO	↓ 56.0% Fcast Accuracy	↑ 99.0% PMOP	⇒ 81.0% PPOP	↑ 92.0% PDP	↑ 93.0% PWHOP	↑ 98.0% PDP	↘ 72.0% POP	
		Cycle Time	↓ 1.9 SCT	↗ 12.8 MCT	↓ 4.7 IPCT	↘ 7 MCT	↑ 14.3 POCT	⇒ 8.2 TCT	↓ 2.4 YTS, WOCT	↘ 5.4 DCT	↑ 17.3 SCCT	
SHAREHOLDER	Finance	Cost	↓ \$ 1.23 \$/case	↑ \$ 4.21 \$/case	↓ \$ 1.22 \$/case	↗ \$ 2.99 \$/case	↓ \$ 0.99 \$/case	\$ 1.88 \$/case	↘ \$ 2.11 \$/case	↘ \$ 1.82 \$/case	↑ \$ 16.45 \$/case	
			ROS	↓ 0.30% TSCI/sales	↓ 0.90% TMCC/sales	⇒ 2.80% ICC/sales	↓ 1.10% TMC/sales	↓ 0.80% TSC/sales	↑ 5.50% TTC/sales	↗ 4.30% TWC/sales	↘ 2.10% TDC/sales	↑ 17.80% GM/Sales
		ROA	↓ 6.00% SROA	↓ 8.00% MROA	↓ 12.00% GMROI	↗ 33.00% GMROA	↘ 21.00% GMROI	↓ 9.00% GMROA	↑ 45.00% GMROA	↗ 33.00% DROA	↑ 19.00% SCROI	
			Productivity	Labor	⇒ 67 cpmh	↓ 21 cpmh	↘ 43 \$/FTE	⇒ 78 cpmh	↓ 34 cpmh	↑ 124 cpmh	↑ 112 cpmh	↗ 100 cphm
		Capital		↓ 12.8 Sales/\$I	↓ 13.9 Sales/\$I	↑ 25.6 turns	↑ 23.9 cases/\$invest	⇒ 19.1 turns	↓ 12.3 cases/\$invest	↘ 15.8 cases/\$invest	↓ 12.9 cases/\$I	↓ 11.9 cases/\$invest
		Space		↓ 0.998 GM/cube	↓ 0.991 GM/cube	↓ 0.876 GM/cube	↓ 0.776 GM/SF	↓ 0.601 GM/cube	↓ 0.398 GM/cube	↑ 21.3 cases/SF	↓ 0.511 GM/cube	↑ 18.99 cases/SF
	Utilization	Labor	↑ 90.0% % labor util	↑ 93.0% % labor util	↑ 92.0% % labor util	↑ 91.0% % labor util	↓ 65.0% % labor util	↘ 73.0% % labor util	↗ 82.0% % labor util	↗ 82.0% % labor util	⇒ 81.0% % labor util	
		Capital	↓ 28.0% % buy util	↑ 89.0% % buy util	↓ 34.0% % buy util	↗ 81.0% % prod util	↑ 99.0% % buy util	↓ 34.0% % fleet util	↘ 44.0% % cap util	↓ 39.0% % fleet util	↗ 82.0% % cap util	
		Space	↑ 91.0% % space util	↑ 89.0% % space util	↘ 80.0% % space util	↓ 78.0% % space util	↓ 79.0% % space util	↓ 77.0% % space util	↘ 80.0% % space util	↑ 89.0% % space util	↘ 80.0% % space util	
		Aggregate	↓ \$ 18.91 TSLC/PSO	↓ \$ 12.55 TMCC/PMO	↓ \$ 13.45 TIC/PIO	↓ \$ 11.10 TMC/PMO	↓ \$ 9.97 TSC/PSO	↓ \$ 8.88 TTC/PTO	↓ \$ 9.12 TWC/WHPO	↓ \$ 11.10 TDC/PDO	↑ \$ 28.93 TLC/PfctOrder	
	Conditions	Complexity	↓ 912 # SKUs	↓ 800 # SKUs	↓ 765 # SKUs	↓ 488 # SKUs	↓ 411 # Suppliers	↑ 12,988 # Locations	↓ 981 # SKUs	↓ 981 # Stops	↑ 10,912 SKU-Channels	
		Practices	↑ 4.2 out of 5	⇒ 3.1 out of 5	↘ 2.8 out of 5	⇒ 3.3 out of 5	↓ 2.1 out of 5	↗ 3.6 out of 5	↗ 3.4 out of 5	⇒ 3.2 out of 5	⇒ 3.2 out of 5	
		Risk	↓ 2.1 out of 5	⇒ 3.3 out of 5	↑ 4.3 out of 5	↘ 2.9 out of 5	↑ 4.8 out of 5	↑ 4.7 out of 5	↘ 2.7 out of 5	⇒ 3.5 out of 5	⇒ 3.5 out of 5	

Figure 3.2 RightHouse Scoreboard summary screen.

RightHouse™ Scoreboard

[illegible]

3. *Red, yellow, green.* We recently completed a warehouse performance and practices assessment for the U.S. Army. The Army was pleased with all the aspects of the assessment except one—RYG. To be honest, I did not know what the acronym meant, so I asked. The representative explained that RYG is simply “red-yellow-green” and that it is a critical aspect of the presentation of the Army’s indicators. When I pressed further, the representative explained that in battle, military personnel may be trying to understand an assessment with little to no sleep, little to no food, and with bullets flying around. In trying to make good, quick decisions under those circumstances, it is helpful to simply know if things are okay (green), in trouble (red), or somewhere in between (yellow).
4. *For better or worse.* Trending indicators of improving or declining performance are another useful feature in metrics presentations. We use directional arrows in each metrics cell to illustrate trending.
5. *Down and down we go.* Our RightHouse Scoreboard allows users to drill down to a specific warehouse, to a specific activity in a specific warehouse, and to a specific operator in a specific activity in a specific warehouse. Results are filtered by month, location, and channel of business.
6. *Practice makes perfect.* Warehouses perform the way they practice. Accordingly, our RightHouse Scoreboard reports a practice score for each warehouse activity.
7. *Sum the whole.* The metrics either add or multiply across the activities to indicate the overall performance of the warehouse.

3.2 Workforce Facing Metrics: A Great Place to Work

A great place to work is safe, operates with a high cross-functional percentage, operates with a healthy operator-to-supervisor ratio, and is evidenced by a high retention rate of high-performance workers.

There are two basic reasons why workers leave for another workplace: they feel unsafe and/or they feel undervalued. Physical safety is the most

basic provision organizations for their warehouse workforce. Two very simple measures provide of warehouse safety are the personnel-hours worked between each accident and the personnel-hours worked between each recordable accident. We monitor both for each warehouse activity and for the warehouse as a whole.

Cross-Functionalism

Another reason workers leave is boredom and injury due to repetitive tasks. By educating and encouraging workers to qualify for and work in multiple functions, boredom and repetitive tasks are minimized, and overall staffing requirements are reduced. Cross-functionalism measures the percent of operators who are trained to work in multiple functions.

Operator-to-Supervisor Ratio

Several years ago, a crazy idea called *self-directed work teams* crept into business buzzword vernacular. The implementers quickly rediscovered that teams need direction. There is an optimal level of direction for any activity, including each warehouse activity. In our benchmarking research, we have found that an operator-to-supervisor ratio between 8 and 12 yields optimal performance.

Retention

In our annual survey of concerns for warehouse managers the top two primary concerns have always been the same—turnover and aging ([Figure 3.3](#)). The impact of turnover on warehouse productivity and quality is grossly underestimated. In our recent survey, we correlated turnover rates with our Warehouse Quality Index (WQI). The correlation is strong and unmistakable. Retention of high-performing warehouse operators is one of the common denominators in world-class warehousing operations ([Figure 3.4](#)).

Figure 3.3 Warehouse managers' primary workforce concerns. Worker retention has been the number one indicator for as long as we have been conducting this survey.

Benchmarks >

RightChain™ Research | Benchmarks | Warehousing | Workforce Concerns

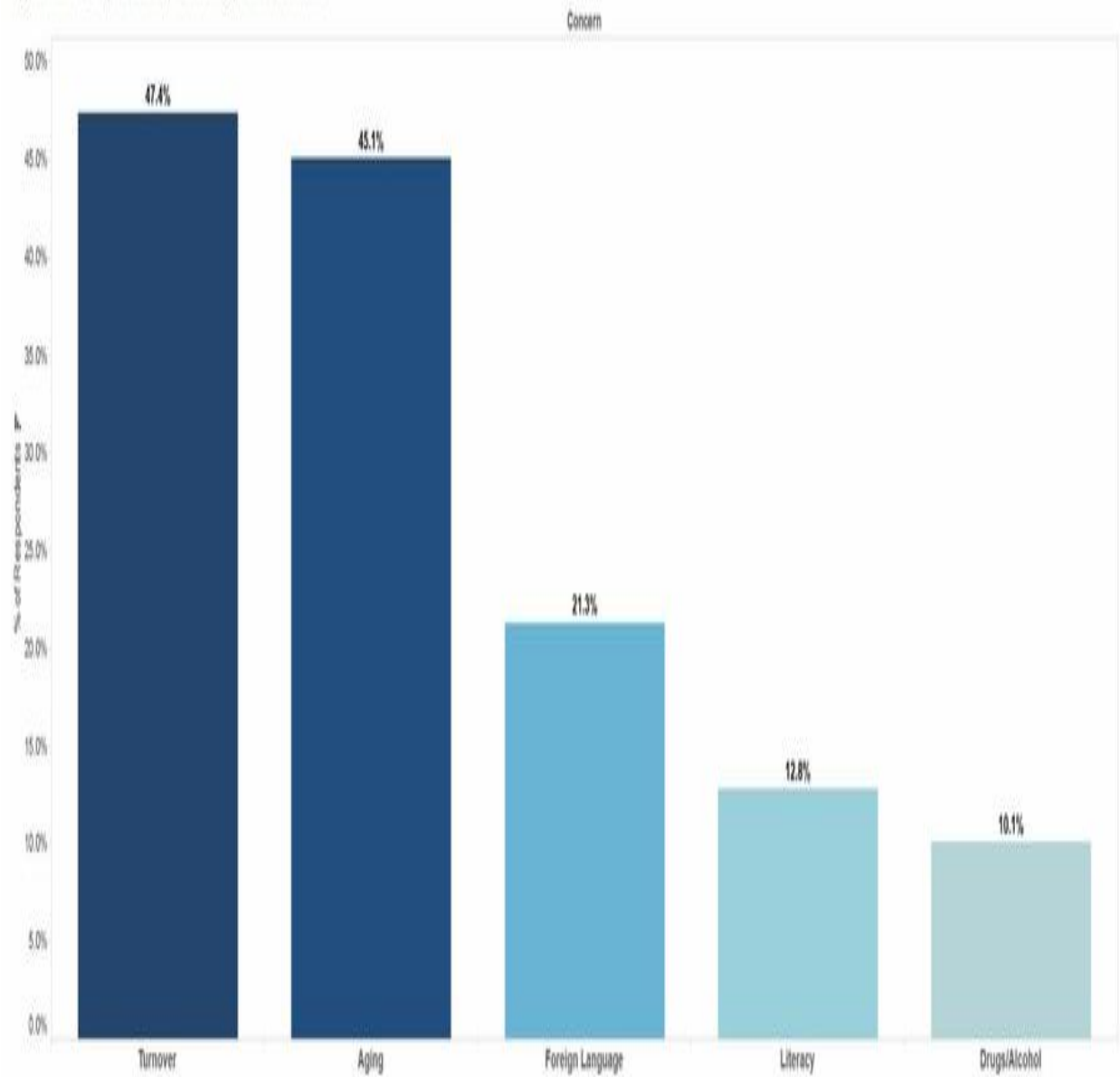
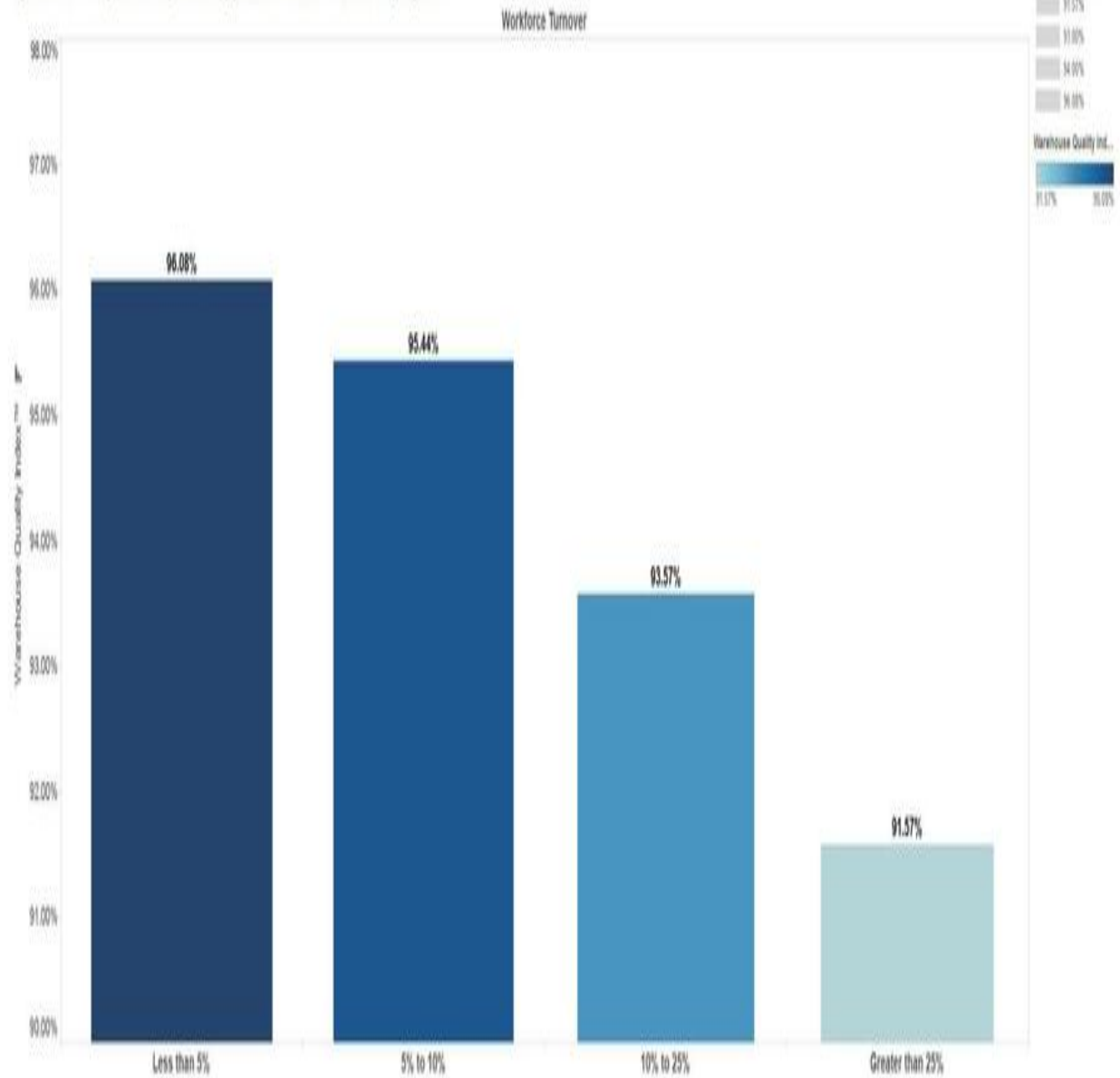


Figure 3.4 Warehouse workforce turnover versus Warehouse Quality Index (WQI). The WQI, the product of inventory and shipping accuracy, is one of our overall indicators of warehouse quality performance. There is a dramatic drop-off in the WQI as turnover increases. When we compare the cost of poor quality with the cost of retaining a high-quality workforce, we have yet to come across a situation where the warehouse was not significantly better off investing in the workforce.

[Benchmarks >](#)

RightChain™ Research | Benchmarks | Warehousing | Workforce Turnover vs Warehouse Quality Index™



3.3 Customer-Facing Metrics

Warehouses contribute to customer service when they provide accurate orders, on-time in short cycle times.

Accuracy

Our RightHouse Scoreboard tracks ([Figure 3.5](#)) at least one accuracy indicator for each warehouse activity and summarizes those indicators into four accuracy indicators—two for inbound handling and two for outbound handling.

Figure 3.5

[illegible]

Inbound Accuracy High inbound accuracy prepares a warehouse for high outbound accuracy, we recommend two inbound indicators—put-away accuracy and inventory accuracy.

Put-away accuracy measures the number of put-away transactions that are executed to the correct system-directed put-away location. It is difficult, if not impossible, to recover from an inaccurate put-away.

Warehouse inventory accuracy measures the number of inventory locations that hold the system-recorded level of inventory. High levels of inventory accuracy are achieved through high put-away accuracy, ABC cycle counting, disciplined housekeeping, and real-time transactions. Under the drag of poor warehouse inventory accuracy, trust in the supply chain breaks down. No inventory strategy can properly operate without high degrees of trust in the numbers used to support it ([Figures 3.6 through 3.8](#)).

Figure 3.6 Inventory accuracy benchmarks. We recently surveyed organizations with uniquely high requirements for warehouse inventory accuracy. Their location, item, and financial inventory accuracies are depicted in the figure (RightChain Research)

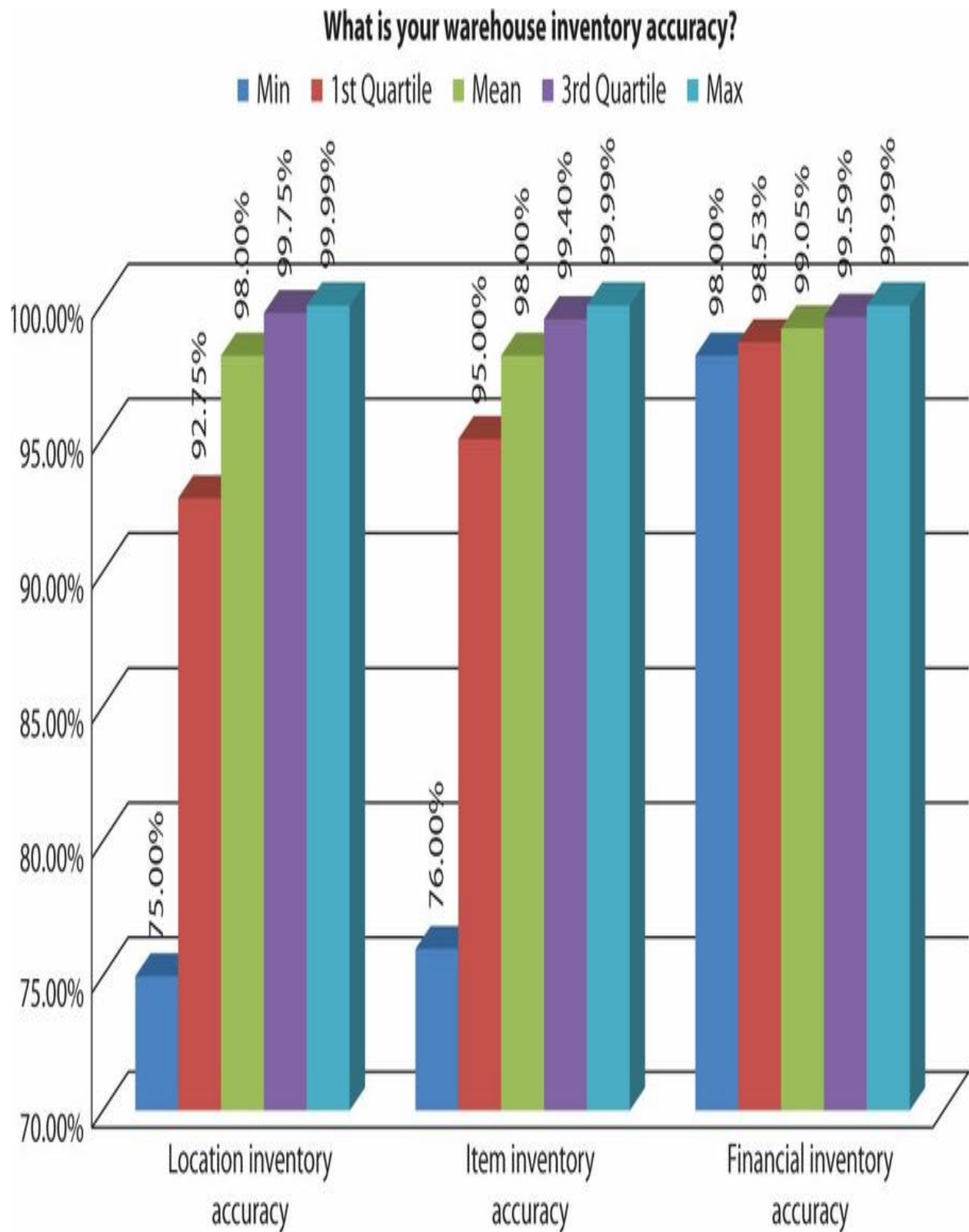


Figure 3.7 In the same survey, we asked the participants what methods

of inventory counting they employ in various stages of the supply chain (RightChain Research).

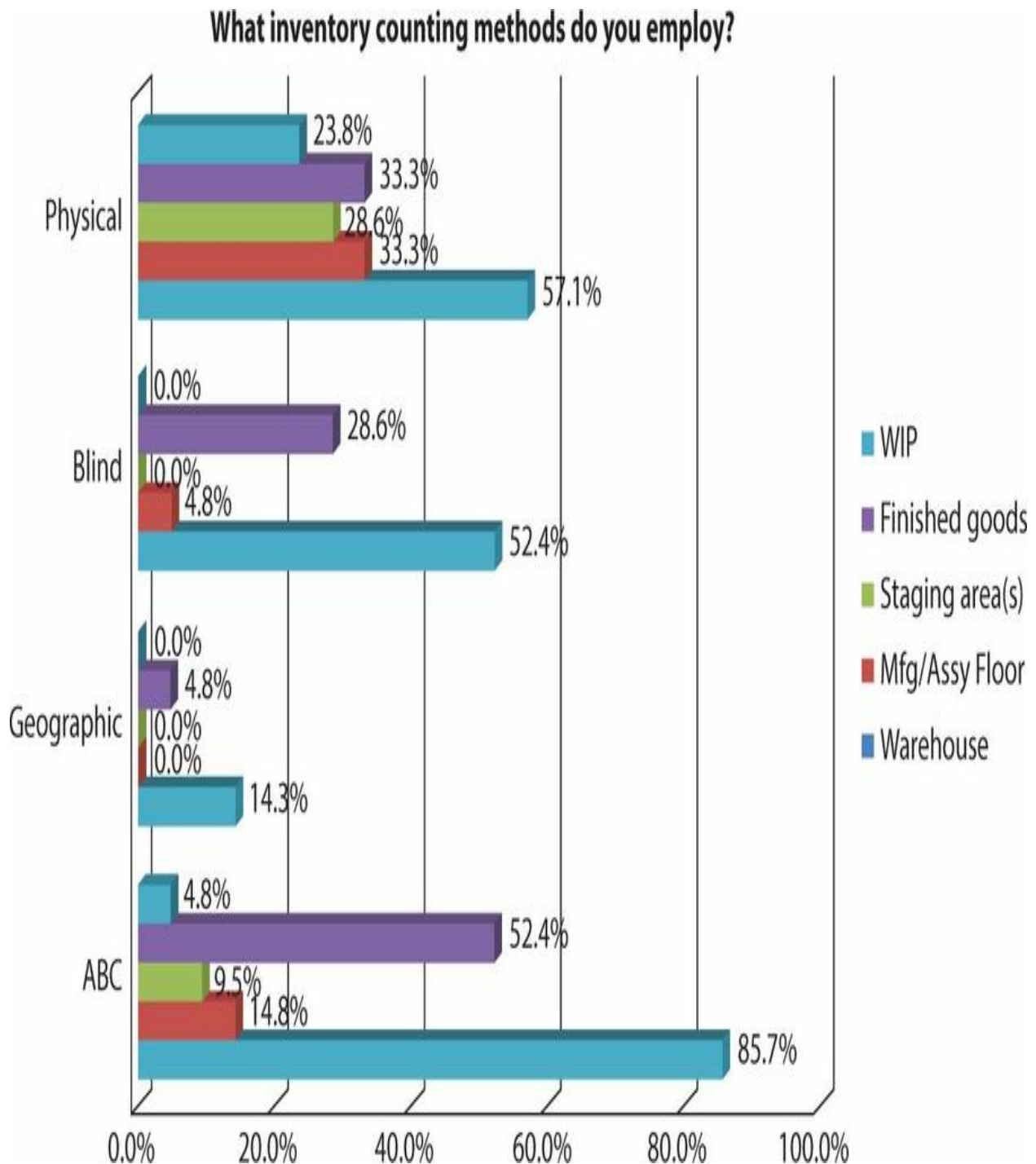


Figure 3.8 Accuracy performance screen from the RightHouse

Scoreboard. Inventory accuracy is along the x axis, and shipping accuracy is along the y axis. Each bubble represents a distribution center in a supply-chain network. The size of the bubble corresponds to the transaction volume in the distribution center (RightChain Analytics).

[illegible]

Outbound Accuracy Our RightHouse Scoreboard monitors two indicators of outbound accuracy—picking accuracy and shipping accuracy. Picking accuracy is the portion of order-line picks executed with the correct stock-keeping unit (SKU) in the correct quantity. Shipping accuracy is the portion of shipping-line transactions executed with the correct SKU in the correct quantity.

Our best warehouse clients ([Figures 3.9](#) through [3.11](#)) in the United States have shipping accuracies at or near 99.97 percent. Our best warehouse clients in Japan have shipping accuracies at or near 99.997 percent, an order of magnitude improvement.

Figure 3.9 Accuracy and damage indicators monitored in survey warehouses (RightChain Research).

RightChain® Research | Benchmarks | Warehousing | Warehouse Accuracy Metrics

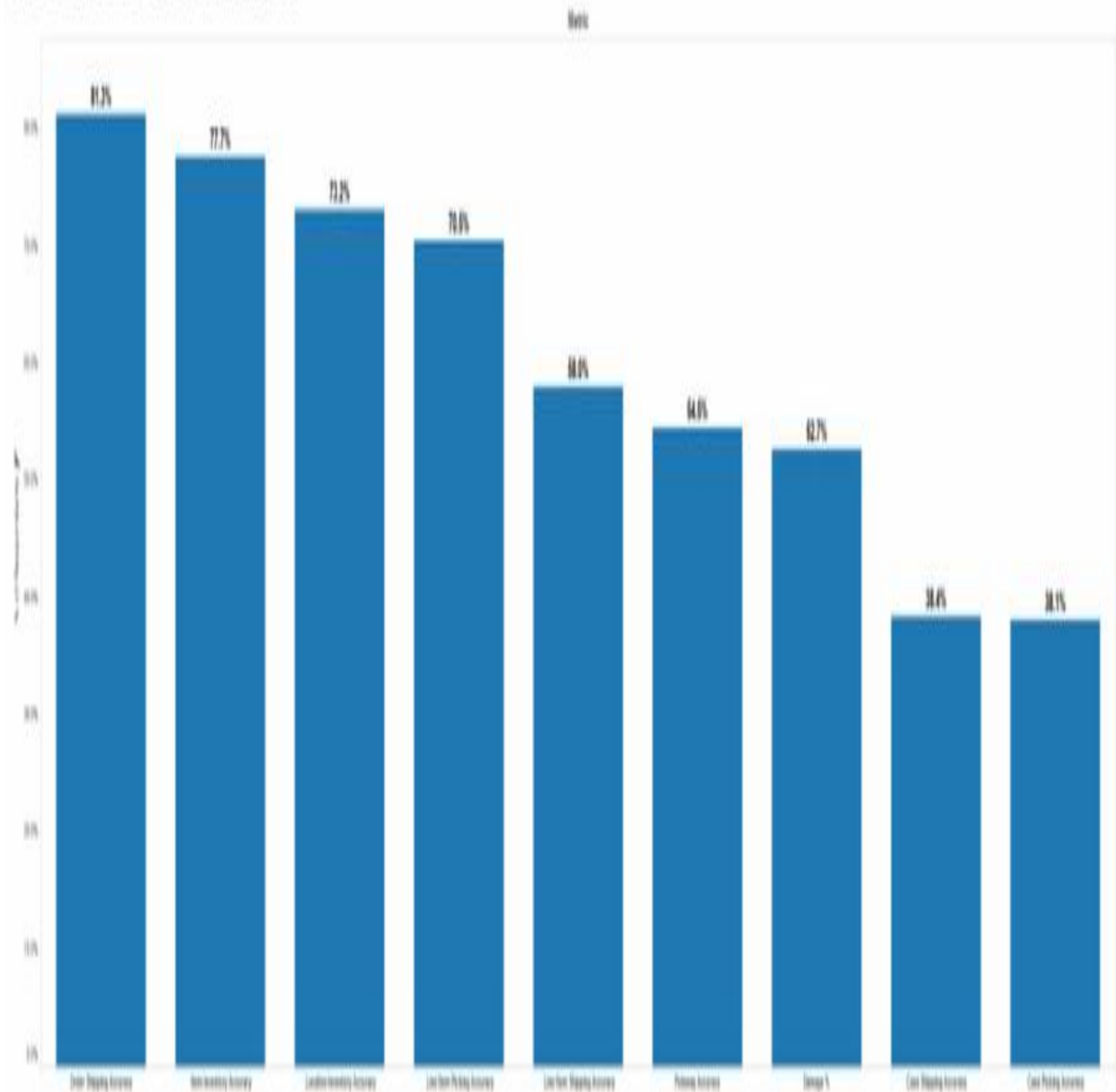


Figure 3.10 Means of determining picking and shipping accuracy in survey warehouses.

RightChain® Research | Benchmarks | Warehousing | Accuracy Determination

Accuracy Determination

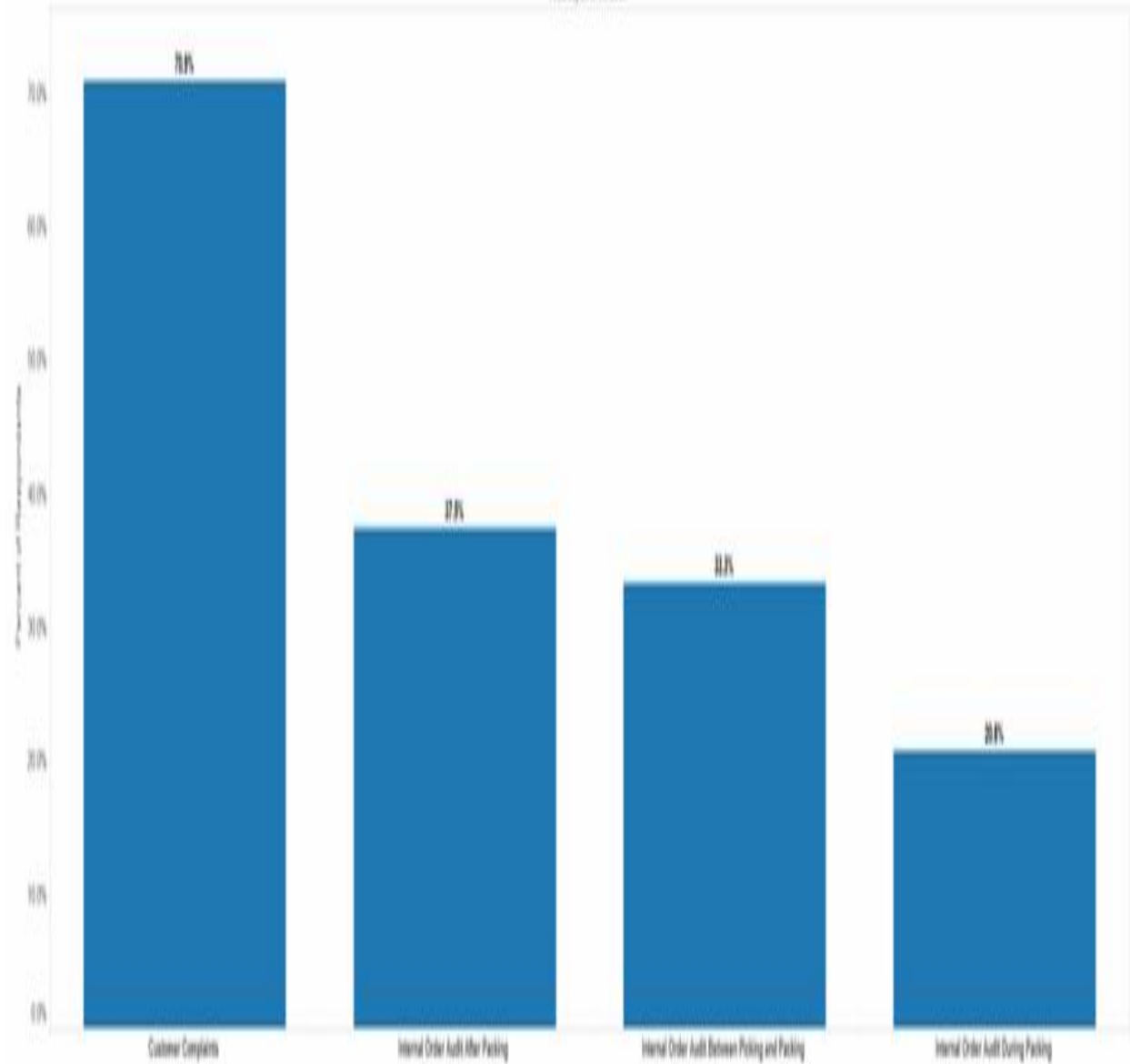
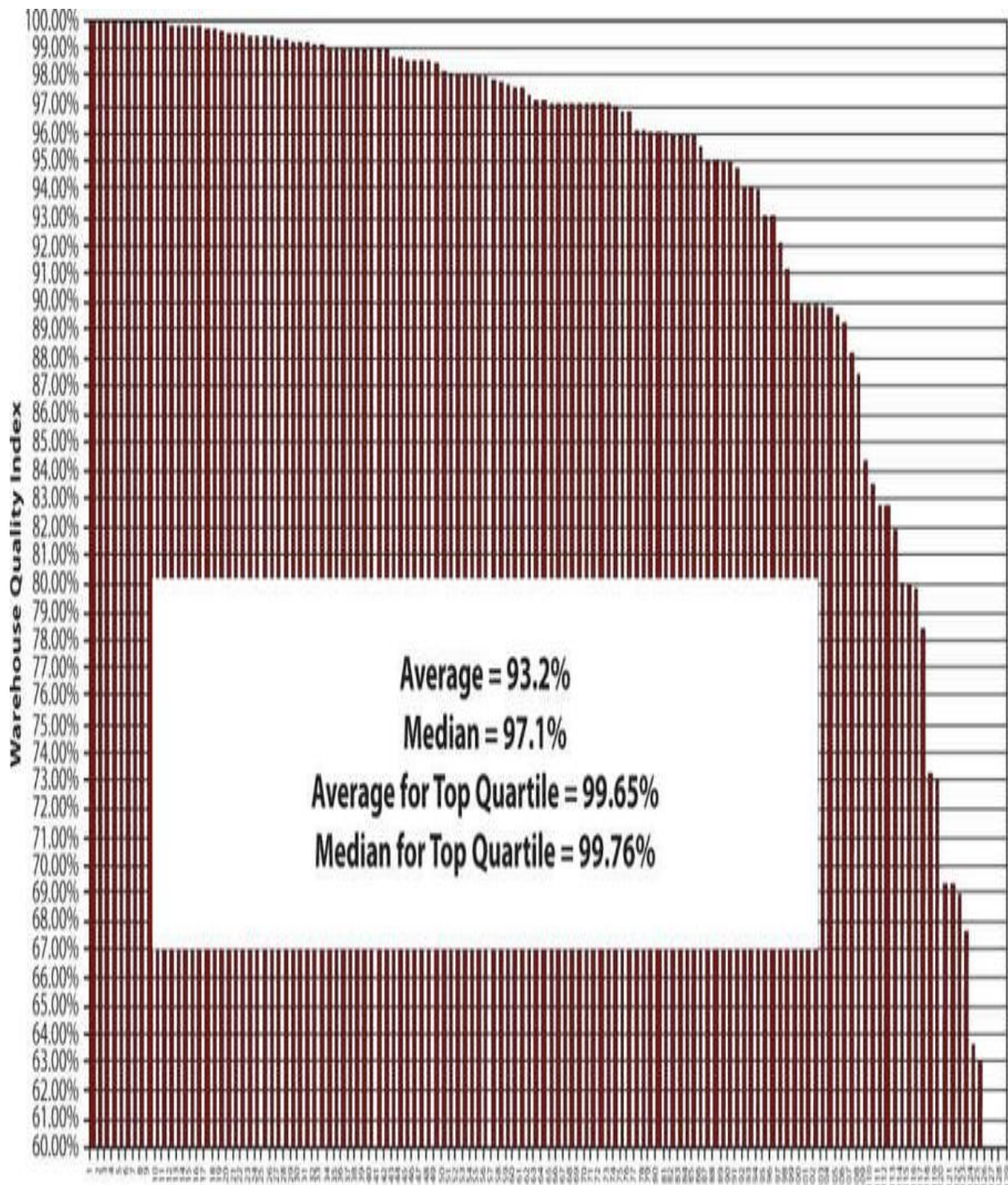


Figure 3.11 Our Warehouse Quality Index is the product of a warehouse's inventory accuracy and its shipping accuracy (RightChain Research).



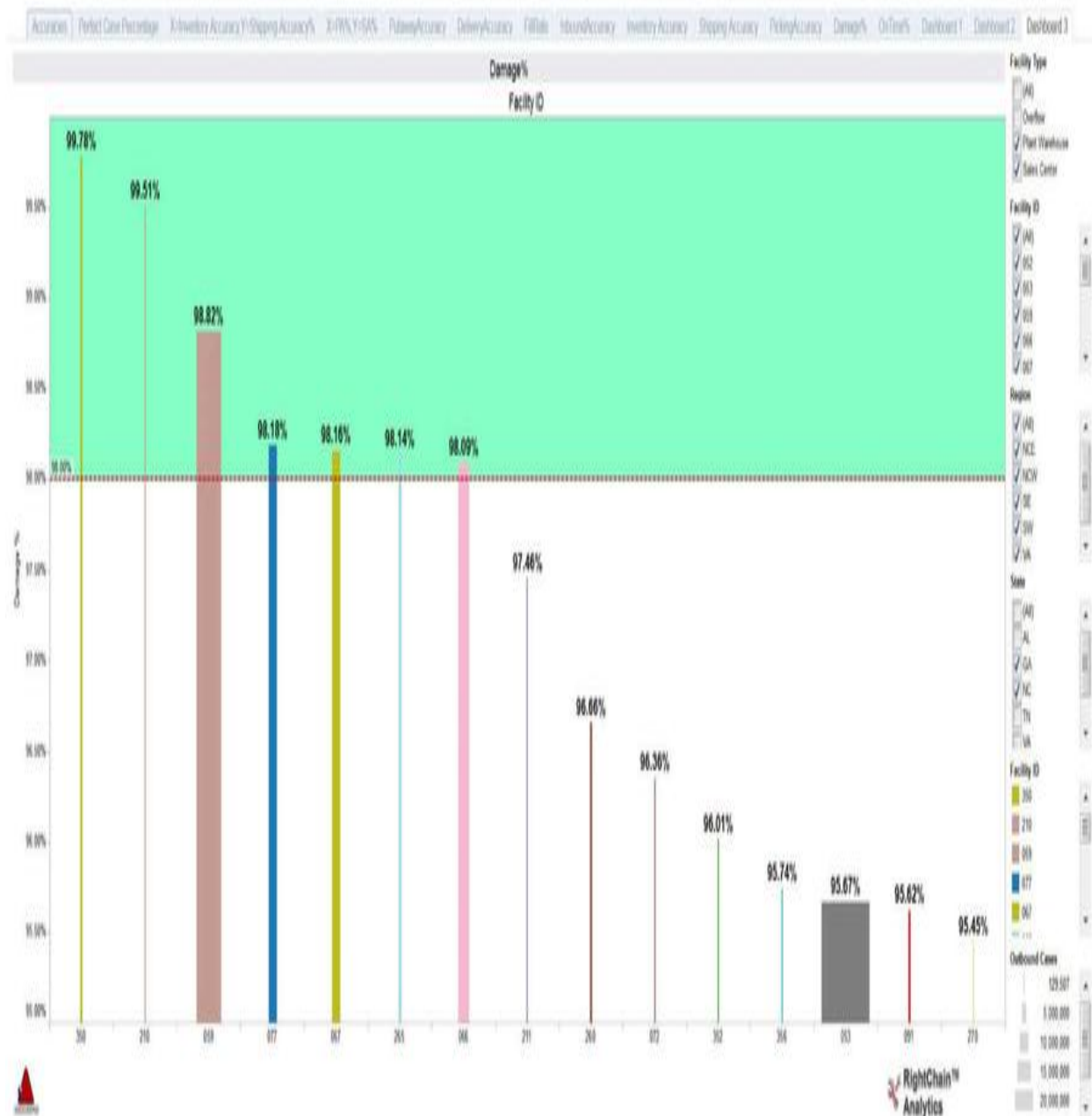
Damage

If accurate orders arrive on time to the right location with damage, all the production and logistics work in the world is for naught. Accordingly, the RightHouse Scoreboard tracks damage rates for each warehouse activity and for the warehouse as a whole ([Figure 3.12](#)).

Figure 3.12 RightHouse Scoreboard damage performance analysis.

Scoreboards >

Damage Performance



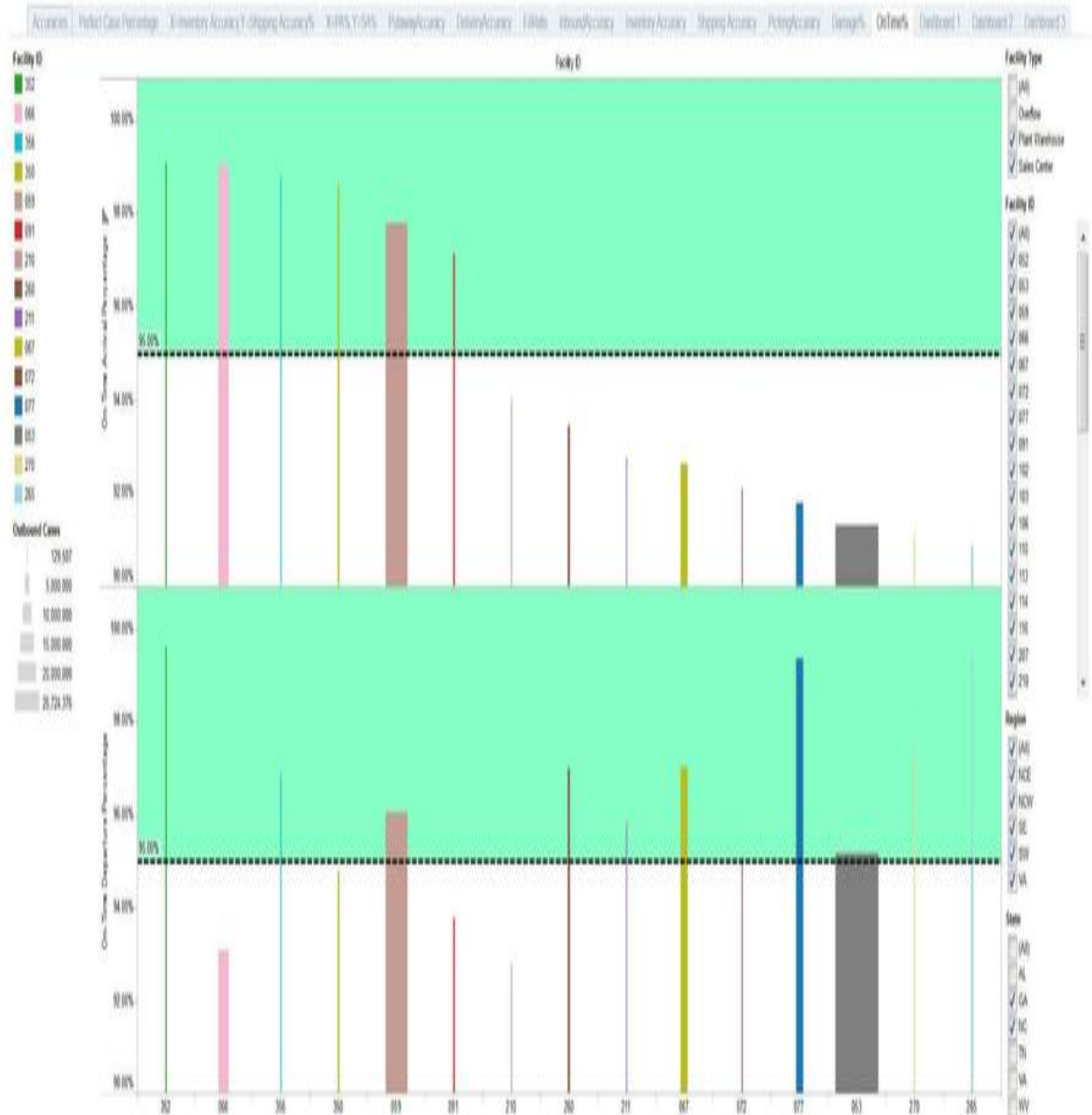
On-Times

The RightHouse Scoreboard monitors three key on-time performance indicators—supplier on-time arrivals, on-time put-aways, and on-time departures. Supplier on-time arrivals are measured as the percentage of inbound product that arrives on time. If suppliers arrive late, it is very difficult to keep a warehouse or supply chain on time. On-time put-aways measure the portion of put-away lines that are executed on time. Again, if put-aways are late, it is very difficult to keep the warehouse on time. Lastly, on-time departures measure the percent of loads that depart the warehouse on time ([Figure 3.13](#)).

Figure 3.13 RightHouse Scoreboard on-time performance analysis.

Scoreboards >

Warehouse Accuracies



Cycle Times

The RightHouse Scoreboard includes two cycle-time indicators—dock-to-stock time and warehouse order cycle time. Dock-to-stock time (DST) is the elapsed time from when a receipt arrives on the warehouse premises until it is ready for picking or shipping. Warehouse order cycle time (WOCT) is the elapsed time from when an order is released to the warehouse floor until it is picked, packed, and ready for shipping.

A few years ago, we were asked to assist a large apparel retailer with its supply chain strategy. We toured the main distribution center during one of the initial visits. I noticed that the receiving dock looked especially full. I asked the manager what the dock-to-stock time was. He proudly shared that it was 96 hours. I shared that our benchmarking showed that 24 hours was a norm, 8 hours was above average, and a few hours was world class. The manager was somewhat defensive and said that the company had investigated systems that were designed to reduce dock-to-stock time but could never produce an acceptable return on investment. I asked how much inventory was sitting on the dock. It was \$8 million worth of inventory. I asked the manager what range of investment proposals the company had received for the material-handling systems required to help reduce dock-to-stock time to 24 hours. Quotes were in the range of \$2 million. I did some quick math and calculated that by reducing their dock-to-stock time by 75 percent, the company could reduce its inventory by \$6 million. I then asked, “Wouldn’t it make sense to spend \$2 million to take \$6 million out of inventory or to reduce inventory carrying costs by \$2 million per year at the 33 percent inventory carrying rate?” The manager shared that the company had only tried to compute an ROI based on labor savings alone and had not considered inventory savings. This reconsideration launched one of the nation’s most successful supply chain strategies.

3.4 Shareholder-Facing Metrics

Our recommended categories of shareholder-facing metrics are cost, productivity, and utilization.

Warehouse Cost Performance

The main cost categories to operate a warehouse are labor, space, material-handling equipment, and warehouse management systems. These typically add up to between 2 and 5 percent of sales.

Ideally, these cost categories will be analyzed across the activities of the warehouse in a warehouse activity-based costing program ([Figure 3.14](#)). In the example ([Figure 3.15](#)), a cost for each warehousing activity (i.e., receipt, put-away, store, pick, ship, and load) is established. The activity costs become the basis for comparing third-party warehousing proposals, budgeting, measuring improvement, and menu-based pricing for warehousing services.

Figure 3.14 RightHouse activity-based costing allocates the cost of personnel, space, systems, supplies, and fees to each warehouse activity. Activity costs then may be allocated to product lines and/or business units.

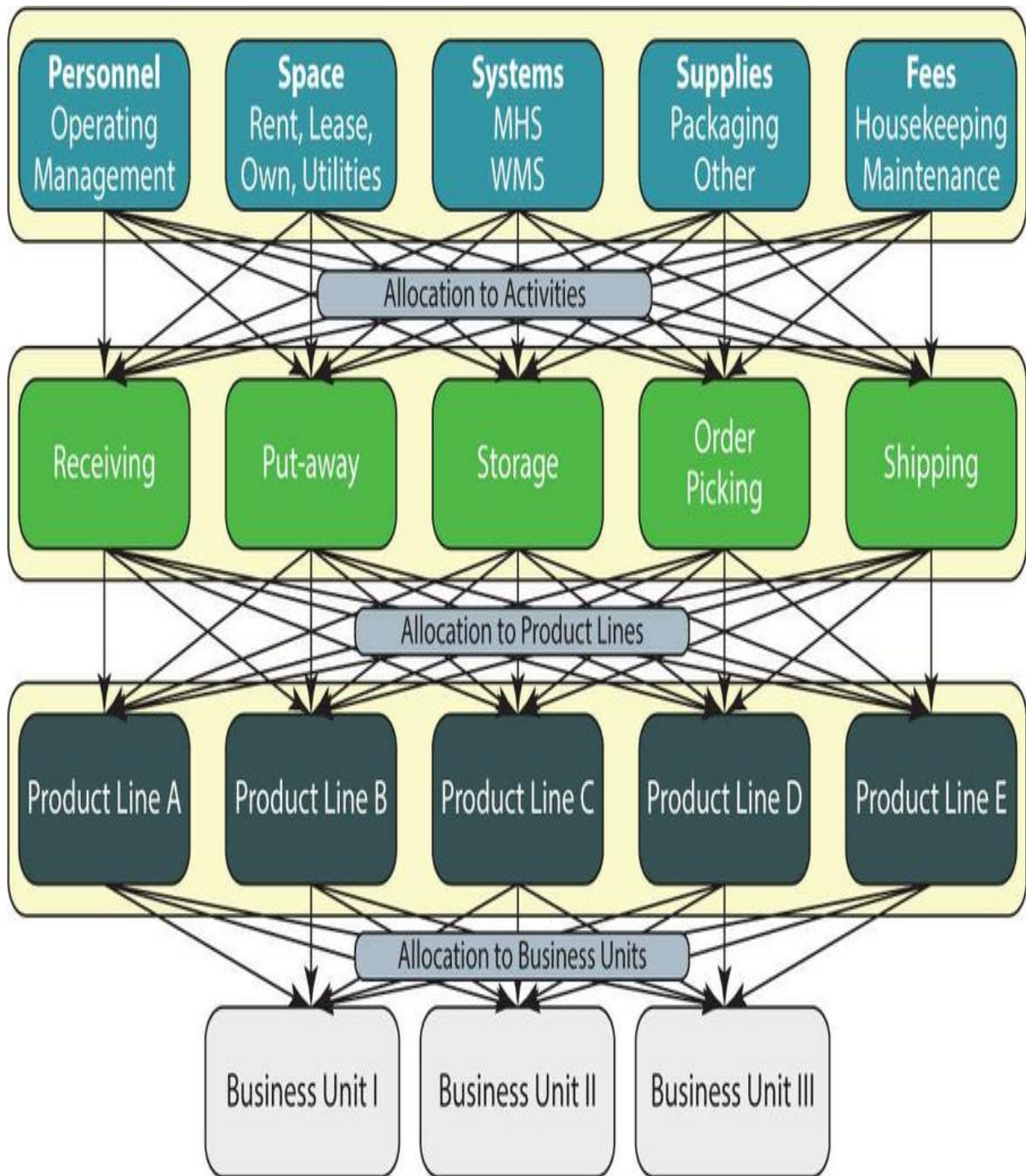
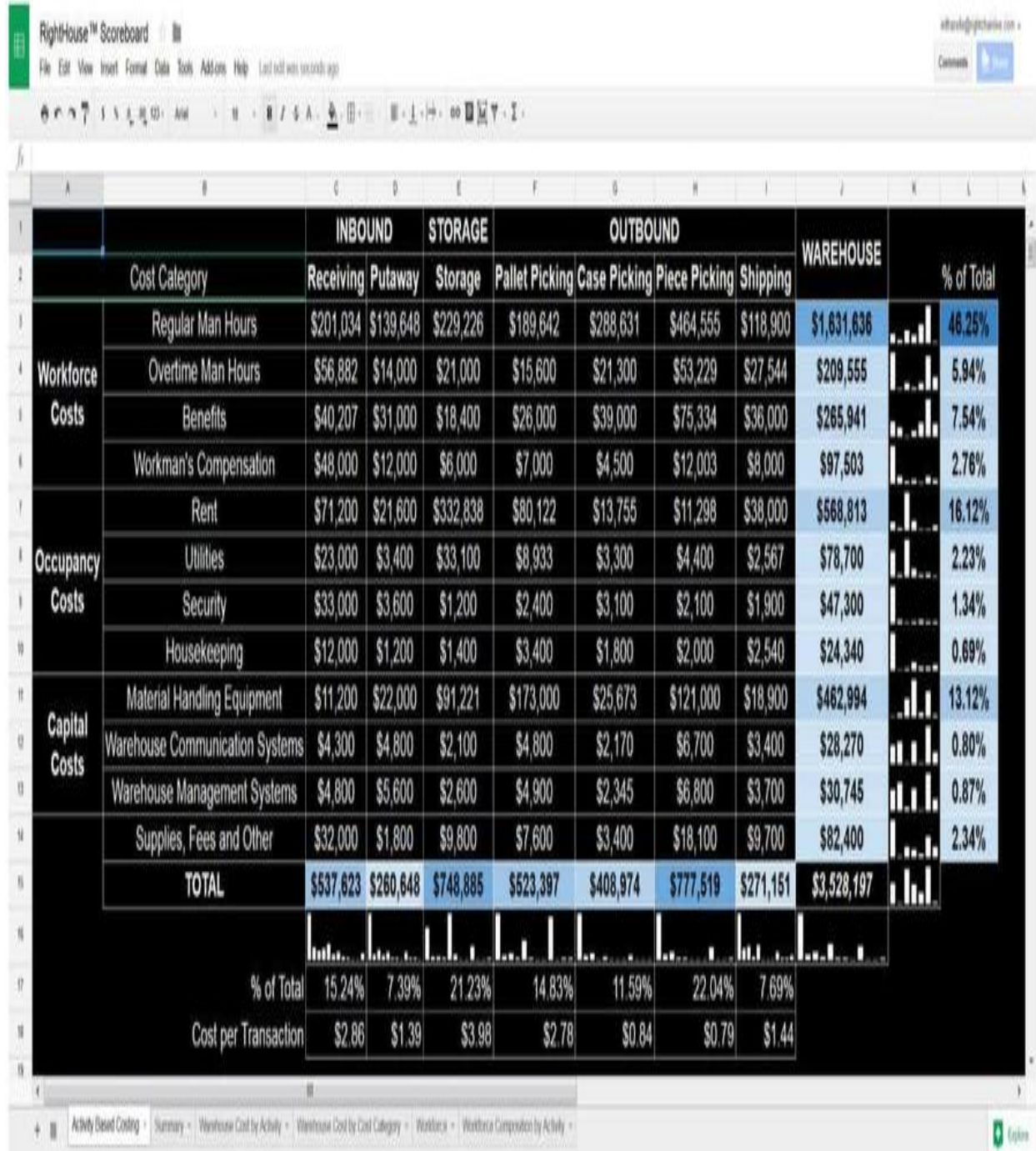


Figure 3.15 RightHouse activity-based costing example.

Scoreboards >



In this particular analysis, the cost of storing and handling an item in the warehouse for a year was estimated to be \$340.37. This warehouse managed over 70,000 items, 40,000 of which did not yield \$340.37 in sales per year—not even enough to cover their storage and handling costs. Needless to say, the finding was taken up with the marketing area, and a SKU reduction ensued.

Once a warehouse activity-based costing analysis has been completed, it is not unusual to find that most of the warehousing costs are labor costs (Figure 3.16) and that outbound activities make up the majority of costs by activity (Figure 3.17). Outbound costs dominate because a single-pallet put-away may require many trips to that pallet to deplete its contents in case picking, or a single-carton put-away may require many trips to deplete its contents in broken-case picking.

Figure 3.16 Typical warehouse cost allocation by cost category.



RightHouse™ Scoreboard

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edward@rightchain.com

Comments

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Warehouse Cost by Cost Category

Supplies, Fees and Other

2.3%

Material Handling Equipment

13.1%

Security

1.3%

Utilities

2.2%

Rent

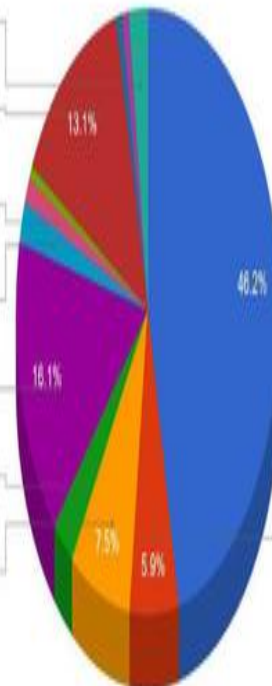
16.1%

Workman's Compensation

2.8%

Benefits

7.5%



Regular Man Hours

46.2%

Overtime Man Hours

5.9%



Activity Based Costing

Summary

Warehouse Cost by Activity

Warehouse Cost by Cost Category

Workforce

Workforce Composition by Activity



Explore

Figure 3.17 Typical warehouse cost breakdown by activity.



RightHouse™ Scoreboard

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edfrazz@rightchain.com

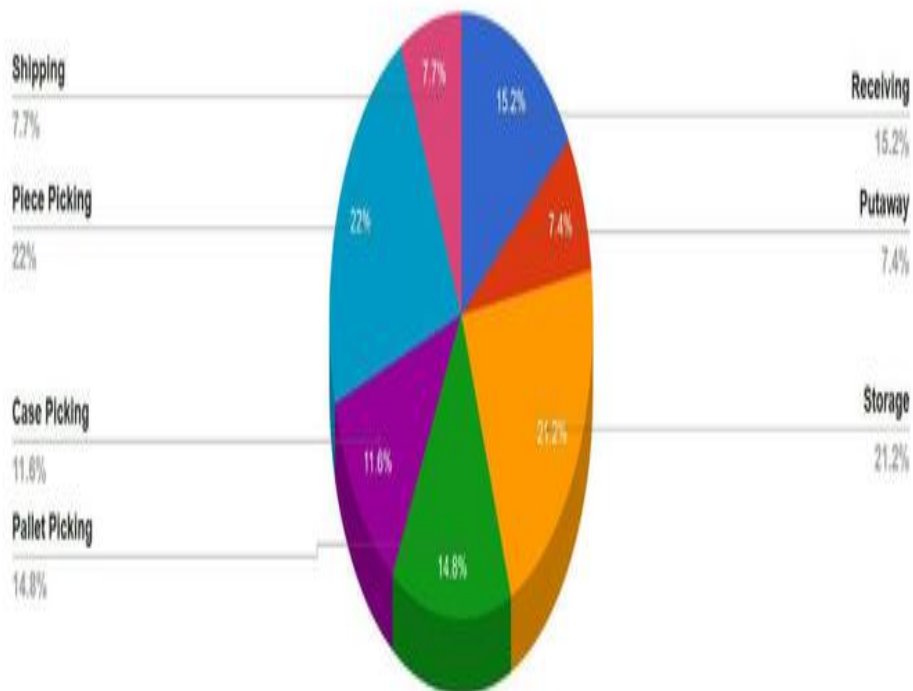
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Percent of Total Cost



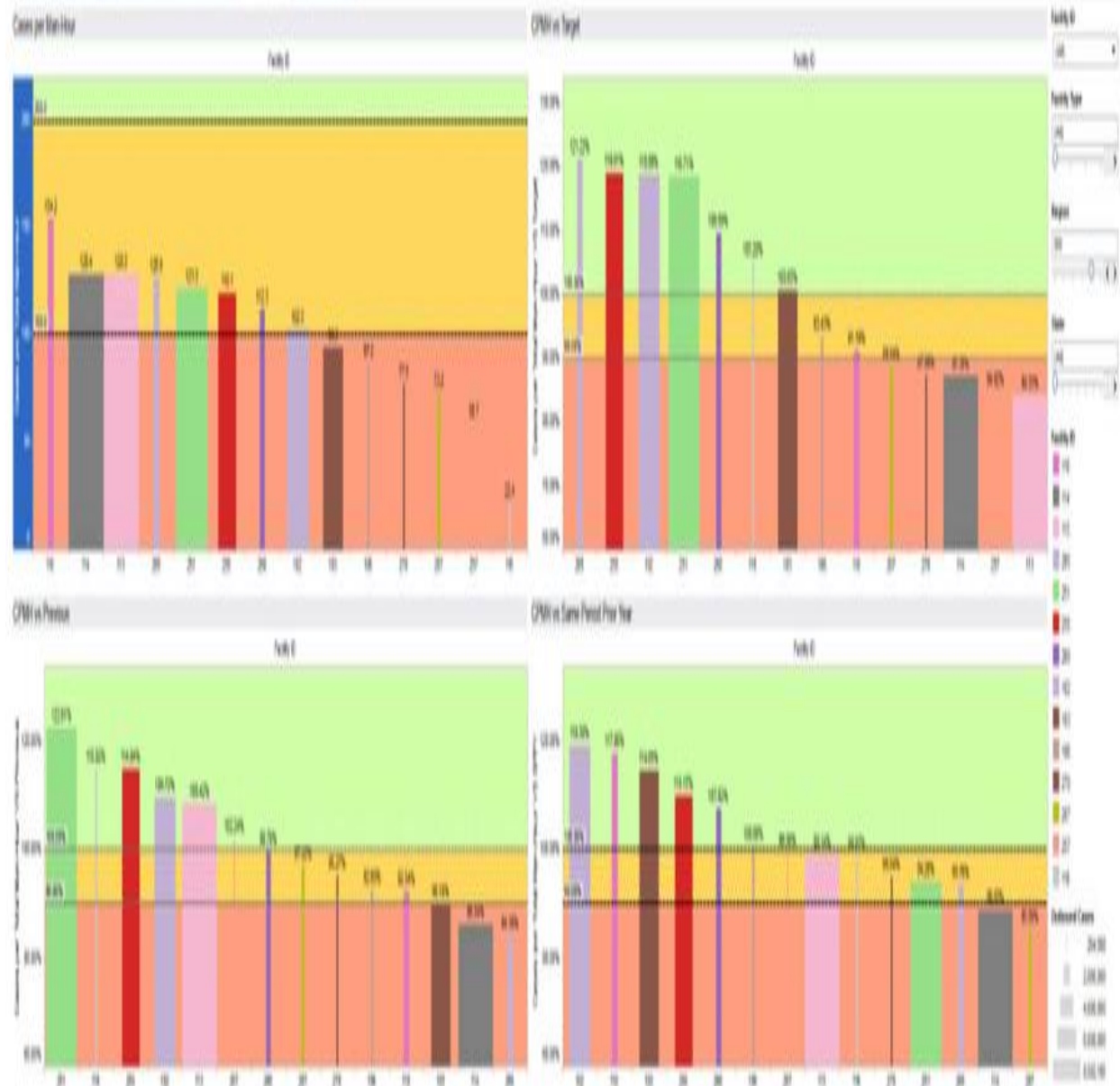
Warehouse Productivity Performance

The most popular and traditional warehouse performance measure is productivity ([Figure 3.18](#)). The formal definition of *productivity* is the ratio of the output of an entity to the resources consumed achieving that output. We recommend that our clients monitor the productivity and utilization of all key assets in the warehouse—labor, space, material-handling systems, and warehouse management systems. We typically measure overall labor productivity as the ratio of units, orders, lines, or weight shipped out of the warehouse to the number of person-hours spent in operating, supervising, and managing the warehouse. We typically measure overall space productivity as storage density, the ratio of the amount of inventory storage capacity to the square footage in the warehouse. It is normally expressed as the value, cube, pieces, or positions of inventory that can be accommodated per square foot.

Figure 3.18 RightHouse Scoreboard facility productivity screen

DC Productivity

ToolPerformance CPNinDays CPNinHours CPNinPM Productivity30 3-yrAvgProduct



Warehouse Asset Utilization

Whereas the *productivity* of a resource is the ratio of output to consumption, the *utilization* of a resource is the ratio of consumption of the resource to the capacity of the resource ([Figure 3.19](#)). One typical warehouse resource utilization measure is labor utilization, usually expressed as the ratio of the actual units processed per hour to the theoretical maximum units per hour. Another common utilization measure is the storage-location utilization, expressed as the ratio of the number of occupied warehouse locations to the available warehouse locations. Equally important to monitor is the warehouse cube utilization, expressed as the ratio of the occupied cube to the total available cube ([Figure 3.20](#)).

Figure 3.19 RightHouse Scoreboard utilization 360 screen.

Scoreboards >

Warehouse Utilizations

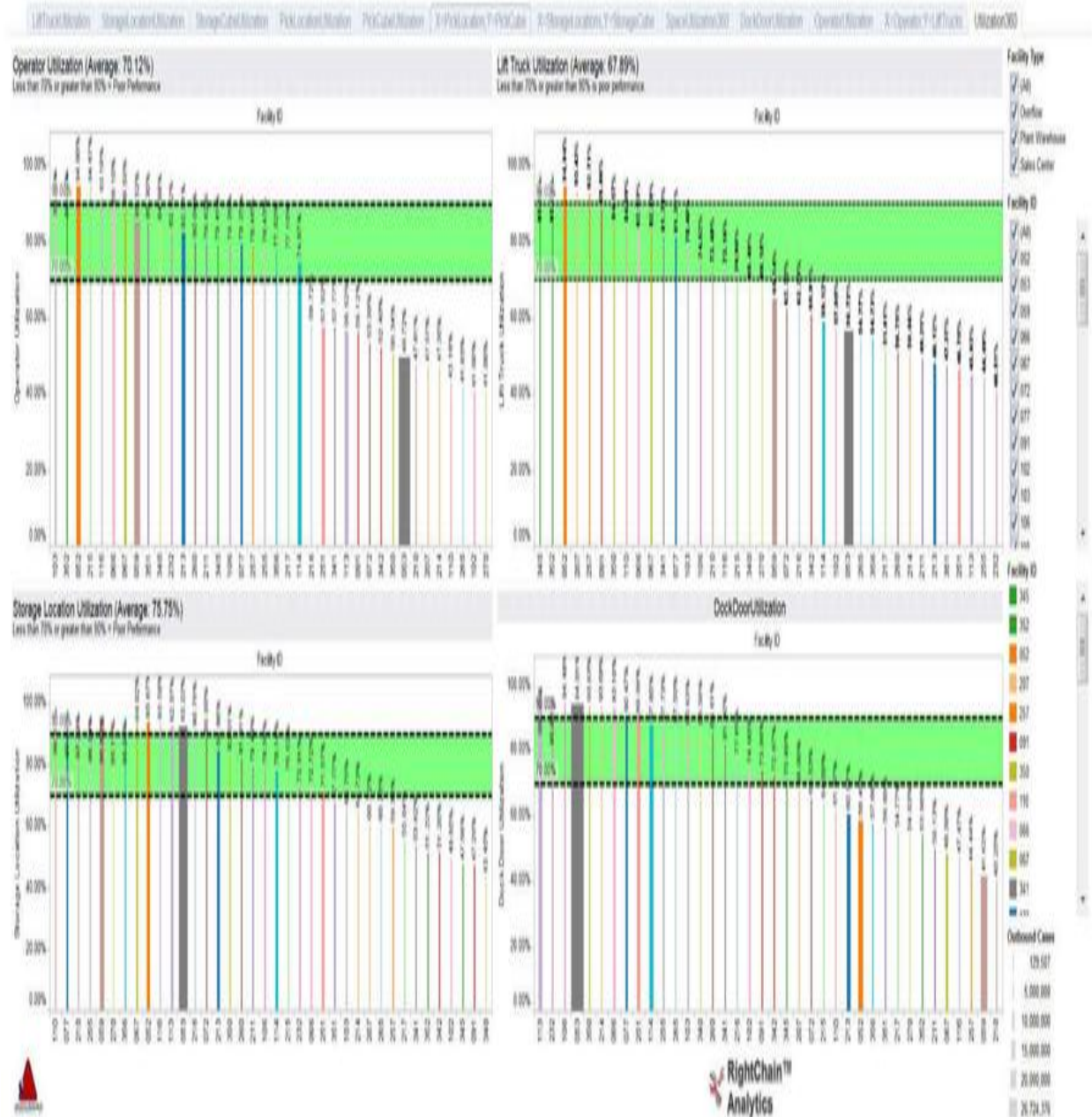
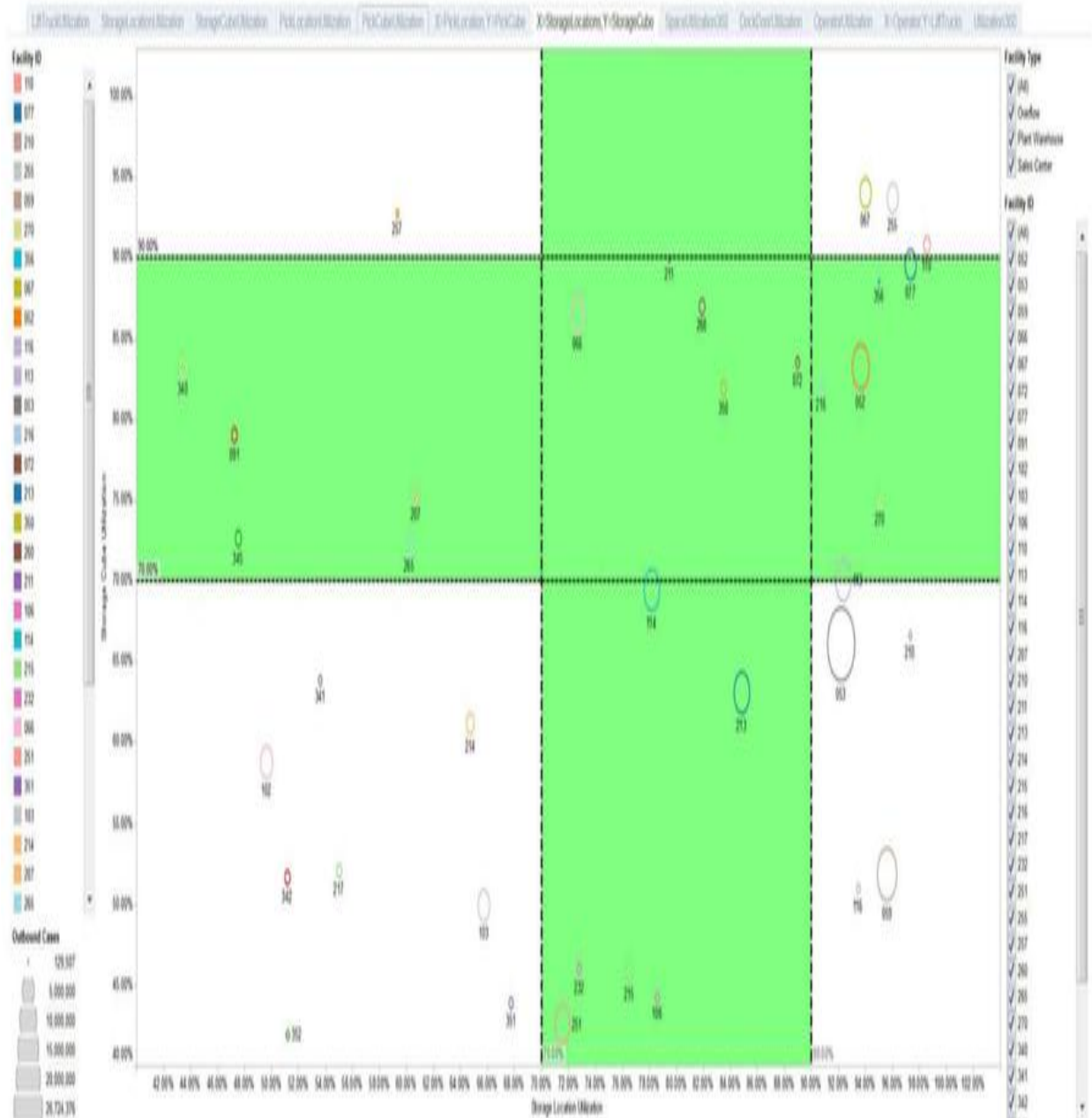


Figure 3.20 RightHouse Scoreboard storage-location utilization versus storage-cube utilization.

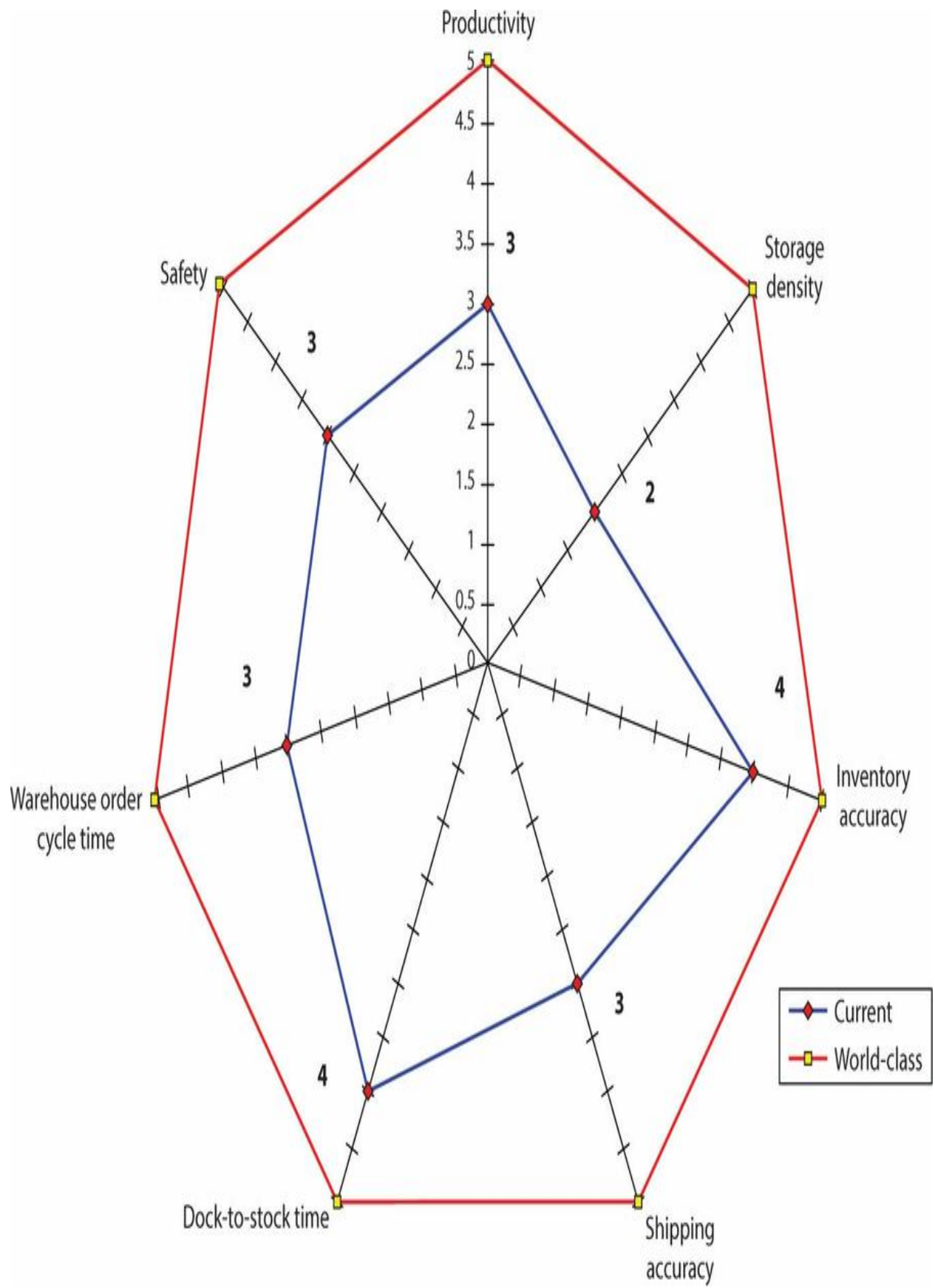
Scoreboards >

Warehouse Utilizations



A major difference between productivity and utilization is that we always want to maximize productivity, whereas there are appropriate control limits for utilization. For example, we always want to maximize storage density, the number of storage positions available per square foot, but the utilization of storage space should range between 70 and 90 percent on a consistent basis (Figure 3.21). Storage location utilization that is higher than 90 percent inhibits productivity and creates potential safety problems. Utilization that is lower than 70 percent suggests excessive storage capacity.

Figure 3.21 Example warehouse performance gap analysis.



Maintaining healthy storage utilization helps to enforce healthy inventory management. In our early work with Honda, the company's warehouse space utilization was in excess of 98 percent. When it came time to implement a new warehouse management system, the warehouses were so full that there was no room to move product to create the space needed to relabel and reconfigure racking to accommodate the new system. I suggested that the company delay implementation and reset the storage-utilization capacities to 85 percent, what it should be for most warehouses. The managers asked me what they would do with their excess inventory. I half-jokingly suggested that they rent a warehouse in a remote location where space was especially cheap. Any product occupying space over and above 85 percent should be shipped to that remote location. When the 85 percent occupancy had been established, the company could install the warehouse management system.

I was a bit surprised to learn later that the company had accepted my recommendation. The remote warehouse occupied more than 500,000 square feet. The company president received the monthly bill and dispatched an associate to look at the operation. It turned out that the material was essentially excess safety stock generated by the company's forecasting system. Previously, the excess had been stuffed into the company's facing distribution centers. Pulling the material out of the forward distribution centers helped them understand just how much excess safety stock its inventory plan was producing. The visualization and the bill from the third-party warehouse helped to motivate a highly successful makeover of their forecasting process and system.

3.5 Warehouse Performance Gap Analysis

We often assess our clients' performance with our warehouse performance gap analysis ([Figure 3.21](#)). The analysis indicates to the client their standing versus world-class norms. The (spokes) represent the key performance indicators for the operation. The outer ring defines world-class performance.

In the example, the warehouse performance indicators are productivity (lines per hour), storage density (case storage capacity per square foot),

inventory accuracy, shipping accuracy (percent of lines shipped in error), dock-to-stock time, warehouse order cycle time, and safety. The annual savings opportunity for attaining world-class warehousing is \$1.7 million per year, leading to a justifiable investment in a RightHouse initiative of \$857,000 ([Figure 3.24](#)).

The value in the gap analysis is the single-page, graphical presentation of the multi-performance profile. The analysis quickly points out weak and strong points in the performance of the operation. The gap chart also can be used to establish project goals. For example, in [Figure 3.21](#) the inner ring may represent the current performance of an operation. Another ring may represent the goals of a reengineering project.

The gap analysis also can be used to justify capital expenditures for new information- and/or material-handling systems. Because the chart quantifies the gap relative to world-class metrics, we can compute the annual financial benefit (i.e., cost savings, cost avoidance, and/or revenue increases) of closing the gap in each performance area. The estimated annual benefit in relation to corporate payback goals suggests an appropriate investment to close the gap.

3.6 Practice Makes Perfect

After presenting all this analysis, I am often asked what separates world-class performers from the rest of the pack. After all is said and done, the distinguishing feature of world-class warehouses is their practices. You often hear coaches say that their teams perform the way they practice. It is the same in warehousing. The warehouse performs as a function of its practices.

I developed a warehouse practices gap analysis similar in concept to the warehouse performance gap analysis. As you may have guessed, it is called *warehouse practices gap analysis*. An example is illustrated in [Figure 3.24](#). Each of the radials represents one of the functional areas in the warehouse. As before, the outer ring defines standards. The current warehouse practices RightHouse are plotted relative to the world-class definitions. As before, this technique can be used to set project goals, to assess benchmarking partners, and in this particular example to conduct a functional evaluation of a

warehouse management system. The major difference is that practice descriptions are not quantifiable. Instead, we have defined for each functional area (i.e., receiving, put-away, storage, replenishment, slotting, order picking, shipping, communications, and work measurement), world-class (stage 5), middle-class (stage 3), and no-class (stage 1) practices. This book is essentially a journey through the world-class practices included in a RightHouse™ Assessment.

Figure 3.22 RightHouse financial opportunities assessment.

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Company

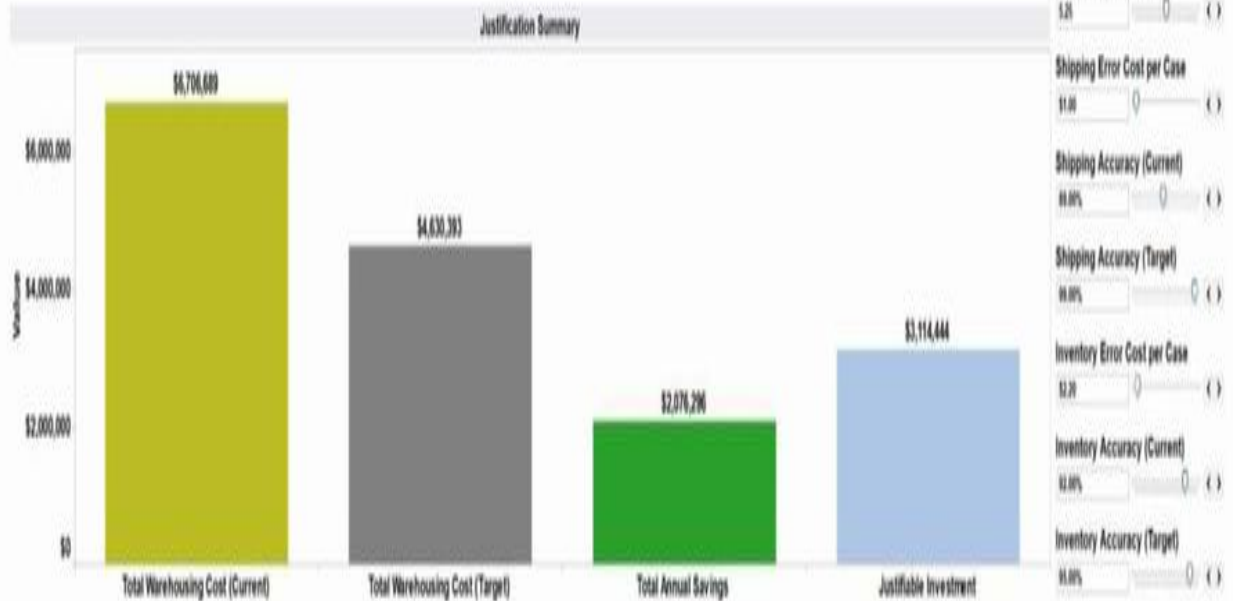
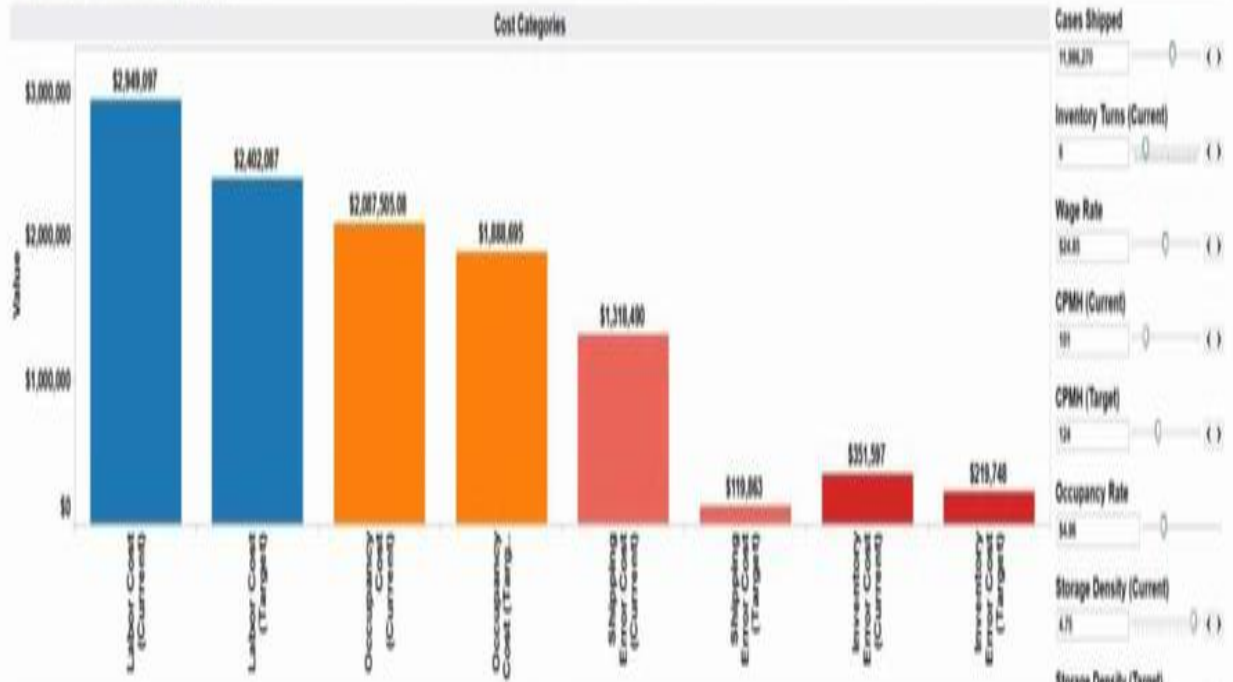


Component	Value
Productivity	\$247.4K
Storage Density	\$220.0K
Inventory	\$40.5K
Shipping	\$10.4K
Dock-to-Dock	\$10.1K
Warehouse	\$1.1K
Safety	\$100.0K

Figure 3.23 Warehouse performance simulation screen.

RIGHTHOUSE™ PROJECT JUSTIFICATION

Cost Categories Justification Summary VP/260



Payback Period 1.5

Figure 3.24 RightHouse practices assessment.

Figure 1 displays ten RapiDox™ colorimetric pH sensors arranged in two rows of five. Each sensor is a circular device with a color scale ranging from red (acidic) to green (basic). The pH values indicated on the sensors are: 3.77, 3.86, 3.70, 3.83, 3.72 (top row) and 3.75, 3.85, 4.10, 4.06, 3.13 (bottom row). The sensors are labeled 'RapiDox™' and 'pH'.

CHAPTER FOUR

WORLD-CLASS RECEIVING AND PUT-AWAY

- 4.1 Receiving Flow Optimization**
- 4.2 Direct Shipping**
- 4.3 Cross-Docking**
- 4.4 Direct Put-away**
- 4.5 Receiving Scheduling**
- 4.6 Pre-receiving**
- 4.7 Dock Assignment Optimization**
- 4.8 Automated Unloading**
- 4.9 Delivery Quality Compliance**
- 4.10 Automated Receiving Inspection**
- 4.11 Prepackaging**
- 4.12 Inbound Cubing and Weighing**
- 4.13 Directed Put-away**
- 4.14 Batch, Sort, and Sequence Put-away**
- 4.15 Prioritized Put-away**

4.16 Put-away Location Verification

4.17 Automated Put-away

4.18 Interleaving and Continuous Moves

You may be familiar with the expression “garbage in, garbage out.” This expression applies perfectly to warehousing operations. If you receive “garbage” in the form of damaged and noncompliant products in damaged and noncompliant packaging, then you will no doubt ship “garbage” in the form of damaged products and inaccurate orders. If you allow damaged or inaccurate deliveries in the door, you are likely to ship damaged or inaccurate shipments out the door.

The RightHouse receiving and put-away principles presented here are a sure defense against inducting inefficiencies, and serve as guidelines for streamlining receiving operations. They are intended to simplify the flow of materials through the receiving process and to insure minimum work content and processing time are required.

In optimized receiving, receipts and their appropriate resources are scheduled, follow the minimum-cost flow path, are processed at the dock in a manner that minimizes put-away time, and are inspected, dimensioned, and weighed. Put-aways are verified, prioritized, executed immediately on receipt, directed to optimal locations, combined with retrievals to maximize labor and equipment utilization, batched, sequenced, and transported with the appropriate material-handling equipment.

The following world-class receiving and put-away practices are described and illustrated in this chapter:

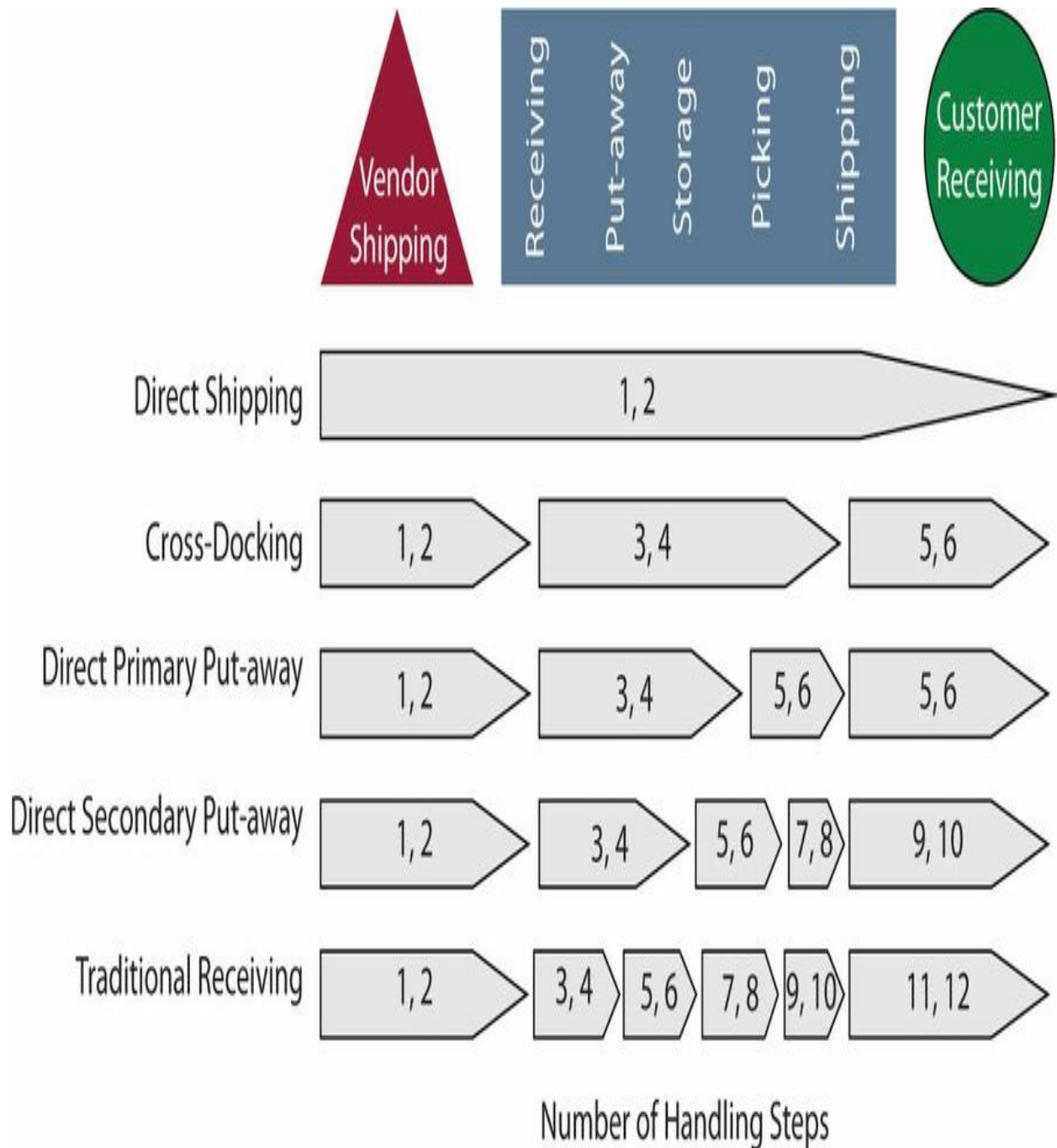
- Receiving flow optimization
- Direct shipping
- Cross-docking
- Direct put-away

- Receiving scheduling
- Inbound dock assignment
- Automated unloading
- Delivery quality compliance
- Automated receiving inspection
- Inbound cubing and weighing
- Prepackaging
- Direct directed put-away
- Batched, sequenced put-aways
- Automated put-away
- Interleaving and continuous moves

4.1 Receiving Flow Optimization

The performance of any system diminishes with increasing complexity. Supply chain logistics systems are no different. In supply chains, the number of handling transactions is one of the greatest contributors to system complexity. Hence, minimizing work content, mistakes, time, and accidents is accomplished in supply chain logistics by reducing handling steps. [Figure 4.1](#) illustrates the reduction in handling steps that can be achieved by applying advanced receiving and put-away practices.

Figure 4.1 Receiving flow optimization for a large semiconductor company.



In order from least handling steps to most, the receiving practices are the following:

- *Direct shipping* bypasses the warehouse completely, requiring two touches—one to load the outbound truck at the origin and one to receive the inbound truck at the destination.

- *Cross-docking* requires six, with product moving directly touches from the DC's inbound dock to the outbound dock.
- *Direct primary put-away* checks to see whether there are any empty primary locations and directs put-aways to those locations, thus bypassing receiving inspection, put-away, storage, and replenishment. Eight touches are required.
- *Direct secondary put-away* bypasses receiving staging and inspection and moves product directly from unloading into reserve locations.
- *Traditional receiving* requires staging at receiving, inspection, put-away to reserve storage, and replenishment to primary picking locations.

There are many more opportunities to mishandle, misplace, miscoordinate, and/or miscommunicate in 12 handling steps than there are in 10, 8, 6, 4, or 2 steps. The costs of those extra steps are reflected in the receiving flow optimization we recently completed for a large food company (Figure 4.2). It includes the number of touches, inventory days on hand, damage percentage, fill rate, and cost per case related to direct shipping, cross-docking, direct primary put-away, direct secondary put-away, and traditional receiving. The cost per case ranges from \$0.83 with direct shipping to \$3.56 with traditional receiving.

Figure 4.2 Receiving flow optimization for a large food company.

RightHouse™ Layout Optimization System

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Comments



Flow Path

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Flow Path	Supplier	Unload	Stage	Inspect	Putaway	Store	Replenish	Pick	Inspect	Stage	Load	Customer	Cost per												
													Touches	Unit	Damage %										
Direct Shipping	1											2	2	\$0.83	0.50%										
Cross Docking	1	2									3	4	4	\$1.94	0.80%										
Direct Primary Putaway	1	2			3			4	5	6	7	8	8	\$3.16	1.40%										
Direct Secondary Putaway	1	2			3	4	5	6	7	8	9	10	10	\$3.98	1.90%										
Receiving Staging	1	2	3		4	5	6	7	8	9	10	11	11	\$5.01	2.70%										
Receiving Staging & Inspection	1	2	4	4	5	6	7	8	9	10	11	12	12	\$5.72	3.00%										

FLOW PATH	Item Types	Supplier Types	Scenarios
Direct Shipping	A+ Cube Movers	A+ Reliability	Back Orders, Bulky Merchandise
Cross Docking	Consistent A Movers	A+ Reliability	Back Orders, Transfers, Customer Specials, Single SKU Unit Loads
Direct Primary Putaway	A, B & C Movers	A+ Reliability	Empty Primary
Direct Secondary Putaway	A, B & C Movers	A to B+ Reliability	Empty Secondary
Receiving Staging	A, B & C Movers	B Reliability	Quick Turn Trailers or Docks
Receiving Staging & Inspection	B & C Movers	B & C Reliability	Seasonal, High Variability



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4.2 Direct Shipping

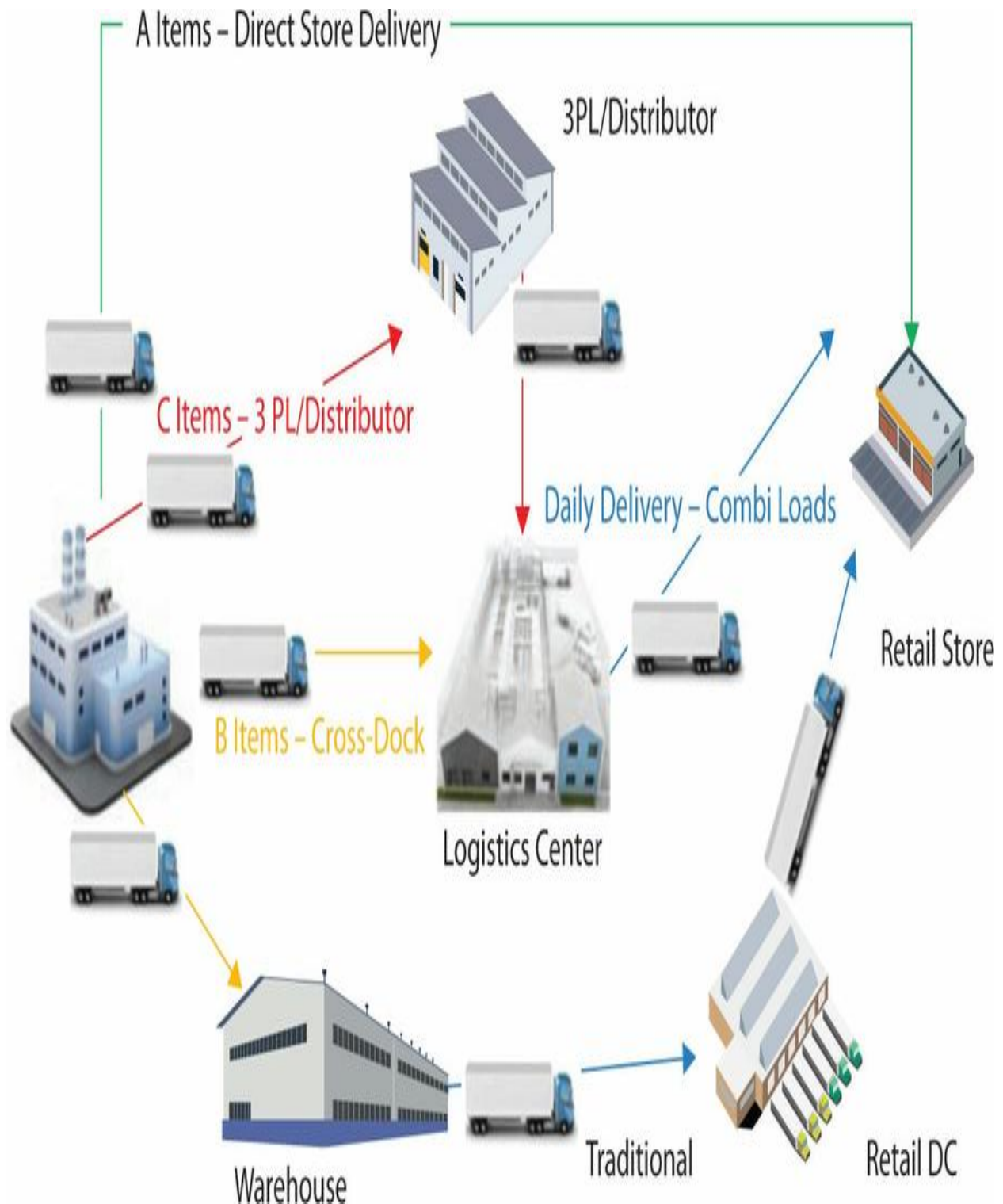
For some materials, the best receiving is no receiving! In direct (or drop) shipping, vendors bypass the warehouse completely and ship directly to customers. Because product never arrives at a distribution center, there is no unloading, staging, put-away, replenishment, picking, packing, checking, or loading. All the labor, time, and equipment normally consumed and all the mistakes and accidents that often occur in the warehouse are eliminated.

Opportunities for direct shipping include large, bulky items, made-to-order items, and combinations of items for which the regular shipping volume occupies at least a full truckload. For example, one of our large mail-order clients ships canoes, large tents, and furniture directly to customers from the manufacturer. An increasing number of our food, beverage, and consumer products manufacturing clients are producing and assembling store orders at their factories for direct delivery to their retail customers' store locations.

4.3 Cross-Docking

A classic example of direct shipping and cross-docking is from a large grocer headquartered in the mid-west. ([Figure 4.3](#)). “A” movers (based on cube movement) are shipped in truckload quantities from food manufacturers to grocery retail stores. “B” movers are precisely scheduled into a central distribution center for daily cross-docking to build consolidated (e.g., frozen, refrigerated, and ambient temperature) loads for retail stores. “C” movers are stored in a contiguous distribution center specially designed for dense storage and batch picking of slow-moving items. A daily batch of C items is picked and inducted into the cross-docking operation.

Figure 4.3 Supply-chain flows in the food industry.



When material cannot be shipped directly, the next best option may be cross-docking. In cross-docking,

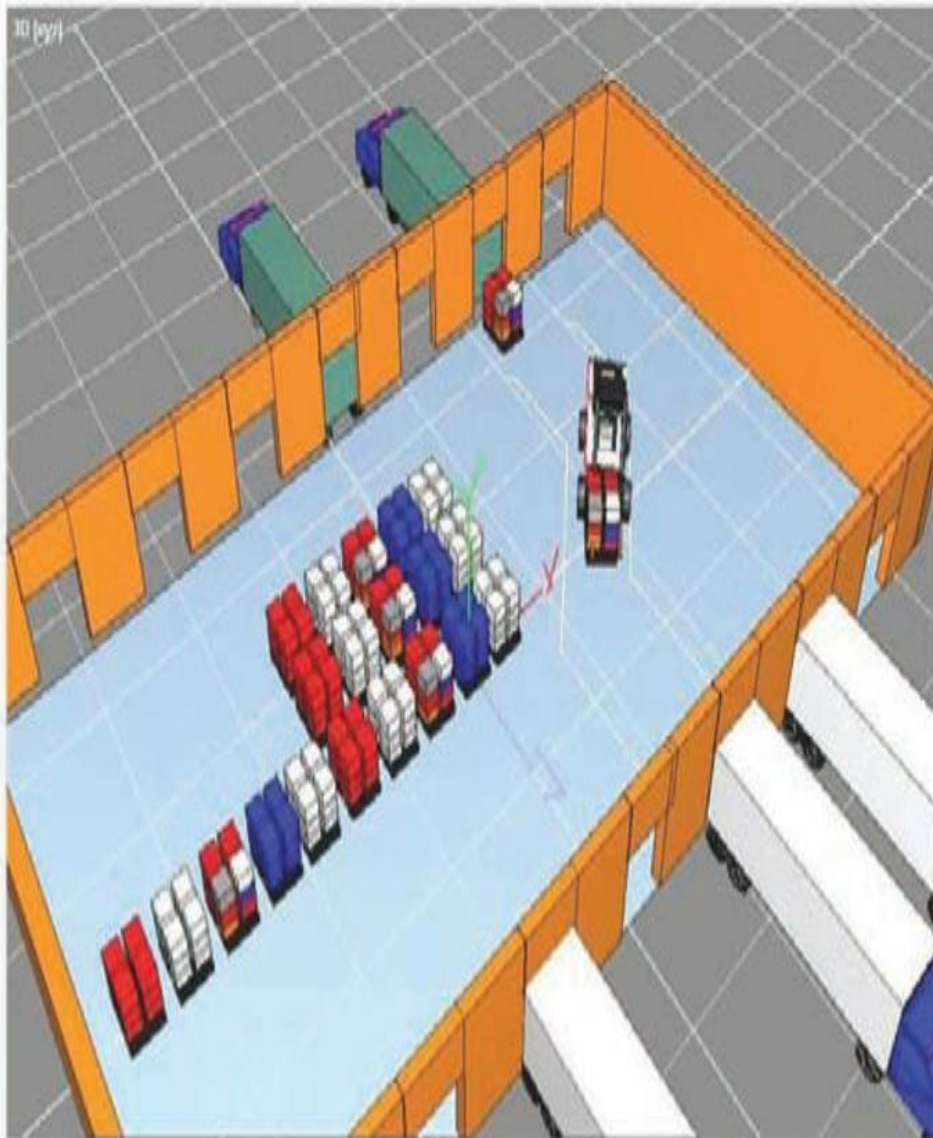
Inbound loads are precisely and tightly scheduled into the warehouse,

sorted immediately into outbound orders, and moved immediately to their outbound docks.

In so doing, receiving inspection, receiving staging, put-away, storage, pick-location replenishment, order picking, and order assembly are eliminated.

Back orders, special orders, and transfer orders are especially good candidates for cross-docking. The sense of urgency to process those orders is high, the inbound merchandise is prepackaged and labeled for delivery to the customer, and the merchandise on those orders does not have to be merged with other merchandise to complete customer requirements ([Figure 4.4](#)).

Figure 4.4 Cross-docking simulation for a large consumer products company.

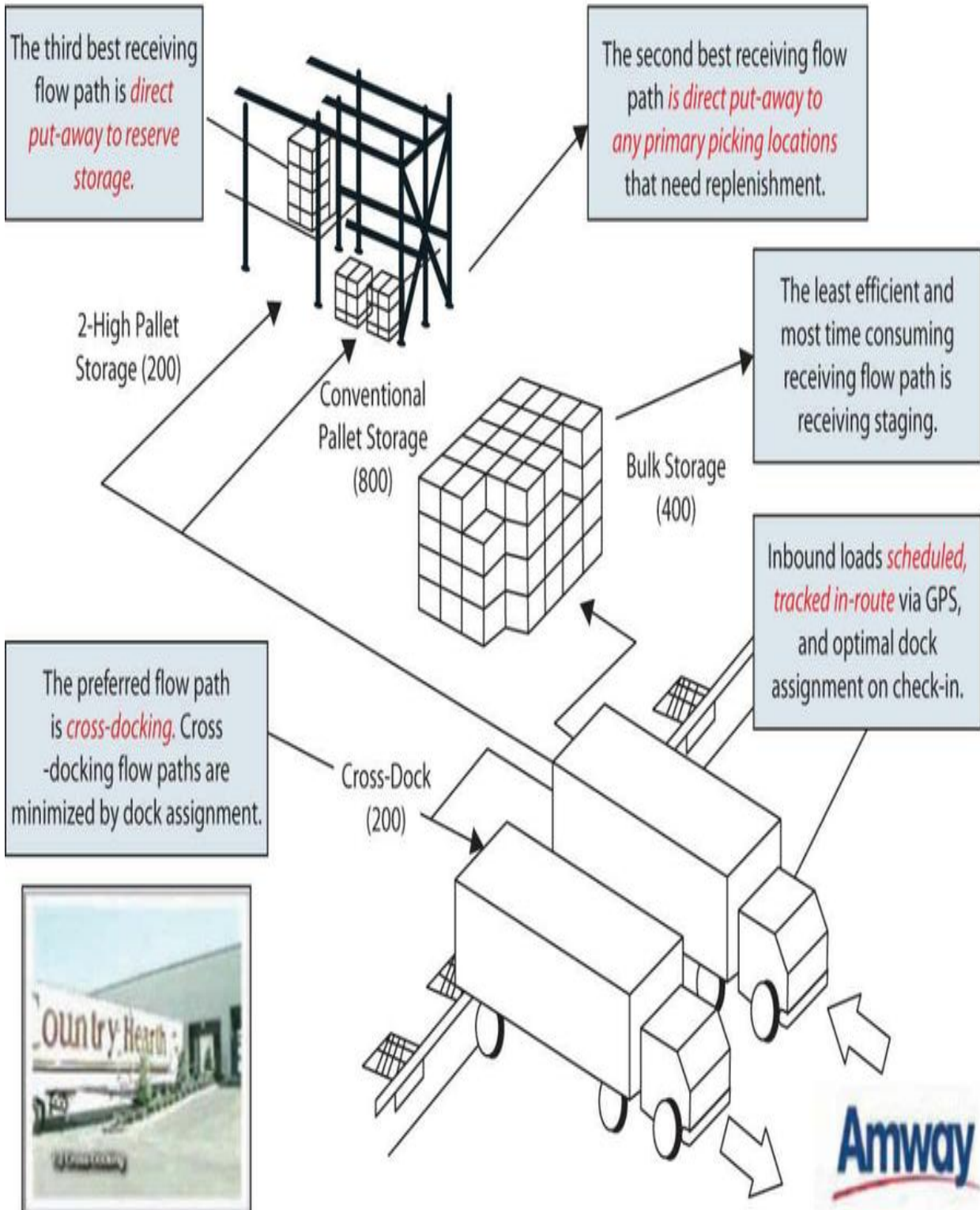


Cross-Docking the Amway Way

Amway is a major manufacturer and direct-to-consumer distributor of consumer and personal products, including soaps, cleaning supplies, and cosmetics. At its central distribution center are identified, receipts from manufacturing are optimally scheduled, and all incoming pallets bar-code license plates ([Figure 4.5](#)). As a lift truck operator unloads a trailer, a pallet license plate (bar code) is scanned to inform the warehouse management system that the pallet is on site. The warehouse management system then directs the operator to move the inbound pallet to its assigned warehouse location. The first priority for the pallet is cross-docking. In fact, if the item is required in an outstanding order that is currently being loaded (and if there is no violation of code-date expiration windows for pallets in inventory of the same item), the operator is directed to move (cross-dock) the pallet to that dock for shipping. The next priority is direct put-away to a primary pick location. If there is an opening for the pallet in the primary pick location. The last priority is to move the pallet to its reserve warehouse location.

Figure 4.5 Receiving flows concept plan for Amway logistics.

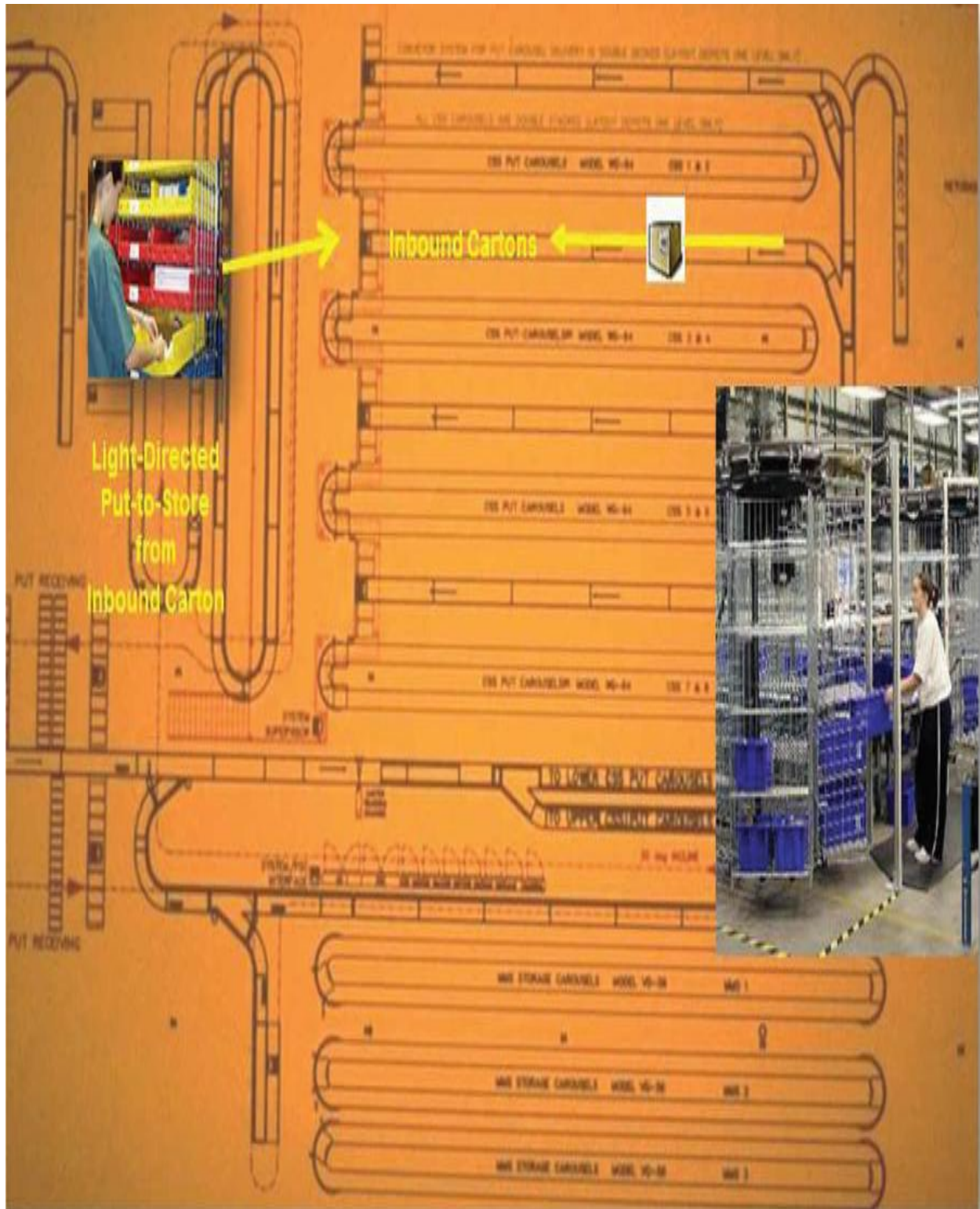
Receiving and Put-away Conceptual Plan



K-Mart Cross-Docking

At K-Mart's jewelry distribution center ([Figure 4.6](#)), suppliers are required to place a bar-code license plate on each carton. At the receiving dock, inbound cartons are properly oriented and manually off-loaded onto a telescoping conveyor. The telescoping conveyor feeds a sorting conveyor just inside the doors of the distribution center. A bar-code scanner located on the conveyor reads each carton's license plate to make the real-time warehouse management system aware that the carton is on site. In turn, the warehouse management system instructs the conveyor to direct the carton to the cross-docking operation (if there is an outstanding open order for the item) or to the traditional store, pick, pack, and ship operation.

Figure 4.6 Jewelry cross-docking concept at K-Mart.



In the cross-docking operation, each K-Mart store has a tote position in one of six carousels. As an inbound carton is presented to a carousel operator,

the operator is directed by a screen and a light tree to distribute the contents of the carton to the stores in the carousel carrier in front of the operator. The contents of the carton are depleted as subsequent carriers are presented to the operator. A store a flashing light indicates when order is complete. The operator pushes the corresponding tote through the back of the carousel, where a take-away conveyor transports the tote to shipping. More than 50 percent of the merchandise in the distribution center is cross-docked in this manner.

Cross-Docking at Sony Logistics

At Sony Logistics distribution center ([Figure 4.7](#)) just outside of Tokyo, a cart-on-track conveyor system is used to move full-pallet loads between dock doors. Each dock door may be used for inbound or outbound loads, thus dramatically increasing the utilization of any given dock door. Also note that the entire cross-dock operation is executed without labor.

Figure 4.7 Cross-docking in a Sony Logistics distribution center. (Chiba, JAPAN)



Manual Cross-Docking

Cross-docking does not always require substantial investments in material- and information-handling systems. At Sun Distribution's third-party logistics center ([Figure 4.8](#)) in Chiba, Japan, a network of roller and ball-transfer conveyors is embedded in the floor throughout the distribution center to permit finger-point movement of cases on slave pallets. One use of the conveyors is at the receiving and shipping docks, where inbound loads are easily moved along the floor between their inbound and outbound docks.

Figure 4.8 Manual cross-docking operation. (Tokyo, JAPAN)



Cross-Docking Candidates and Enablers

Some inbound loads are better candidates for cross-docking than others. As the preceding examples suggest, full pallets with a single stock-keeping unit (SKU) on board are prime candidates because the pallet's contents do not have to be sorted. Instead, the entire pallet is cross-docked, and the entire pallet can be automatically identified with a bar-code license plate. Floor-loaded loose cartons are also good candidates for the same reasons—the carton's contents do not have to be sorted, the entire carton is cross-docked, and the carton can be automatically identified with a bar-code license plate. Mixed SKUs on a pallet or mixed SKUs in a carton are difficult for cross-docking because the contents of the unit load must be sorted before an operator or conveyor can cross-dock the merchandise. By the time the contents of the unit load have been sorted out, the time window for effective cross-docking frequently has passed.

The other natural scenarios for cross-docking include

- *Back orders* because there is, by definition, an urgent outstanding order for products on back order.
- *Made-to-order products* because, by definition, there is an outstanding order for those products when they hit the receiving dock.
- *Customer-ready products* customized by the supplier.
- Branch and inter-distribution center transfers.

Specific containerization and communication requirements must be met before high-volume cross-docking can be implemented. First, each container and product must be automatically identifiable via a bar-code label or radiofrequency (RF) tag. Second, loads must be optimally scheduled into the distribution center and assigned to dock doors automatically. Third, inbound pallets or cases that will be cross-docked should contain only a single SKU or be preconfigured for their destination to minimize sorting requirements.

4.4 Direct Put-away

When material cannot be cross-docked, material-handling steps can be minimized by bypassing receiving staging and putting material away directly to primary picking locations—essentially replenishing primary locations from the receiving dock. Direct primary put-away is recommended if there is an opening for an inbound pallet or case in the primary pick location and shelf-life requirements will not be violated. In direct put-away systems, staging and inspection activities are eliminated.

To this end, one of our large healthcare clients does not allow receiving staging space in its warehouse layouts. The company “forces” warehouse operators to put goods away immediately on receipt as opposed to incurring the delays and multiple handlings characteristic of traditional receiving and put-away activities.

4.5 Receiving Scheduling

Premeditated cross-docking requires the ability to schedule inbound loads to match outbound requirements on a daily or even hourly basis. In addition, balancing the use of receiving resources—dock doors, personnel, staging space, and material-handling equipment—requires the ability to schedule carriers and to shift time-consuming receipts to off-peak hours. Through real-time electronic links, companies have improved access to schedule information on inbound and outbound loads. This information can and should be used to proactively schedule receipts.

An familiar example of cross-docking is passengers transferring between flights to make a connection in a major airline hub. Think of the resource synchronization required to successfully connect with a departing, on-time flight. The same constraints that prohibit 100 percent connection and on-time success rates are constraints in cross-docking.

To release an outbound load, all the required inbound loads must have arrived. To avoid exhausting dock and receiving crew capacities, the inbound arrival pattern must balance the unloading workload, to maintain proper outbound load sequencing and minimize staging requirements, the arrival pattern must give priority to inbound loads with early departures. This degree of receiving scheduling sophistication is found only in the most advanced

warehouse management systems and is required for an effective cross-docking program.

The most sophisticated crew scheduling systems in the world are found in the airline industry, where a large crew of flight attendants, pilots, engineers, maintenance staff, baggage handlers, and catering personnel must arrive simultaneously to ensure an on-time departure. Similarly, the personnel and equipment required to unload each inbound warehouse load should be optimally prescheduled to eliminate the possibilities of delays and/or dock congestion.

4.6 Pre-receiving

The rationale for staging at receiving is often the need to hold material for location assignment, product identification, and so on. This information can be processed as goods are in-transit or immediately as they pass through a yard gate ([Figure 4.9](#)).

Figure 4.9 An optical memory card used for pre-receiving at the U.S. Army Logistics Command to download the contents of an entire trailer into a PC at a yard gate.

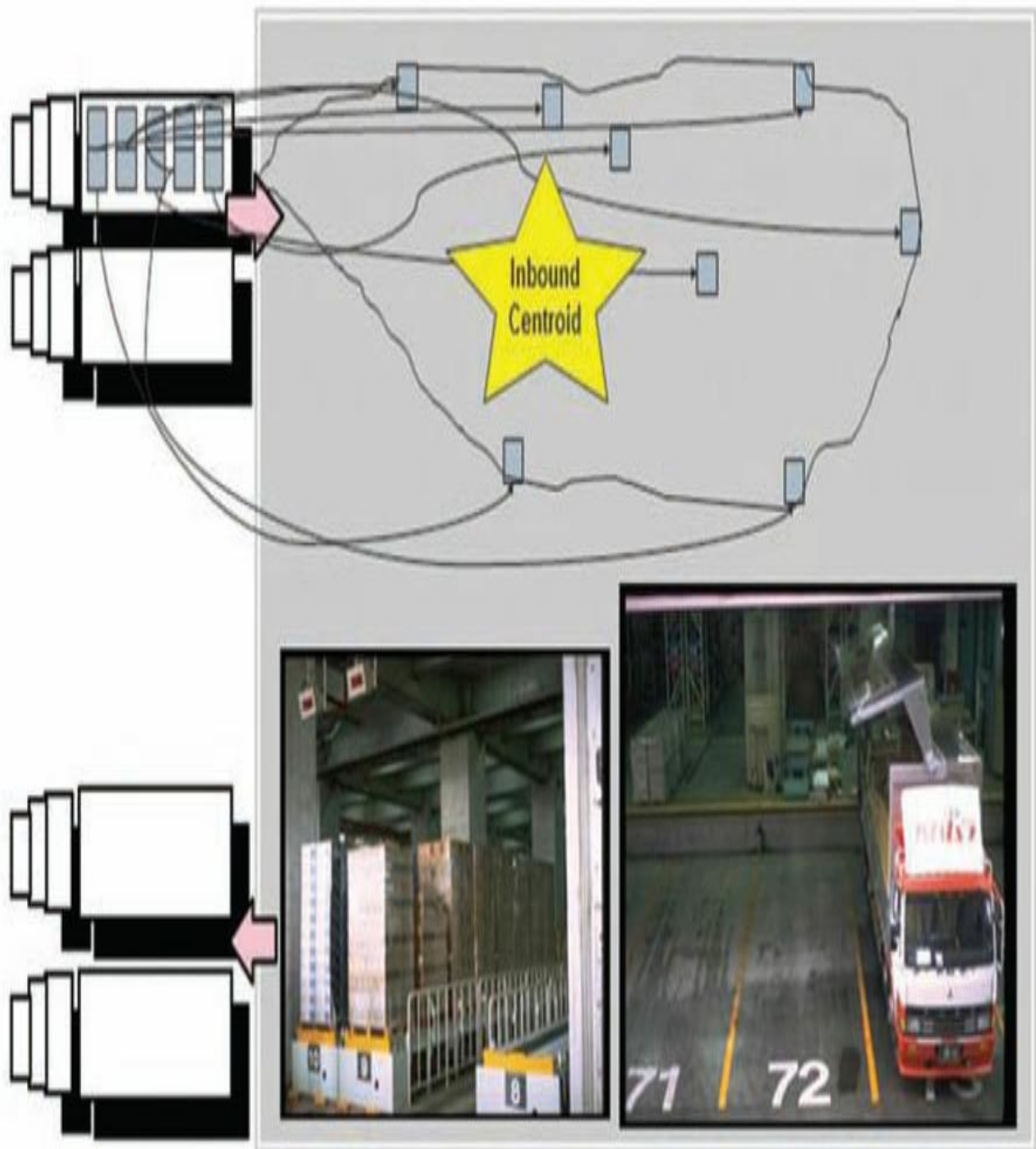


4.7 Dock Assignment Optimization

Whether for cross-docking or regular receiving, dock doors should be assigned to minimize the travel required in unloading and put-away. A simple algorithm ([Figure 4.10](#)) for inbound dock door assignment is to choose the

open door closest to the centroid of the put-away locations represented on the inbound load. Dock assignment optimization is even easier if all the inbound products arrive from one vendor and/or are the same commodity. Then if items in the warehouse are located by vendor and/or commodity, simply assign the inbound load to the door closest to the corresponding vendor or commodity.

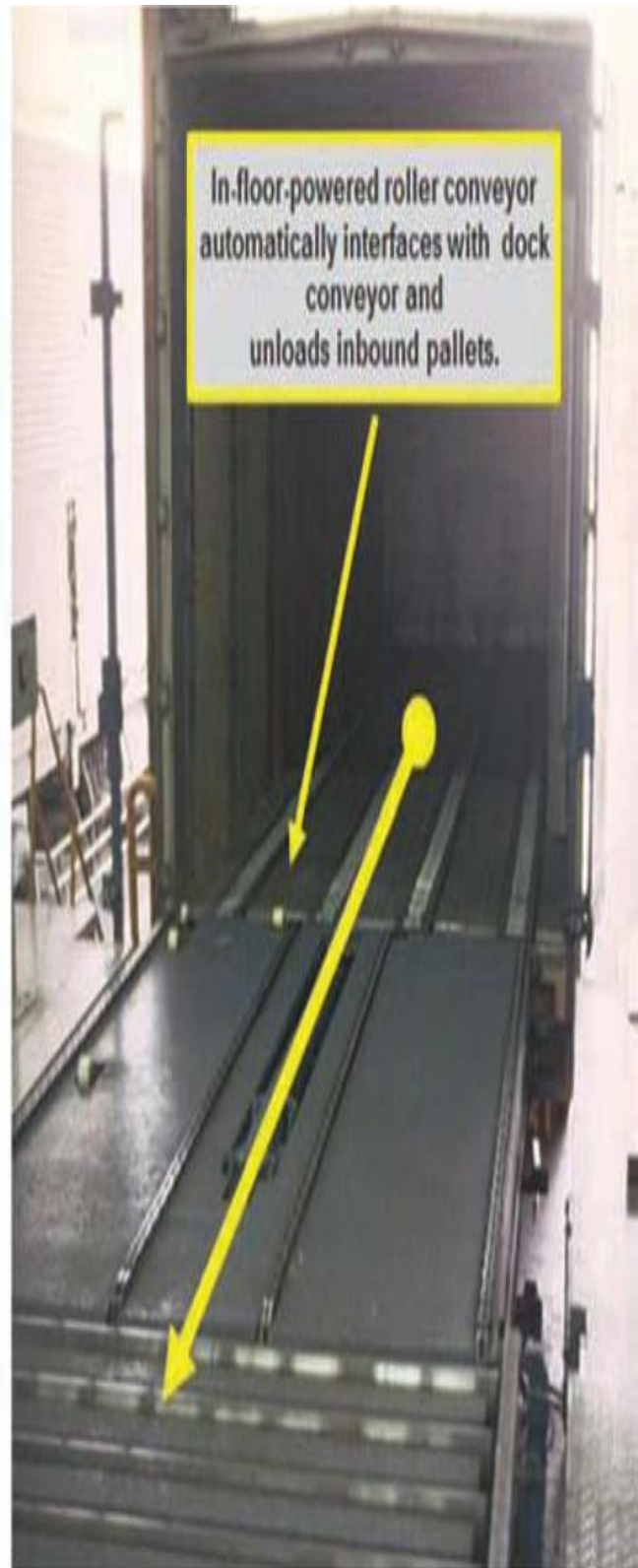
Figure 4.10 Inbound dock assignment optimization.



4.8 Automated Unloading

When justifiable, automated unloading systems ([Figure 4.11](#)) significantly increase productivity and reduce dock-to-stock time. In this example from KAO's Iwatsuki distribution center inbound loads from KAO factories are automatically unloaded from trailer beds equipped with in-floor-powered roller conveyors. The in-floor conveyors interface automatically with pallet roller conveyors on the dock, which, in turn, feed other pallet roller conveyor lines headed directly to an automated storage and retrieval system.

**Figure 4.11 Automated unloading at a KAO distribution center.
(Iwatsuki City, JAPAN)**



4.9 Delivery Quality Compliance

A set of criteria for acceptable receipt quality should be established as a part of vendor selection criteria and vendor performance-monitoring programs. Each noncompliant receipt should be digitally imaged, recorded in the vendor's performance record, and invoiced back to the offending vendor according to charge-back penalties documented in the delivery quality section of the vendor compliance report. One of our retail clients categorizes its suppliers as “white hats” (reliable) and “black hats” (unreliable) based on historical logistics compliance. “Black hat” suppliers are charged \$50 per person-hour required to inspect their goods.

4.10 Automated Receiving Inspection

Ideally, receiving inspection should be eliminated or minimized via supplier evaluation and certification programs. However, if required, receiving inspection can be automated. For example, Quelle, developed a vision system that automatically reads, photographs, and identifies the vendor, SKU, condition and case quantities for each inbound case ([Figure 4.12](#)). Any violations of delivery quality requirements are automatically captured by the digital camera and sent with a corresponding invoice for the compliance violation(s).

Figure 4.12 Automated receiving inspection at a Quelle distribution center. (Leipzig, GERMANY)



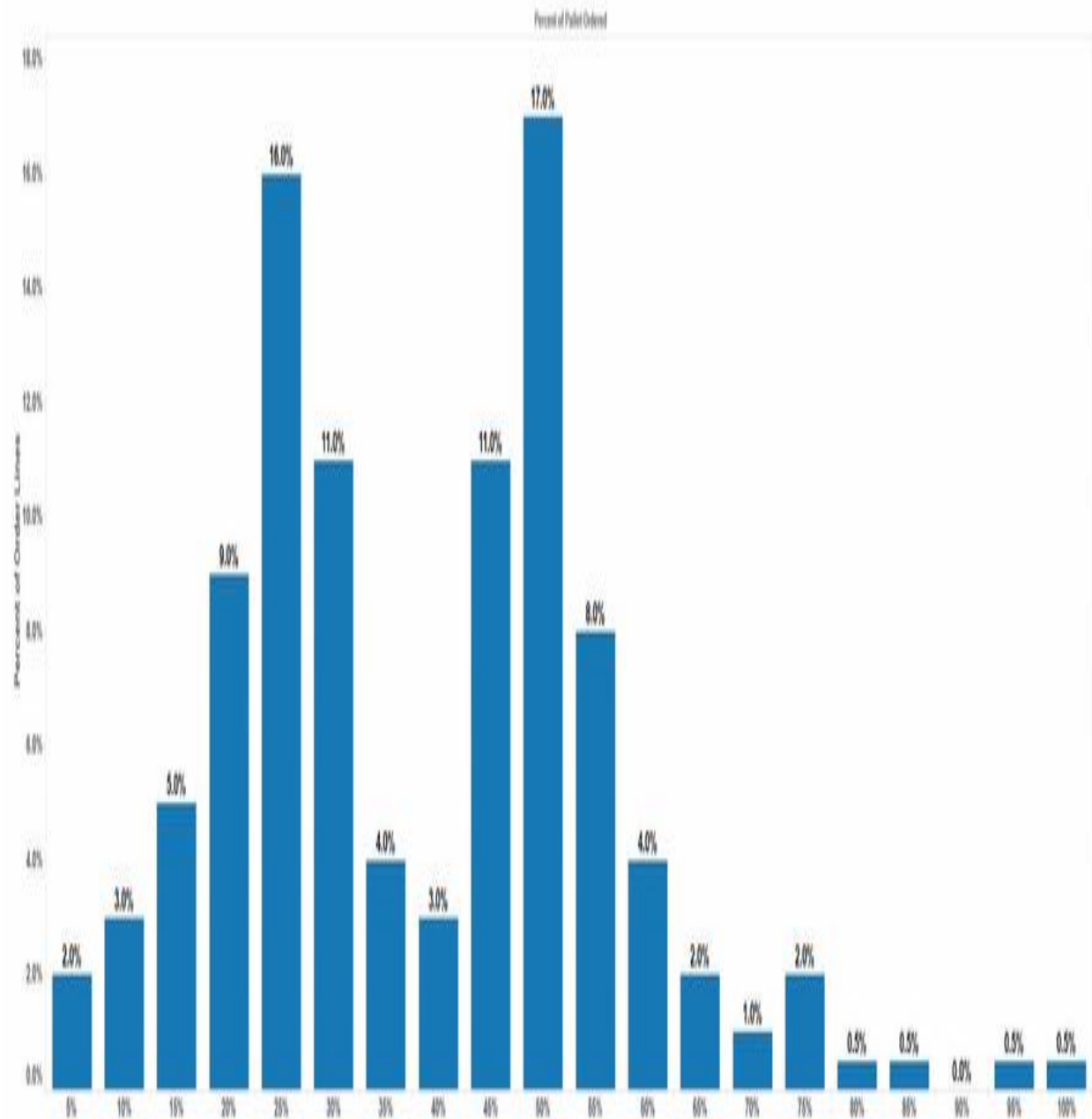
4.11 Prepackaging

Nashua Corporation is a large manufacturer of computer and office supplies.

Its warehouse activity profile indicated that customers tend to order quarter-, half-, and full-pallet quantities. Yet the company did not have any quarter- and half-pallet quantities preconfigured. Their distribution center is attached to manufacturing. Hence we need only direct the palletizer to create the appropriate mix of full-, half-, and quarter-pallet quantities. Then we need to let the customer service group know about the unit-load configurations so that they can encourage customers to order in the preconfigured increments. In this case, the head of sales and marketing was on the design team, and he instituted the new policy the next week.

The same concept can apply in broken-case picking, in which customers often order in common increments. Examples are quarter- and half-case quantities and numerical increments of 5, 10, 20, 25, 50, 100, etc. ([Figure 4.13](#)). Again, these are opportunities for prepackaging on site at receiving or at the supplier's site. In either case, the practice reduces the work, time, and likelihood of error in the order filling process.

Figure 4.13 RightPack quarter- and half-pallet preparation program at Nashua.



4.12 Inbound Cubing and Weighing

Product cube and weight information is used to make a myriad of key warehouse design and operating decisions, yet few organizations have reliable cube and weight information on their products. If suppliers cannot provide product cube and weight, the information can and should be captured at the receiving dock. A device called a *Cubiscan* is often used at receiving to capture and automatically communicate inbound unit load dimensions and weights ([Figures 4.14](#) through [4.16](#)).

Figure 4.14 In-line cubing and weighing (Cubiscan).



Figure 4.15 Pallet cubing stations (Cubiscan).



Figure 4.16 Inbound cubing and weighing at a major retail distribution center.



At Shinwa's wholesale distribution center, a simple measuring rod is attached to mobile online receiving workstations, allowing receiving operators to quickly classify each incoming pallet into one of five color codes based on its height ([Figure 4.17](#)). Different color strips are placed on the antenna so that the receiving operator can easily classify the height code of the pallet, enter the code into the onboard warehouse management system terminal, and assign the load to its corresponding pallet height opening. The codes correspond to the color-coding scheme used to distinguish the sizes of rack openings throughout the warehouse.

Figure 4.17 Inbound cubing with PC-equipped mobile receiving cart. (Osaka, JAPAN)



4.13 Directed Put-away

Left to their own devices, most put-away operators naturally choose put-away locations that are easiest to find—nearest the floor, nearest their friend,

nearest the break room—using any criterion except where the put-away should be located to maximize storage density and operating productivity. The warehouse management system (WMS) should direct put-away operators to place each a pallet or case in the location that maximizes space utilization, insure good product rotation, and maximizes retrieval productivity ([Figure 4.18](#)).

Figure 4.18 RF-directed put-away operation at a large valve and fitting company.

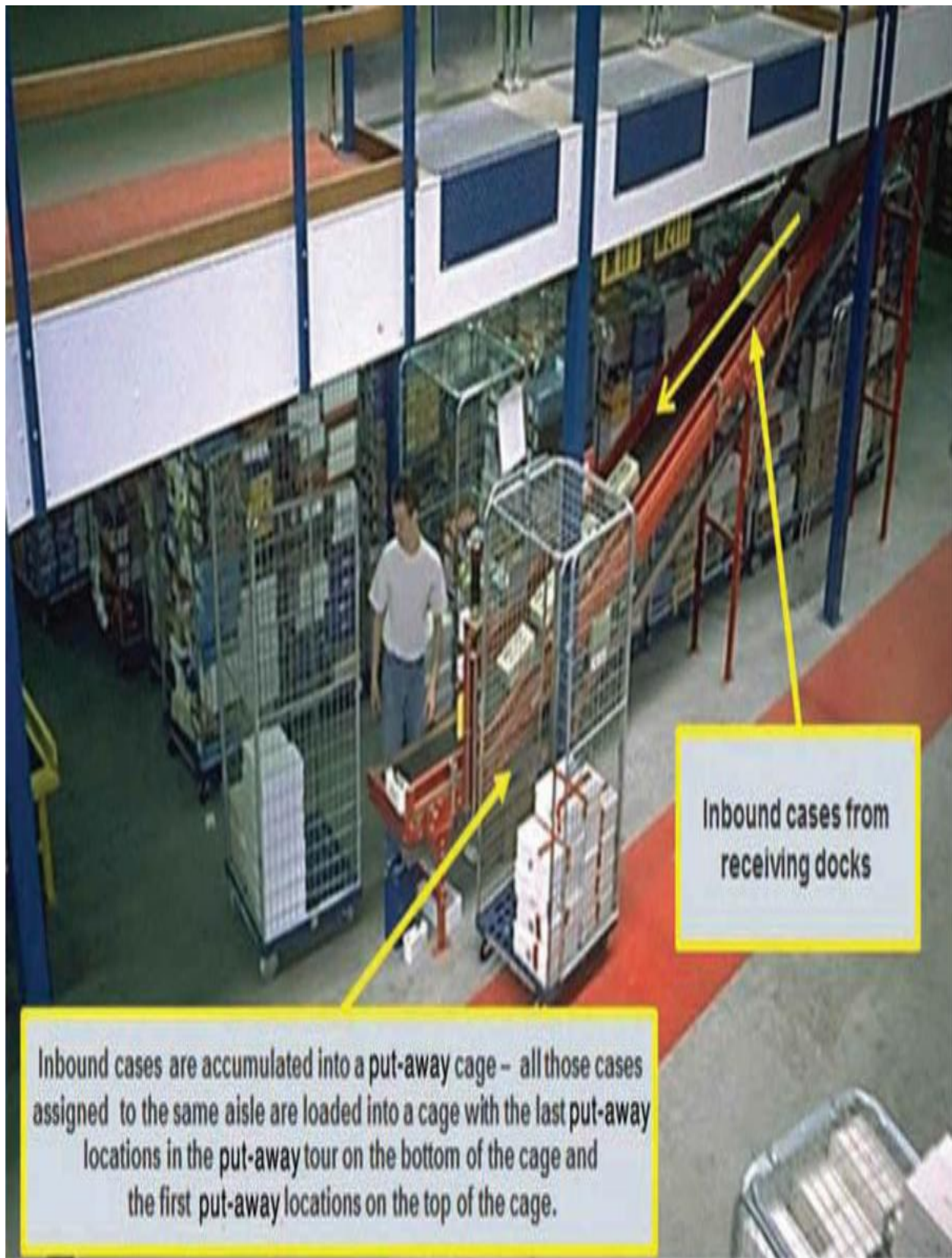


4.14 Batch, Sort, and Sequence Put-away

Just as zone picking and location sequencing are effective strategies for improving order picking productivity, inbound materials can and should be sorted for put-away by warehouse zone and by location sequence. The WMS should batch put-aways within an aisle and/or in close proximity to maximize put-away productivity. The WMS also should sequence put-away transactions within a batch to meet deadlines and/or minimize travel and search times.

At Hogenbosch's shoe distribution center ([Figure 4.19](#)) just outside Amsterdam, inbound cases are batched by and sequenced within aisles in put-away cages.

Figure 4.19 Batched and sequenced put-aways at a large European shoe distribution operation. (Amsterdam, NETHERLANDS)



Inbound cases from
receiving docks

Inbound cases are accumulated into a put-away cage – all those cases assigned to the same aisle are loaded into a cage with the last put-away locations in the put-away tour on the bottom of the cage and the first put-away locations on the top of the cage.

4.15 Prioritized Put-away

Not all put-aways arrive with the same priority. A best-of-breed WMS will flag and sequence high-priority or “hot” put-aways. The flag and execution could take place as goods arrive via the inbound yard gate, while they are in yard storage, and/or once they reach the receiving dock.

4.16 Put-away Location Verification

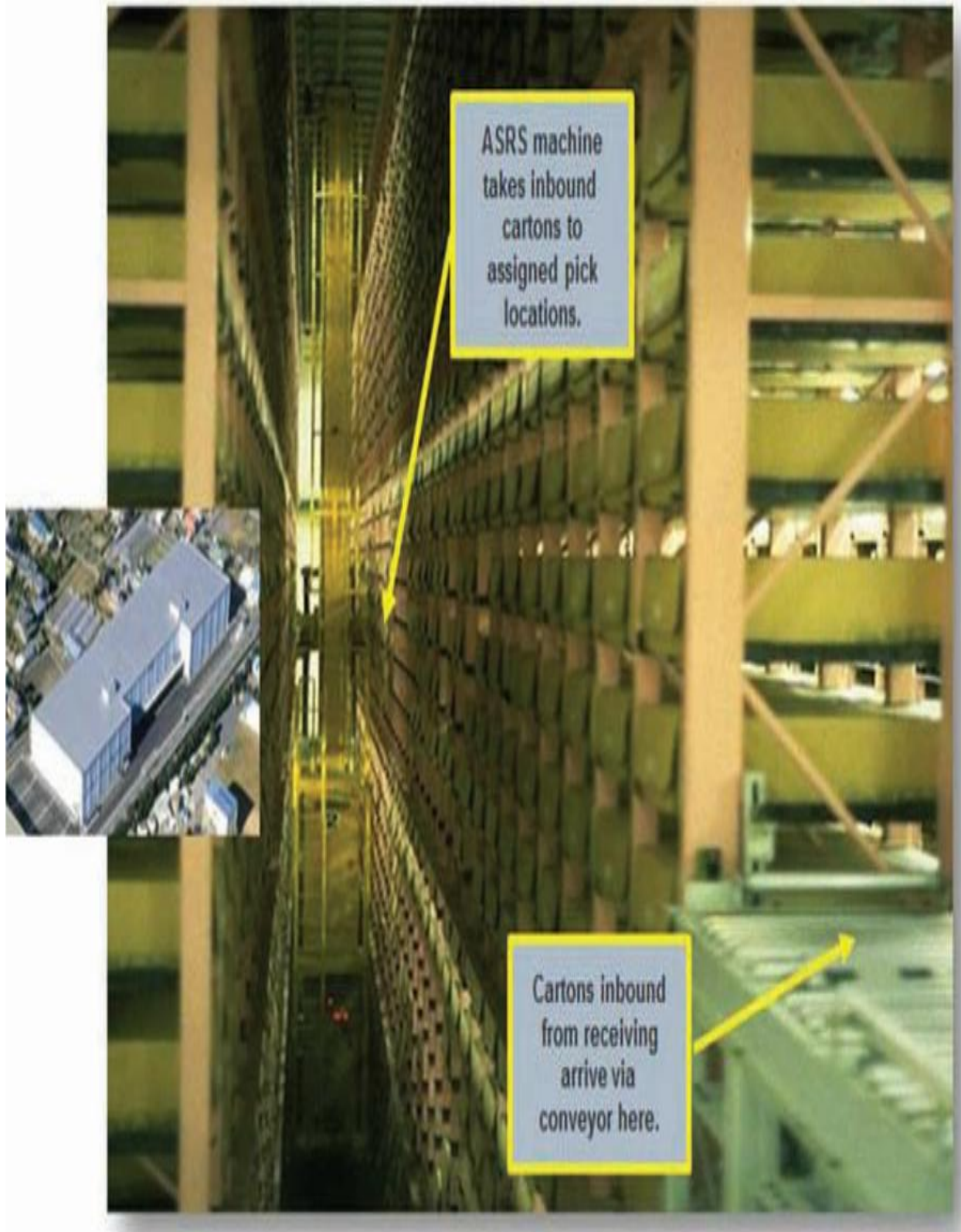
Put-away accuracy is the percentage of put-aways without discrepancies. This is a critical yet often overlooked metric. If an item is placed in the wrong location or in the wrong quantity, it sets up a chain reaction of failed transactions.

4.17 Automated Put-away

The world’s most advanced logistics operations are characterized by automated direct put-away to storage locations. The material-handling technologies that facilitate direct put-away include roller-bed trailers and extendable conveyors.

An excellent example of automated put-away is at Scroll’s omni-channel distribution center just outside Nagoya, Japan ([Figure 4.20](#)). There, inbound cartons are automatically unloaded onto inbound telescoping conveyors. The conveyors feed conveyor lanes that lead directly to the input stations of an automated storage and retrieval system. Cases are sorted into their assigned lanes with an in-line sorting system ([Figure 4.20](#)).

Figure 4.20 Automated put-away to the automated storage and retrieval system. (Nagoya, JAPAN)



ASRS machine
takes inbound
cartons to
assigned pick
locations.

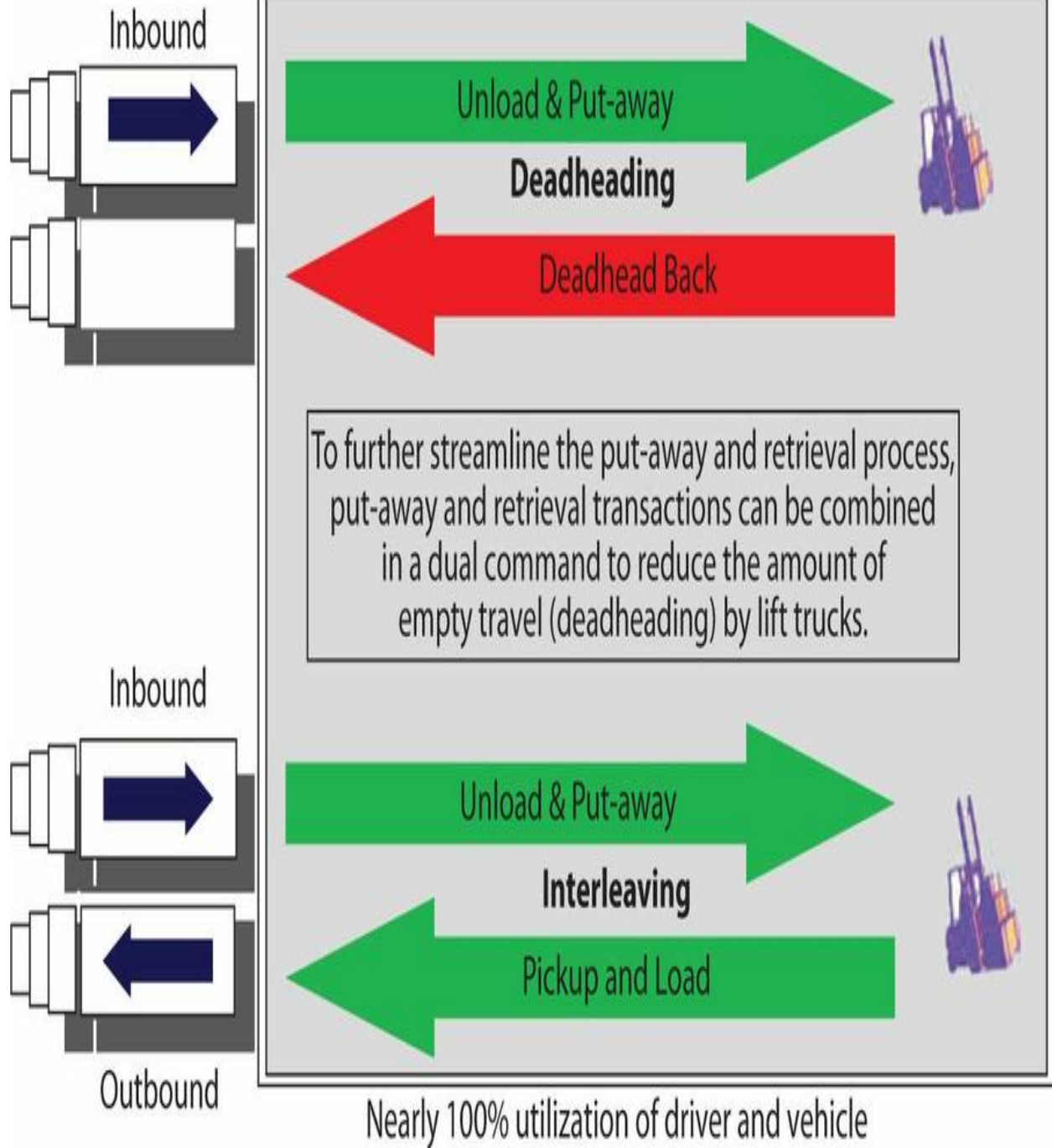
Cartons inbound
from receiving
arrive via
conveyor here.

4.18 Interleaving and Continuous Moves

In interleaving, put-away and retrieval transactions are combined in a dual command to reduce empty travel (deadheading) ([Figure 4.21](#)). For example, Counterbalance lift trucks that can unload, put away, retrieve, and load during a round trip are an efficient means of interleaving. (Interleaving is similar to backhauling in transportation.) The practice of interleaving should be extended to continuous moves within the warehouse, where warehouse operators are directed from most-efficient task to most-efficient task by the WMS.

Figure 4.21 Interleaving concept.

50% utilization of driver and vehicle



CHAPTER FIVE

PALLETS: PALLET STORAGE AND HANDLING SYSTEMS

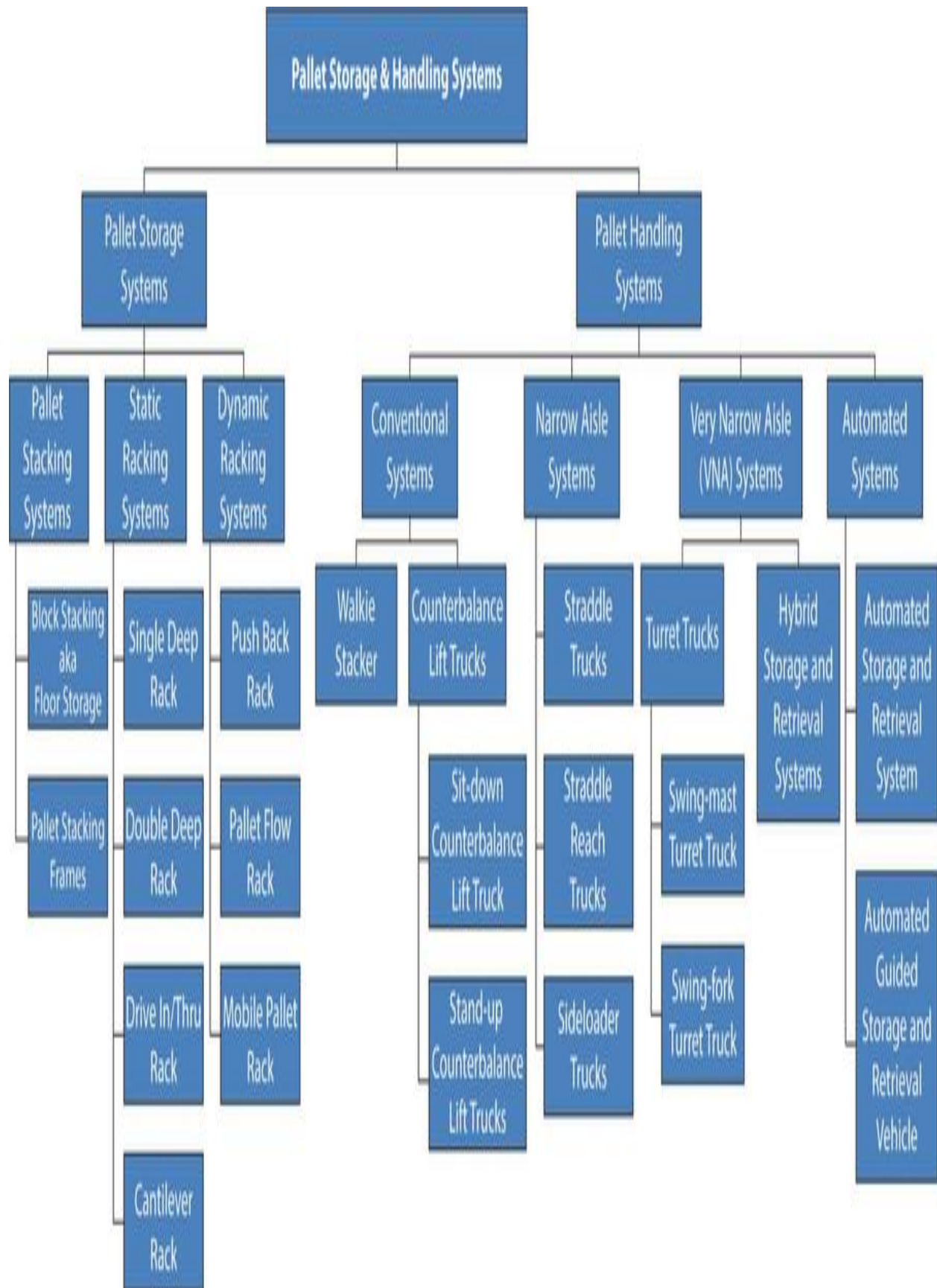
5.1 Pallet Storage Systems

5.2 Pallet Handling Systems

5.3 Pallet Storage and Handling Systems Selection

We begin our RightHouse taxonomy ([Figure 5.1](#)) of pallet storage and handling systems by classifying the systems into (1) pallet storage systems and (2) pallet handling systems. Although the two subsystems work hand in hand, selection of the storage system is driven primarily by the desire to improve storage density and is dictated by the on-hand inventory and turnover of the items in pallet storage. The choice of the handling system is driven primarily by the desire for high handling productivity and tradeoffs in required capital investment.

Figure 5.1 RightHouse taxonomy of pallet storage and handling systems.



5.1 Pallet Storage Systems

Pallet storage systems fall into three subcategories based on the nature of the racking type: (1) pallet stacking systems, (2) static racking systems, and (3) dynamic racking systems. Each alternative is described in this section.

Pallet Stacking Systems

Pallet stacking systems have pallets stacked on top of each other, hence the name *pallet stacking system*. There are two types of pallet stacking systems—*block stacking*, often referred to as *floor storage*, and *stacking frames*.

Block Stacking Block stacking ([Figures 5.2 through 5.4](#)) refers to unit loads stacked on top of each other and stored on the floor in storage lanes (blocks) typically 3 to 10 loads deep. Block stacking is particularly effective when there are multiple pallets on-hand per stock-keeping unit (SKU) and when several loads of the same SKU are received and/or withdrawn at one time. Because no racking is required, the investment in block stacking is low. Block stacking is easy to implement, and it allows near-infinite flexibility for floor-space configuration. Loads in a block are retrieved last in, first out (LIFO). Hence, if highly restrictive first in, first out (FIFO) requirements are in place, block stacking is not a feasible storage method ([Figures 5.2 through 5.4](#)).

Figure 5.2 Block stacking at a Coca-Cola plant warehouse North Carolina. Note that loads are stacked one high, two high, two and a half high (by straddling adjacent stacks), and three high depending on the weight of the product.



Figure 5.3 Floor storage may be the only reasonable pallet storage alternative in a warehouse with low clearings. Such was the case at this Japanese beverage wholesaler's multi-story distribution center.



Figure 5.4 Block stacking with case picking front at a Coca-Cola warehouse.



Stack Height Constraints The storage density in block stacking systems is determined by two factors—the depth of the storage lane and the stacking height. Stacking height is constrained and determined by a mix of the following factors:

- *Load surface shape.* Irregularly shaped product does not stack efficiently.
- *Load weight.* Heavy loads may crush one another ([Figures 5.5 and 5.6](#)).

Figure 5.5 The height of block stacking in this cement manufacturer's warehouse is constrained by product weight and shape.



Figure 5.6 Block stacking in an aluminum can plant. Lightweight and uniform loads permit four-high stacking.



- *Packaging strength.* Weak packaging will not support stacked loads.
- *Pallet condition.* Poorly maintained pallets will not stack properly and may damage stacked product.
- *Floor loading restrictions.* Some floors are not rated to support heavy loads ([Figure 5.7](#)).

Figure 5.7 Block stacking in a raw materials warehouse (Lima, Peru).



- *Weather*. High humidity diminishes packaging strength.
- *Vehicle lift-height capacity*. Obviously, loads may not be stacked higher than the lift-height capacity of the pallet-handling vehicle.
- *Building clear height*. Even more obviously, loads may not be stacked higher than the ceiling clear height.

Honeycombing and Lane Depth Optimization Because only one SKU should be stored in a lane or stack, empty pallet spaces are created that cannot be used effectively until an entire lane is emptied. A ceiling view of a typical block stacking configuration with full, partially full, and empty lanes and stacks looks somewhat like a honeycomb—hence the term *honeycombing* references the loss of pallet storage capacity in block stacking (Figure 5.8). If lanes are too deep, the floor space in front of the back pallets is underutilized. If lanes are too short, too large a portion of the floor space is devoted to aisles. If the pallets are not easily stackable, too much of the available clear height is not useable.

Figure 5.8 Honeycombing at a large beverage distribution center.

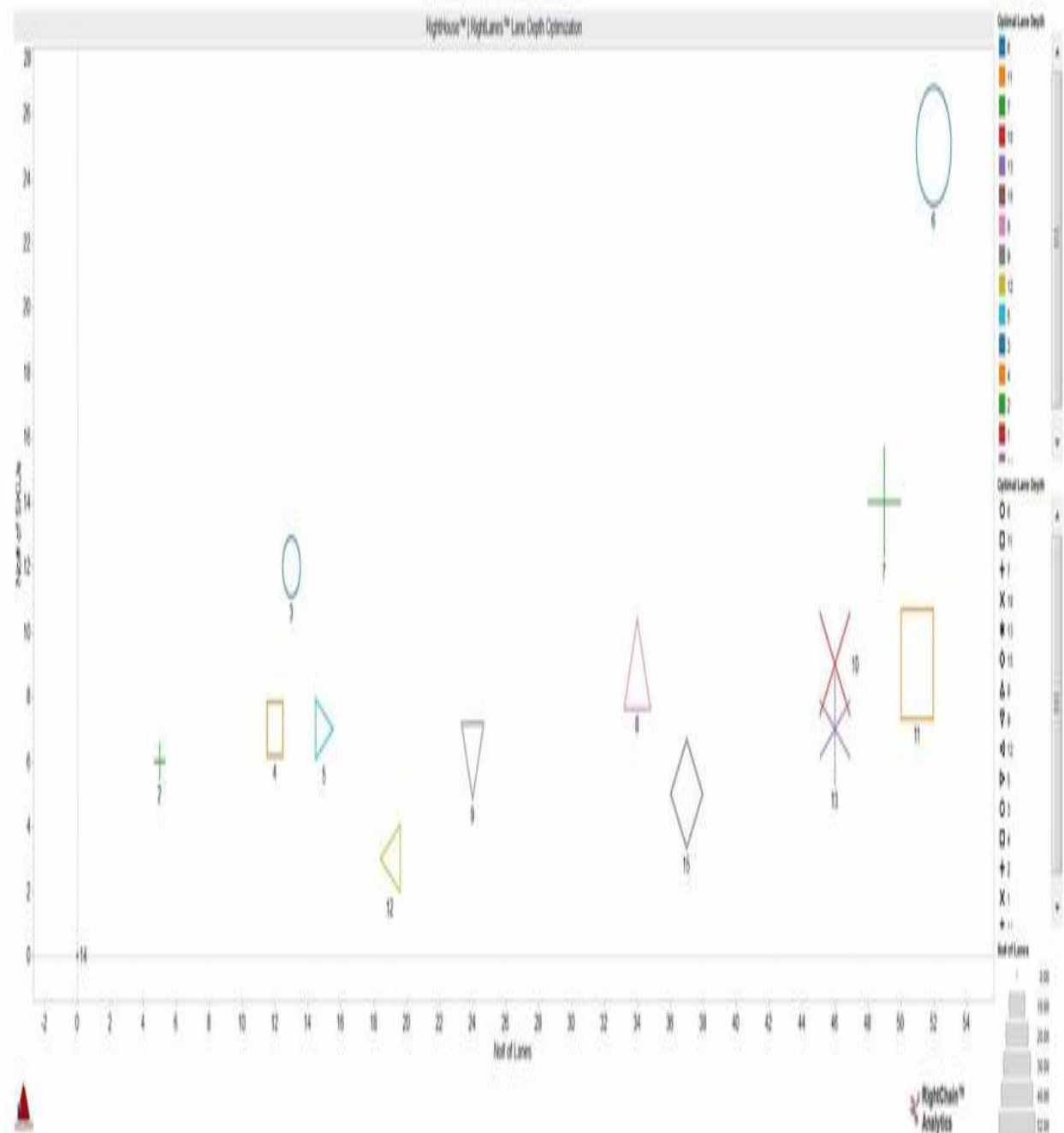


Therefore, to maintain high utilization of the available storage positions, the lane depth must be carefully determined.

A lane-depth optimization analysis developed for a large consumer products company is shown in [Figure 5.9](#). The lane depth yielding the lowest floor-space requirement for each item is recommended by the analysis.

Figure 5.9 RightLanes lane-depth optimization for a large consumer products company.

RightLanes™ Lane Depth Optimization



We use lane-depth optimization to minimize honeycombing. Our lane-depth optimization takes into account pallet dimensions, aisle dimensions, stack heights, and occupancy costs when computing an optimal storage lane depth for each SKU. An estimate of the optimal lane depth can be calculated with the following formula:

$$\text{Optimal lane depth} = [(\text{aisle width} \times \text{lot size}) / (2 \times \text{load length} \times \text{stack height})]^{1/2}$$

In addition to optimizing lane depth, the following operating rules help to improve floor-space utilization in block stacking:

1. Retrieve from the most depleted lane first.
2. Rewarehouse when necessary.
3. Design lanes with access from both sides.
4. Mix lane depths within a bay.

Pallet Stacking Frames Pallet stacking frames ([Figures 5.10](#) and [5.11](#)) are either frames attached to standard wooden pallets or self-contained steel units made up of decks and posts. Stacking frames are portable and enable the user to stack material several loads high. When not in use, the frames can be disassembled and stored in a minimum amount of space.

Figure 5.10 Pallet stacking frames at NTT, (Tokyo, JAPAN).



Figure 5.11 Inbound pallet stacking frames arriving to a Ford warehouse Georgia.



Stacking frames are commonly used when loads are not stackable and when other racking alternatives are not justifiable. In addition, because stacking frames can be leased, they are popular when there is a short-term

spike in inventory. The storage-density losses due to honeycombing described earlier for block stacking also apply to stacking frames.

Static Racking Systems

Static racking systems include single-deep pallet racks, double-deep pallet racks, drive-in racks, and cantilever racks.

Single-Deep Pallet Racks Single-deep pallet racks ([Figures 5.12 to 5.14](#)), also called *selective pallet racks*, are a simple construction of metal uprights and cross-members providing immediate (pick-face) access to each load (i.e., no honeycombing). Because racking is supporting every load, stacking height is not limited by the stackability and/or crushability of the loads, and multiple SKUs can be stacked in the same vertical column of storage space.

Figure 5.12 Single-deep pallet racks at the American Cancer Society's National Logistics Center Georgia. Note that the racks are four levels high; the top two levels are devoted to full-pallet reserve storage for the bottom two levels, which are devoted to case picking. Note also that as many cases as possible are positioned at the front of the case picking face to minimize lifting strain and improve productivity.



Figure 5.13 Single-deep pallet racks with pallet staging bays (London, England).



Figure 5.14 Single-deep pallet racks with all-clear aisle lights (Munich, Germany).



The major advantage of single-deep racks is the full access to all unit loads. The major disadvantage is the amount of space devoted to aisles—typically 50 to 60 percent of the available floor space. As a result, in cases where three or more pallets of a SKU are on hand, a storage method that houses at least two pallets perpendicular to the storage aisle may be preferable.

Double-Deep Pallet Racks Double-deep pallet racks are selective racks that are two pallet positions deep ([Figure 5.15](#)). The advantage of two-deep rack facings (perpendicular to the aisle) is that less aisle space is required. In most cases, a 50 percent aisle space savings is achieved versus single-deep selective racks.

Figure 5.15 Double-deep pallet racks. (London, England).



Double-deep racks are typically used when the storage requirement for a SKU is three pallets or greater and when product is received and picked frequently in multiples of two pallets. (Assigning SKUs with only a single pallet on hand to double-deep racking is wasteful because one of the two positions in a facing is automatically wasted.) Because pallets are stored two deep, a double-reach forklift or reach truck is required for storage/retrieval ([Figure 5.16](#)).

Figure 5.16 Double-deep pallet rack accessed via a double-deep reach truck.



Drive-In/Through Racks Drive-in racks ([Figure 5.17](#)) extend the reduction of aisle space begun with double-deep pallet racks by providing storage lanes 5 to 10 loads deep. Drive-in racks allow a reach truck or forklift to drive into the rack to store and retrieve pallets. The rack consists of upright columns with footings as opposed to beams to support pallet storage.

Figure 5.17 Drive-in racks at a Honda parts distribution center.



One drawback of drive-in racks is the reduction in vehicle travel speed needed for safe navigation within the confines of the rack. Another drawback is the honeycombing losses because no more than one SKU should be housed in a lane. As a result, drive-in racks are best used for slow- to medium-velocity SKUs with several pallets on hand. As was the case with block stacking, loads are retrieved with a LIFO discipline and with a retrieval approach that frees up each lane as quickly as possible.

Drive-through racks are merely drive-in racks that are accessible from both sides of the rack. These racks are often used for staging loads in a flow-through fashion where a pallet is loaded at one end and retrieved at the other end. The same considerations for drive-in racks apply to drive-through racks.

Cantilever Racks Cantilever racks ([Figure 5.18](#)) are commonly used to house long objects such as bar stock, lumber, and pallets. They are typically accessed via a side-loader truck.

Figure 5.18 Bar stock in a cantilever rack at Aurora, Indianapolis, Indiana.



Dynamic Racking Systems

Dynamic racking systems are so called because either pallets move within the rack, as is the case with pallet flow racks and pushback racks, or the rack itself moves, as is the case with mobile pallet racks.

Pallet Flow Racks In pallet flow racks ([Figures 5.19](#) through [5.21](#)) loads are conveyed (FIFO) on skate-wheel conveyors, roller conveyors, or rails from the back of a storage lane to the front. As a load is removed from the front of the storage lane, gravity advances the next load to the pick face. The main benefits are high throughput, good space utilization, and the separation of the picking from the replenishment activity. Pallet flow racks are best used for items with high pallet inventory turnover with several pallets on hand.

Figure 5.19 Pallet flow rack (rear view).



Figure 5.20 Pallet flow rack (new installation).

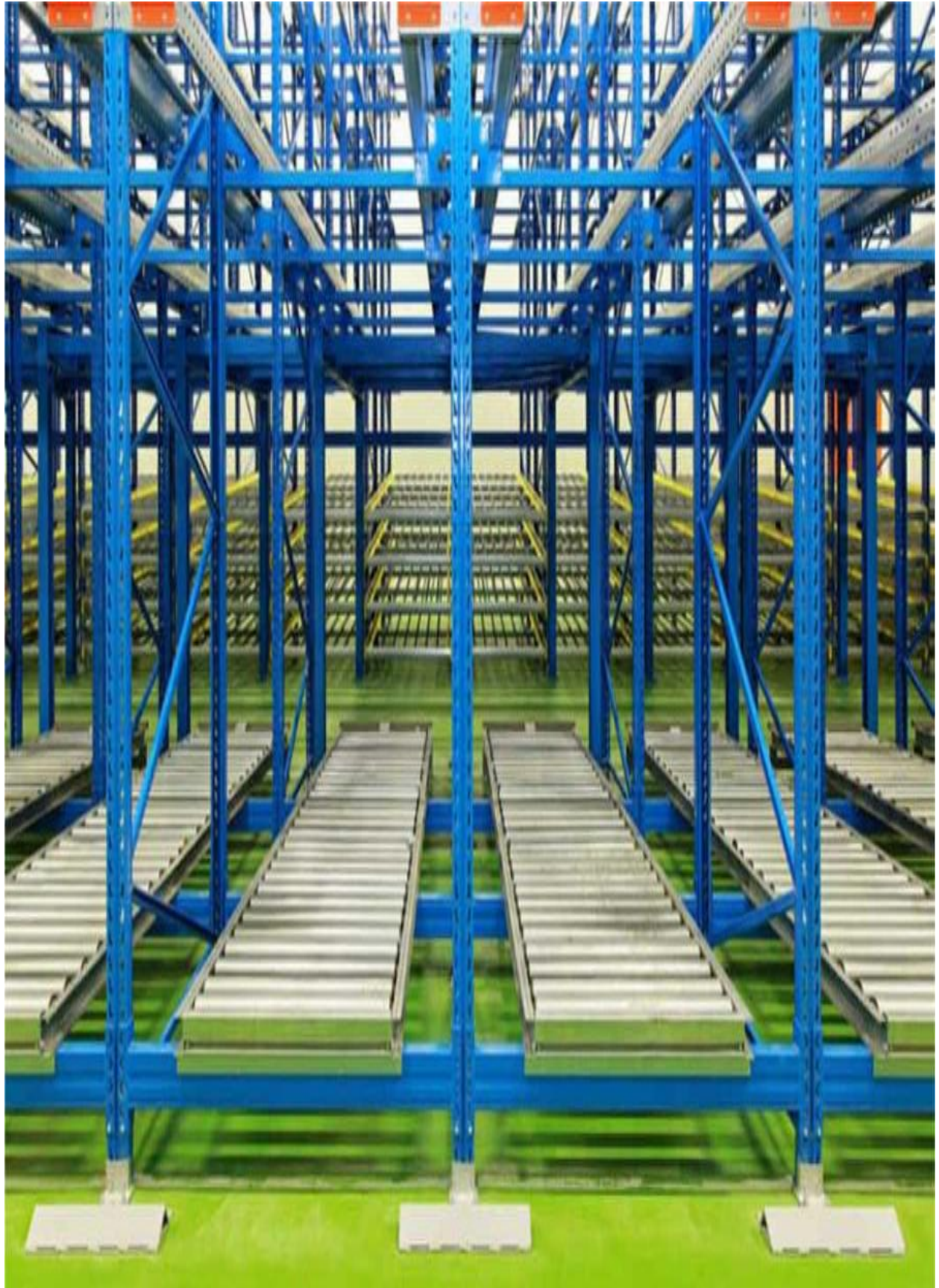
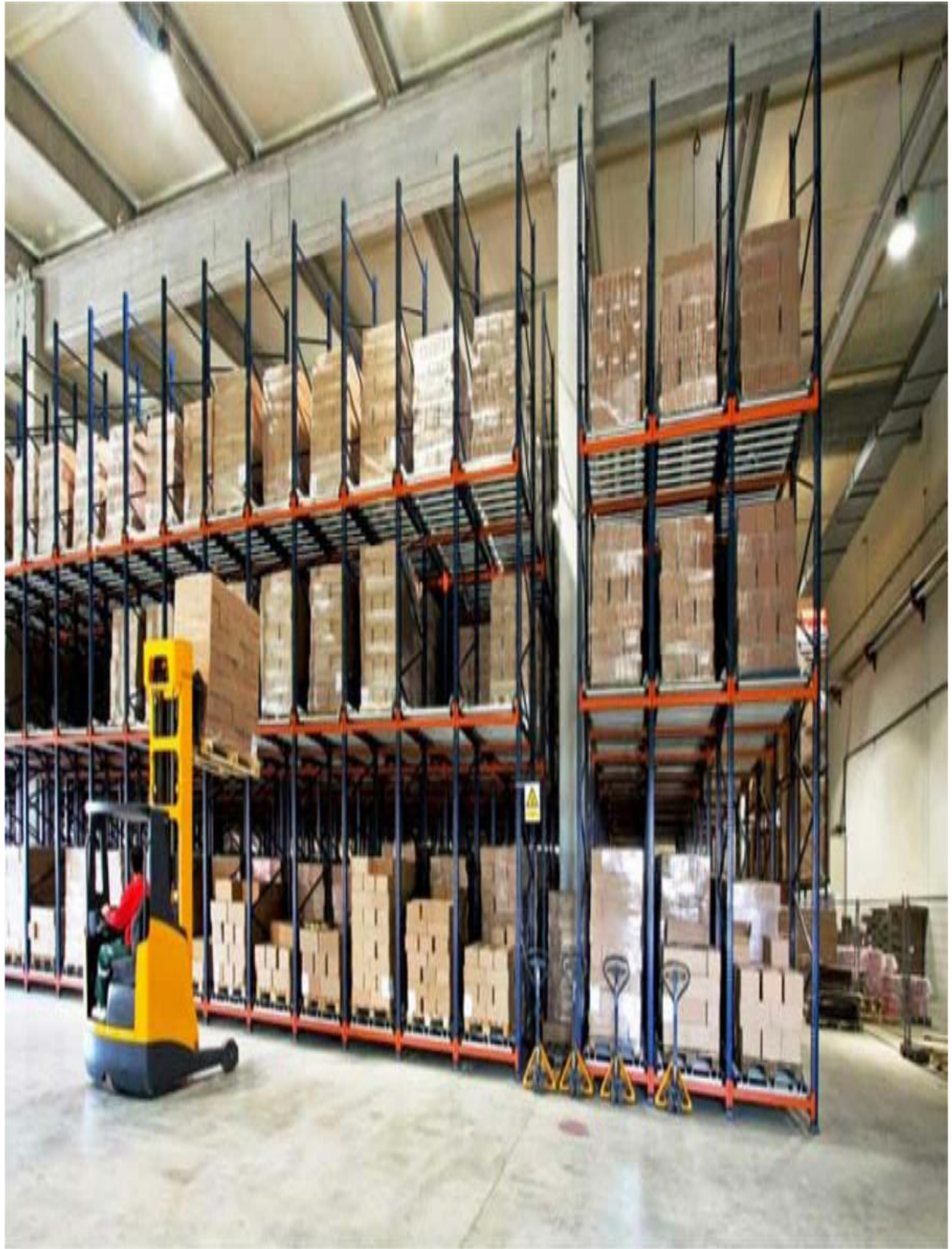


Figure 5.21 Pallet flow rack replenishment.



Push-Back Racks Push-back racks ([Figures 5.22 and 5.23](#)) provide LIFO deep-lane storage (typically two to five pallets deep) employing a rail-guided carrier for each pallet load. As a load is placed into storage, its weight and the force of the put-away vehicle push the other loads in the lane back into the lane to create room for the additional load. As a load is removed from the front of a storage lane, the weight of the remaining loads gravitationally advances remaining loads to the rack face. Hence, every SKU/lane has a load that is immediately accessible along the aisle. In addition, because all the put-away and retrieval take place at the rack face, there is no need for special lift truck attachments, Push-back racks are appropriate for medium- to fast-moving SKUs with 3 to 10 pallets on hand ([Figures 5.22 and 5.23](#)).

Figure 5.22 Push-back racks at a Honda parts distribution center, Georgia.



Figure 5.23 Two-deep push-back rack up against at the American Cancer Society's National Logistics Center, Georgia.



Mobile Pallet Racks Mobile pallet racks ([Figures 5.24](#) and [5.25](#)) are essentially single-deep pallet racks on wheels or tracks permitting aisles to be created on-demand when and where they are needed. Aisles are created by moving (mechanically or manually) the adjacent row and creating an aisle in front of the desired row. As a result, less than 10 percent of floor space is devoted to aisles, and storage density is the highest of any of the pallet storage alternatives. Unfortunately, pallet-retrieval productivity is the lowest of any of the alternatives we have considered. Hence mobile racks are justifiable when space is scarce and expensive and for slow-moving SKUs with one to three pallets on hand.

Figure 5.24 Mobile pallet racks are most easily justified in situations where occupancy costs are extremely high and throughput requirements are fairly low, as is the case at Scroll's slow-mover's warehouse. (Tokyo, Japan)



Figure 5.25 Mobile pallet rack installation.



Pallet Storage System Selection

The key to selecting the appropriate pallet storage system is to *assign each SKU to a pallet storage system whose storage and productivity characteristics match the activity and inventory profile of the SKU*. [Table 5.1](#) summarizes the key features of each pallet storage system, including storage density, load accessibility, throughput capacity, inventory and location control, FIFO maintenance, load size variability, and ease of installation.

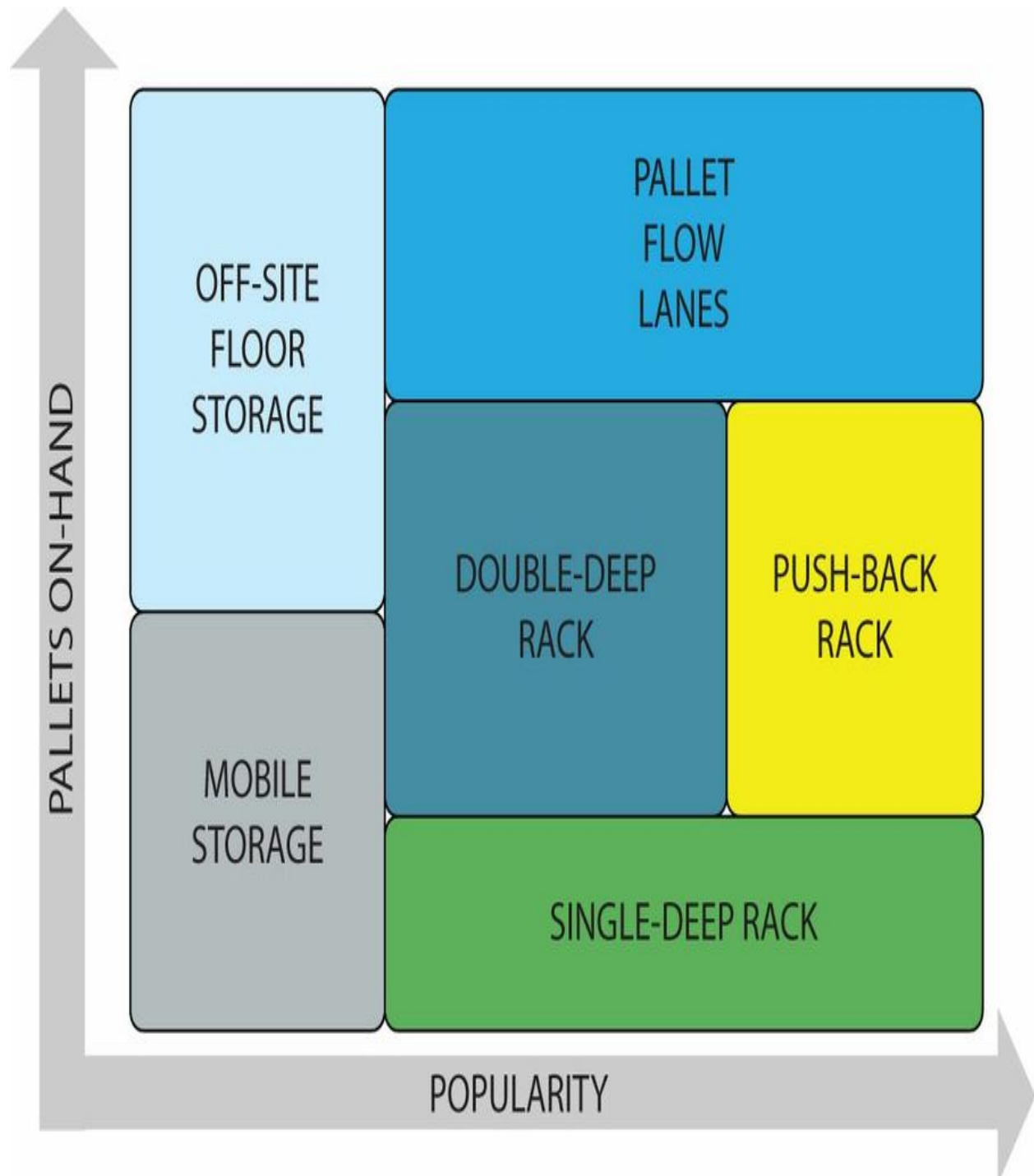
Table 5.1 Pallet storage system comparison.

Pallet Rack Type	Load Always on Aisle	Percent Loads on Aisle	Rotation	Damage	Ease of Handling Variable-Sized Loads	Ease of Installation	Ease of Reconfiguration	Special Vehicle Required	Same Face for Store and Retrieve
Floor storage	No	10–40	LIFO	Medium	High	Easy	Very high	No	Yes
Single-deep rack	Yes	100	Random	Low	Medium	Easy	High	No	Yes
Single-deep narrow aisle	Yes	100	Random	Low	Medium	Easy	High	Yes	Yes
Double-deep rack	No	50	LIFO	Medium	Medium	Easy	Medium	Yes	Yes
Drive-in rack	No	10–30	LIFO	High	Low	Moderate	Low	No	Yes
Push-back rack	Yes	20–50	LIFO	Medium	Medium	Moderate	Low	No	Yes
Pallet-flow rack	Yes	10–30	LIFO	Medium	Low	Difficult	Very low	No	No
Mobile pallet rack	No	10–20	Random	Low	Medium	Difficult	Very low	No	Yes

[Figure 5.26](#) illustrates an example pallet storage mode analysis. The example is taken from a particular case and cannot be generalized because the preference regions vary widely as a function of the cost and availability of

labor and space. The analysis indicates the most economically appropriate assignment of popularity-inventory families to pallet storage modes.

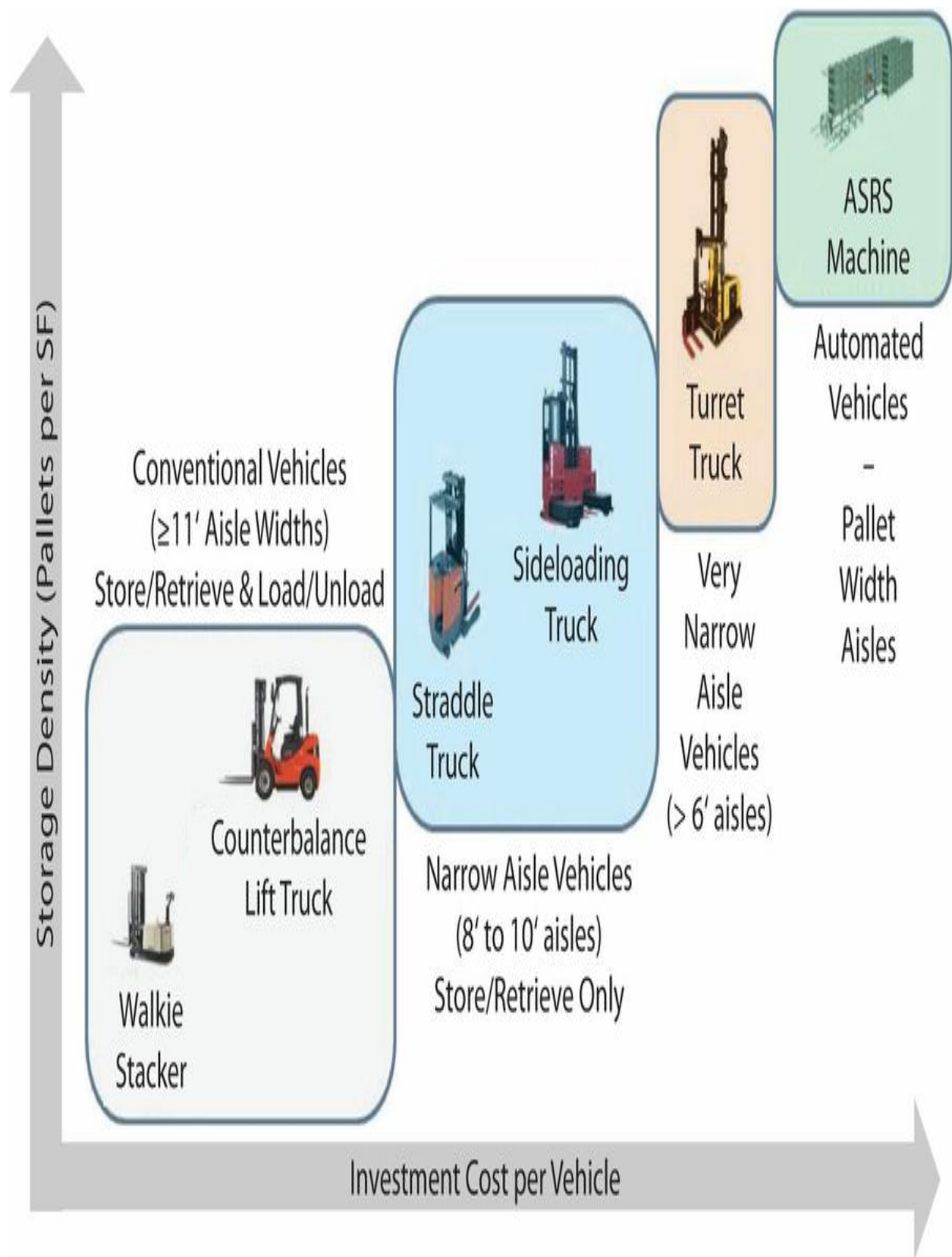
Figure 5.26 Example pallet storage mode optimization for a large grocer.



5.2 Pallet Handling Systems

In rank order from least to most expensive and simplest to most complex, the most popular pallet handling systems ([Figure 5.27](#)) include

Figure 5.27 Pallet handling systems comparison.



- Conventional vehicles
 - Walkie stackers
 - Counterbalance lift trucks
 - Sit-down counterbalance lift trucks
 - Stand-up counterbalance lift trucks
 - Driverless counterbalance lift trucks
- Narrow-aisle vehicles
 - Straddle trucks
 - Straddle reach trucks
 - Side-loader trucks
- Very narrow-aisle vehicles
 - Turret trucks
 - Swing-fork turret trucks
 - Swing-mast turret trucks
 - Hybrid trucks
- Automated vehicles
 - Automated storage and retrieval machines
 - Automated guided storage and retrieval vehicles

The applications, pros and cons, and related costs of each system are described next.

Conventional Vehicles

Walkie stackers and counterbalance lift trucks make up the class of conventional pallet handling systems.

Walkie Stackers A *walkie stacker* ([Figure 5.28](#)) lifts, transports, and stacks. An operator steers from a walking position behind the vehicle. Where there is low throughput, short travel distances, and low storage height, and a low-cost

solution is desired, Walkie stackers are appropriate. A typical walkie stacker can stack loads a maximum of three loads high and offers the dual purpose (no handoff required) of pallet retrieval/put-away and truck loading/unloading.

Figure 5.28 Walkie stacker in receiving operations for a large biotech firm.



Counterbalance Lift Truck As the name implies, *counterbalance lift trucks* ([Figures 5.29](#) through [5.33](#)) employ a counterbalance in the back of the truck to stabilize loads carried and lifted on a mast in the front of the truck. Besides forks, other attachments may be used to lift unique load configurations. The lift height limitation is around 25 feet. Counterbalance trucks are available with operating capacities of up to 100,000 pounds.

Figure 5.29 Sit-down counterbalance lift truck.



Figure 5.30 Stand-up counterbalance lift truck Georgia.



**Figure 5.31 Sit-down counterbalance lift truck with ram attachment
Georgia.**



Figure 5.32 Stand-up counterbalance lift truck at NTT (Tokyo, Japan).



Figure 5.33 Multiload counterbalance truck at Suntory (Nagoya, Japan).



Because the operator rides (seated, or standing in the case of stand-up counterbalance trucks) on the vehicle, counterbalance trucks can be used for longer moves than walkie stackers. Counterbalance trucks also offer the flexibility to retrieve/put away a pallet and load/unload a truck in the same move. This flexibility, coupled with the vehicle's relatively low cost, makes the counterbalance lift truck the benchmark for all other pallet-retrieval vehicles. Multiload counterbalance trucks (Figure 5.33) can be used to increase the overall productivity of lift truck operations.

The major drawback of counterbalance lift trucks is its wide turning radius. As a result, an 11- to 12-foot storage aisle width is typically required.

The aisle width requirement is the justification focus of alternative vehicles. As we proceed through the remaining list, the vehicles operate in progressively narrower aisles (hence the reference to *narrow-aisle vehicles*) and progressively taller reach heights. At the same time, the vehicles are progressively more expensive, and none offers the retrieval/put-away and load/unload flexibility that the counterbalance truck offers. Hence the incremental space cost savings must be sufficient to pay for the incremental vehicle cost and loss of handling flexibility.

Narrow-Aisle Vehicles

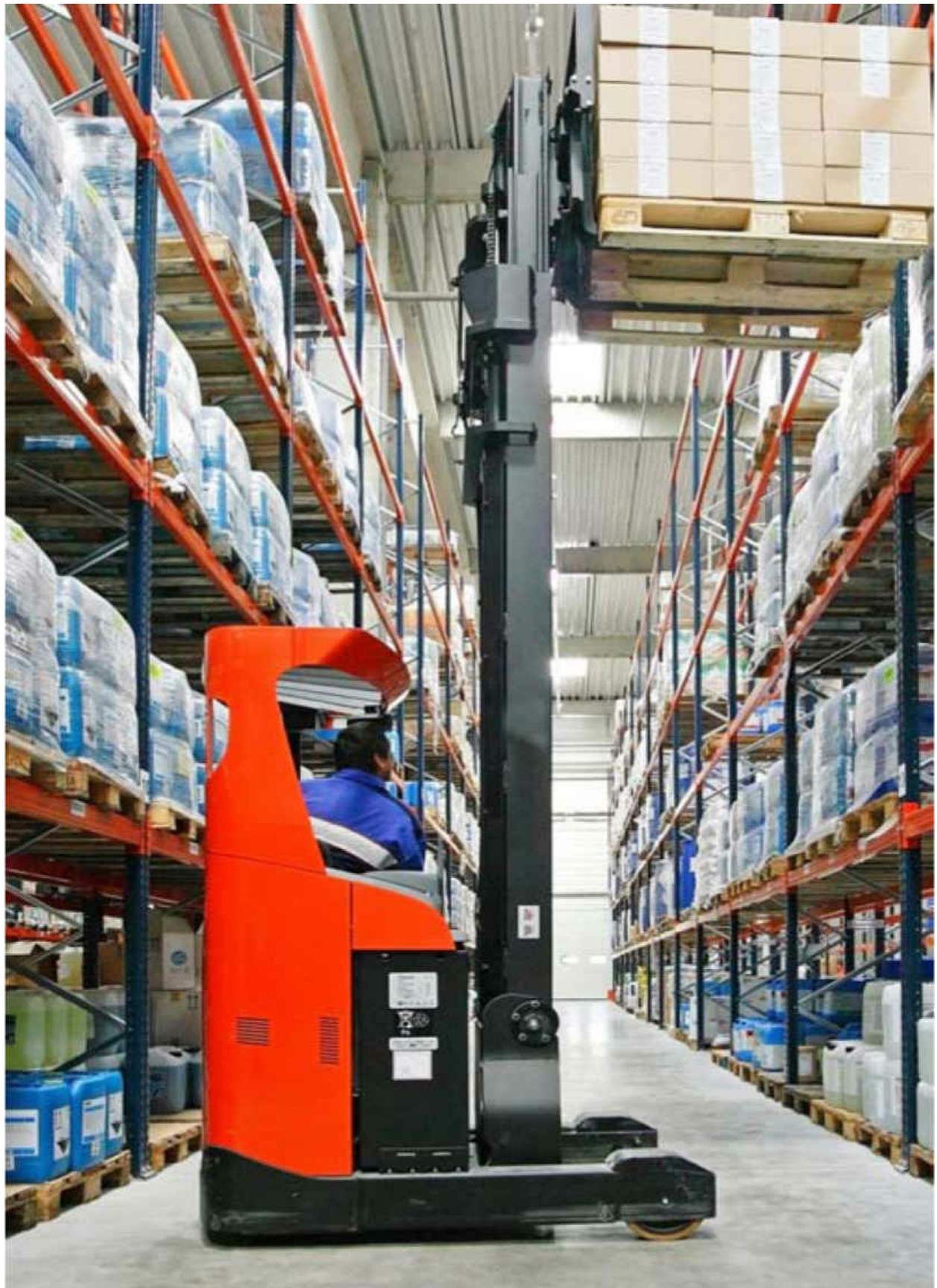
Straddle trucks, straddle reach trucks, and side-loader trucks are classified as narrow-aisle vehicles.

Straddle Trucks A *straddle truck* (Figures 5.34 and 5.35) provides load and vehicle stability using outriggers to straddle the pallet load instead of a counterbalanced weight. As a result, the aisle width requirement is 8 to 10 feet as opposed to the 11 to 12 feet required by a counterbalance truck. To access loads in storage, the outriggers are driven into the rack, allowing the mast to come flush with the pallet face. Hence it is necessary to support the floor-level load on rack beams.

Figure 5.34 Straddle truck in a Caterpillar DC. Georgia.



Figure 5.35 Straddle truck.



Straddle Reach Trucks *Straddle reach trucks* ([Figures 5.36](#) and [5.37](#)) were developed from conventional straddle trucks by shortening the outriggers on the straddle truck and attaching a scissors reach mechanism. In so doing, the outriggers do not have to be driven under the floor-level load to allow access to the storage positions. Hence no rack beams are required at floor level, conserving rack cost and vertical storage space.

Figure 5.36 Straddle reach truck.



Figure 5.37 Straddle reach truck in a Sear's DC Georgia.



Side-Loading Trucks A *side-loading truck* ([Figure 5.38](#)) loads and unloads from one side, thus eliminating the need to turn in an aisle to access storage positions. There are two basic side-loader designs. Either the entire mast moves on a set of tracks transversely across the vehicle, or the forks project from a fixed mast on a pantograph.

Figure 5.38 Side-loading truck.



A typical aisle would be 6½ feet wide, rail or wire-guided. Side loaders

generally can access loads up to 40 feet high.

The major drawback of a side-loading truck is the need to enter the correct end of the aisle to access a particular location, thus adding to the time and complexity involved in truck routing.

The vehicle's configuration particularly lends itself to storing long loads in cantilever racks.

Very Narrow-Aisle Vehicles

Turret trucks and hybrid storage retrieval vehicles are classified as very narrow-aisle vehicles.

Turret Trucks *Turret trucks* ([Figures 5.39](#) and [5.40](#)) do not require the vehicle to make a turn within the aisle to store or retrieve a pallet. Rather, the load is lifted either by forks that swing on the mast, a mast that swings from the vehicle, or a shuttle fork mechanism.

Figure 5.39 Wire-guided turret truck in a Verizon distribution center Georgia.



Figure 5.40 Counterbalance turret trucks operate in very narrow aisles and are a hybrid of a traditional counterbalance lift truck with a turret front end. They are less expensive than conventional turret trucks but cannot operate at the reach height of conventional turret trucks.



Turret trucks provide access to load positions at heights up to 50 feet, and operate in aisles 5 or 6 feet wide, further increasing storage density. Turret trucks generally have good maneuverability outside aisles, and some with telescoping masts may be driven into trailers. The vehicle may be wire or rail guided.

Hybrid Storage/Retrieval Vehicles A *hybrid storage/retrieval vehicle* (Figure 5.41) evolved from the design of an automated storage and retrieval machine used in automated storage/retrieval systems. Unlike the automated machine, the hybrid truck is not captive to an aisle but may leave one aisle and enter another. Present models are somewhat clumsy outside aisles, but they operate within aisles at a high throughput rate.

Figure 5.41 Hybrid storage/retrieval truck at the U.S. Defense Logistics Agency Pennsylvania.



Hybrid storage/retrieval vehicles operate in aisle widths ranging from 5 to 7 feet and access rack storage up to 60 feet high in a rack-supported building. The lack of flexibility, the high capital commitment, and the high dimensional tolerance in the rack are the disadvantages of hybrid storage/retrieval vehicles.

Automated Vehicles

Automated pallet handling systems include automated storage and retrieval systems (ASRSs) and automated guided storage and retrieval vehicles (AGSRVs).

Automated Storage/Retrieval Systems An *automated storage/retrieval system* ([Figures 5.42](#) through [5.45](#)) for pallets is commonly referred to as a *unit-load ASRS*. It is defined by The Material Handling Institute as a storage system that uses fixed-path storage and retrieval machines running on one or more rails between fixed arrays of storage racks ([Figures 5.42](#) through [5.45](#)).

Figure 5.42 Automated storage and retrieval systems in Argos' London distribution center.

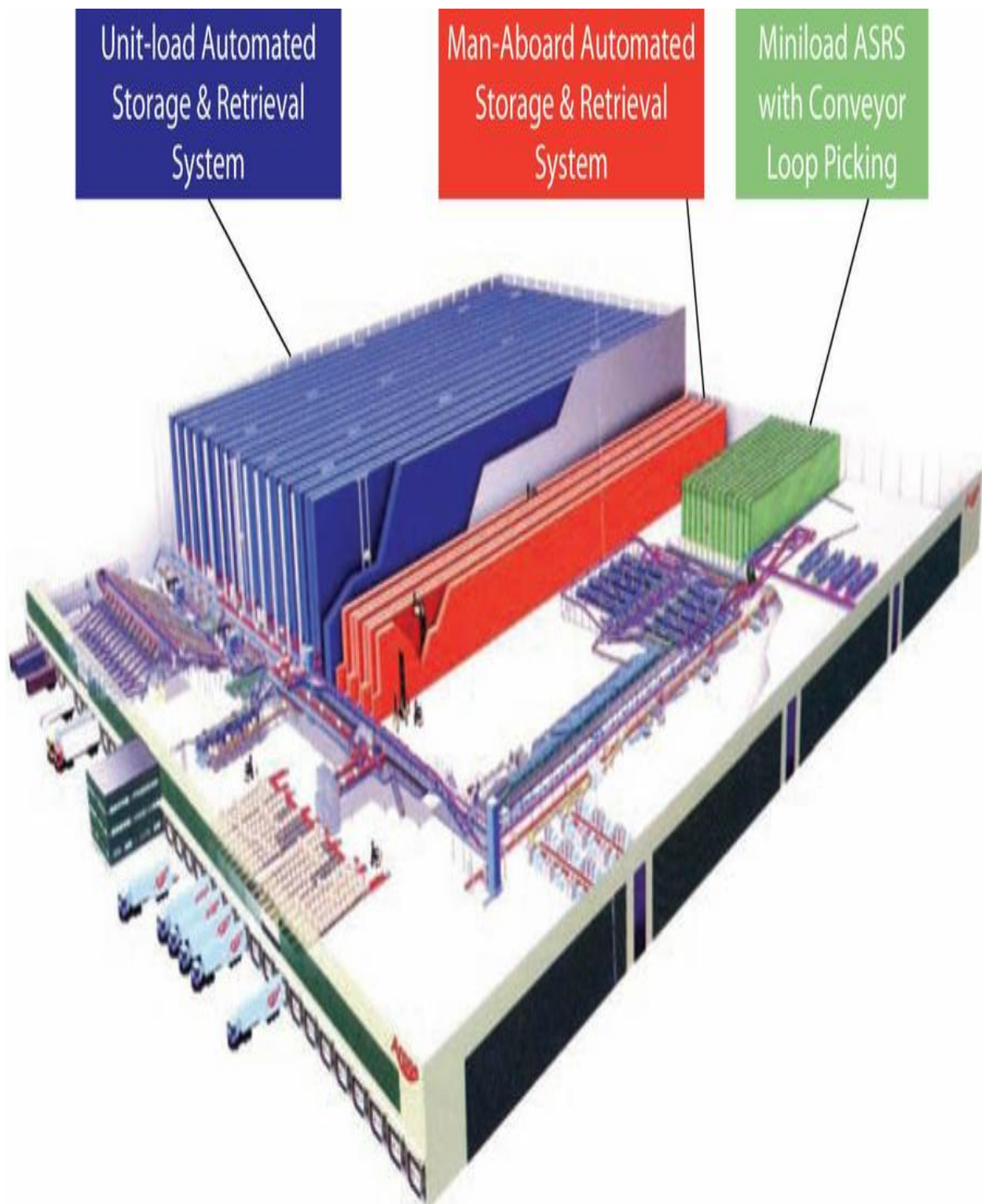


Figure 5.43 ASRS input-output front end in a Netto warehouse (Copenhagen, Denmark).



Figure 5.44 Rack-supported ASRS building at Rittal, Ohio.



Figure 5.45 A peek down the aisle of a pallet automated storage and retrieval system.



A unit-load ASRS usually handles loads in excess of 1,000 pounds and is used for raw materials, work-in-process, and finished goods. A typical ASRS operation has the storage/retrieval machine picking up a load at the front of the system, transporting the load to an empty location, depositing the load in the empty location, and returning empty to the input-output (I/O) point. These single command operations accomplish either a storage OR a retrieval between successive visits to the I/O point. A dual command has the storage/retrieval machine picking up a load at the I/O point, traveling loaded to an empty location (typically the closest empty location to the I/O point), depositing the load, traveling empty to the location of the desired retrieval, picking up the load, traveling loaded to the I/O point, and depositing the load. In a dual-command operation, two operations, a storage and a retrieval, are accomplished between successive visits to the I/O point.

A unique feature of storage/retrieval machine travel is that vertical and horizontal travel occurs simultaneously. Consequently, the time to travel to any destination in the rack is the maximum of the horizontal and vertical travel times required to reach the destination from the origin.

The typical unit-load ASRS configuration, if there is such a thing, would include unit loads stored one deep (i.e., single deep) in long, narrow aisles, each of which contains a single storage/retrieval machine. The one I/O point would be located at the lowest level of storage and at one end of this system.

More often than not, one of the parameters defining the system is atypical. The possible variations include the depth of storage, the number of storage and retrieval machines assigned to an aisle, and the number and location of I/O points.

Automated Guided Storage/Retrieval Vehicles *Automated guided storage/retrieval vehicles* are essentially driverless counterbalance trucks (Figures 5.46 and 5.47). Automated storage/retrieval vehicles receive communication through and run on a grid of wires buried a fraction of an inch beneath the surface of the warehouse floor. Automated storage/retrieval vehicles are rare but can be justified when wage rates are high, when labor is scarce, and when move rates are high and stable, over predictable paths.

Figure 5.46 Automated storage/retrieval vehicle.



Figure 5.47 Driverless counterbalance lift truck at Kirin (Osaka, JAPAN).



Pallet Handling Systems Comparison and Selection

[Table 5.2](#) presents a summary comparison of the key features of pallet

handling systems.

Table 5.2 Pallet Handling Systems Comparison.

		Lift Height Capacity (feet)		Aisle Width Required (feet)				
Vehicle Class	Vehicle Type	Low	High	Low	High	Travel Speed (ft/min)	Lift Speed (ft/min)	Load and Unload?
Conventional	Walkie stacker	5	15	8	10	250	50	Yes
	Counterbalance	15	25	9	12	560	80	Yes
Narrow aisle	Straddle truck	25	35	8.5	10	470	60	Some
	Straddle reach truck	25	35	8.5	10	490	60	Some
Very narrow aisle	Side-loader truck	35	45	7	8	440	50	No
	Turret truck	40	60	5.5	7	490	75	No
	Hybrid storage/retrieval vehicle	50	70	5	6	490	60	No
Automated	ASRS machine	50	120	5.5	5	600	100	No
	ASRS vehicle	8	12	5	6.5	500	70	Some

5.3 Pallet Storage and Handling Systems Selection

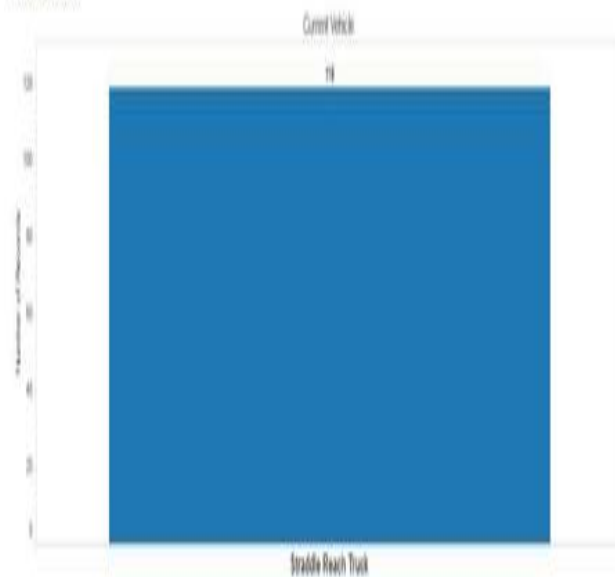
Pallet storage and retrieval systems should be selected in conjunction with one another to provide high-storage density and high storage/retrieval throughput capacity. Because each item has unique demand and dimensional profiles, and because each storage/retrieval system provides different storage/handling capabilities, the key is to optimally determine the proper storage/retrieval combination for each item. To assist our clients in making this determination, we developed the RightStore Pallet Optimization, which computes the lowest cost storage/retrieval alternative for each item in the warehouse, taking into consideration the cost of space, labor, racking, and equipment. An example analysis from a recent client engagement is provided

in [Figure 5.48](#). The RightStore™ solution yielded \$847,000 in annual savings; a 28% reduction in total storage cost.

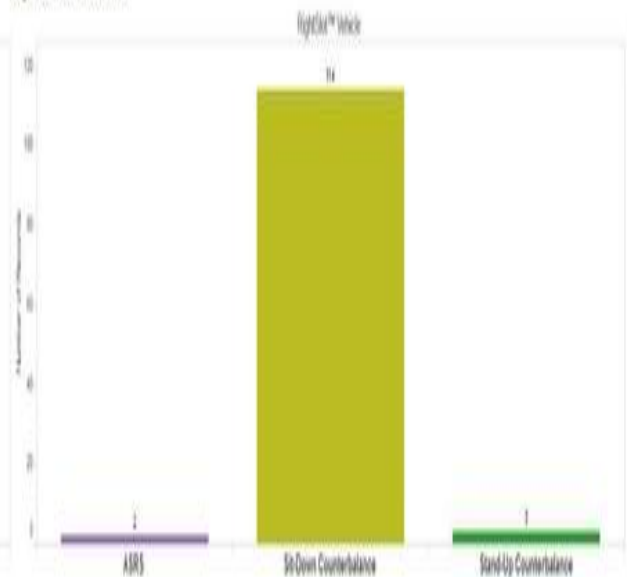
Figure 5.48 This RightStore pallet optimization completed for a large consumer products company recommends sit-down counterbalance trucks, stand-up counterbalance trucks, and ASRS machines, as opposed to the company's straddle-reach trucks. For storage we recommend a mix of floor storage and single-deep, six-high storage as opposed to the company's current double-deep storage configuration.

RightStore™ | Storage Mode Optimization | Pallets

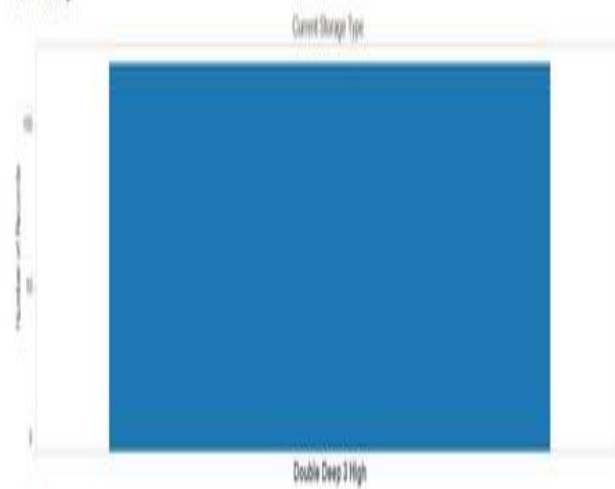
Current Vehicles



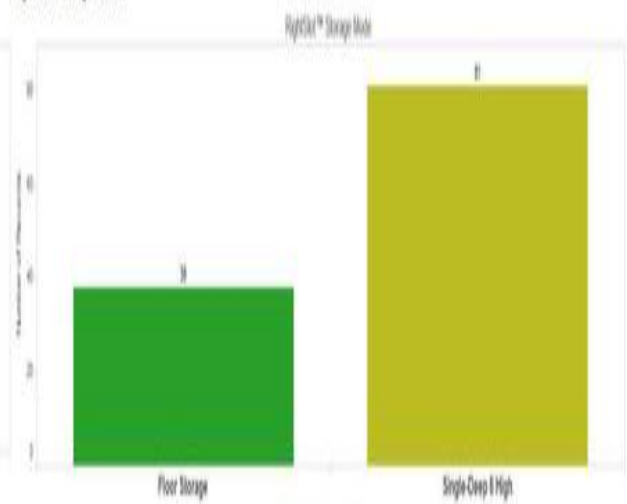
RightStore™ Vehicle Solution



Current Storage



RightStore™ Storage Solution



CHAPTER SIX

CASE PICKING SYSTEMS

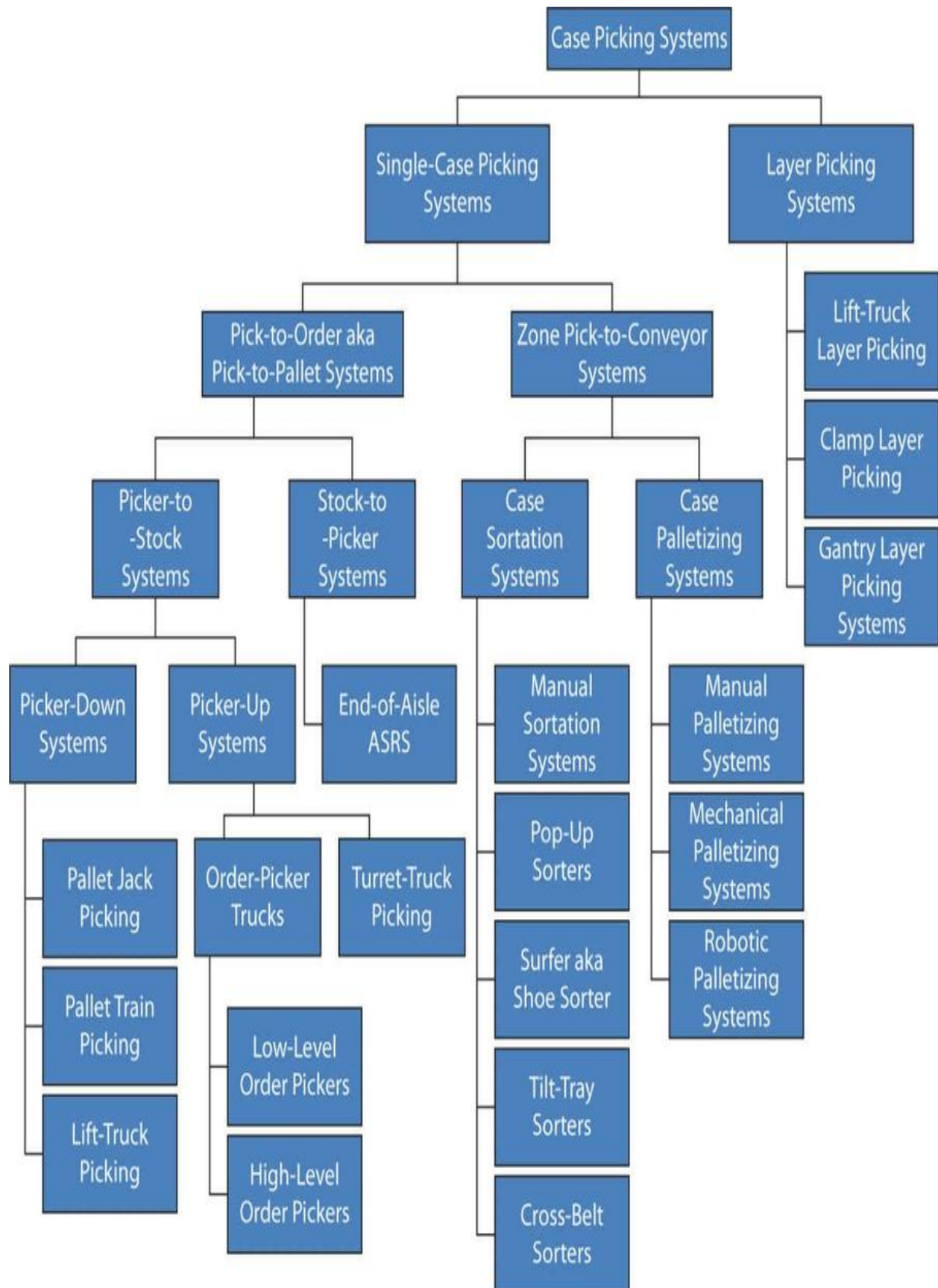
6.1 Pick-to-Order/Pallet Systems

6.2 Zone Pick-to-Conveyor Systems

6.3 Layer Picking Systems

In our RightHouse taxonomy of case picking systems ([Figure 6.1](#)), we first classify case picking systems as to whether or not a single case is selected (single-case picking systems) or an entire layer (layer picking systems).

Figure 6.1 RightHouse taxonomy of case picking systems.



We classify single-case picking systems as pick-to-order/pallet or zone pick-to-conveyor systems. In pick-to-order/pallet systems all the cases for an entire order are picked onto a pallet at a pick face. In zone pick-to-conveyor systems order pickers are assigned to zones and pick cases onto a conveyor with no concern for which order the cases may belong to. As a result, a downstream sorting system is required to sort cases into their outbound orders, and a downstream palletizing system is required to stack cases on pallets when palletization is required.

6.1 Pick-to-Order/Pallet Systems

In *pick-to-pallet systems*, an order picker travels with a shipping pallet to a pick face and palletizes while picking. The advantage is the elimination of any downstream rehandling of cases for sorting and/or palletizing. The disadvantage is the loss of handling productivity at the pick face.

We further classify pick-to-pallet systems as either picker-to-stock systems, wherein a human or robot picker travels to the stock location or stock-to-picker systems, wherein an automated storage and retrieval machine brings pallets to a human or robot stationed at the end of an aisle.

Picker-to-Stock Systems

Picker-to-stock systems can be classified as (1) picker-down systems, (2) picker-up systems, and (3) automated systems.

Picker-Down Systems As the name implies, in *picker-down systems*, human or robot pickers work at floor level, averting the potentially catastrophic consequences of a fall and avoiding the productivity losses inherent to vertical travel. Picker-down case picking systems include (1) pallet-jack picking, (2) pallet-train picking, and (3) lift-truck picking.

Pallet-Jack Picking A *pallet jack* ([Figures 6.2](#) and [6.3](#)) is a motorized vehicle equipped with forks to transport pallets at floor level. The operator

typically rides on the front of the vehicle, with the pallet secured by the forks on the back of the vehicle. A double-pallet jack carries two pallets at a time and allows the operator to pick more than one order at a time. Pallet jacks are by far the most popular method for case picking. They are so common in the grocery industry that pallet-jack picking is often referred to as the *grocery picking method*. Typical pallet-jack picking rates range between 100 and 300 cases per person-hour.

Figure 6.2 Pallet-jack picking at the American Cancer Society's National Logistics Center, Atlanta, Georgia.



Figure 6.3 Double-pallet-jack voice picking at Oxxo's Monterrey, Mexico, distribution center.



The advantages of pallet-jack picking are low capital investment, simplicity, operating flexibility, and safety. Pallet jacks may be equipped with on-board computing, printing, and housekeeping apparatus.

Driverless automated guided pallet jacks ([Figure 6.4](#)) automatically stop at each pick location.

Figure 6.4 Automated guided pallet jack in case picking (Cisco-Eagle).



Pallet Trains A train of pallets ([Figures 6.5 through 6.7](#)) can be pulled behind a motorized vehicle to further increase the number of pallets or orders on a case picking tour. Pallet trains allow the operator to pull three or more pallets increasing the stops per tour, reducing the travel time between successive stops, and increasing operator productivity. One disadvantage of pallet trains is maneuverability – the difficulty in maneuvering a train through narrow aisles and maneuvering around a train while it is stopped in an aisle.

Figure 6.5 Pallet-train picking at Honda’s national parts distribution center.

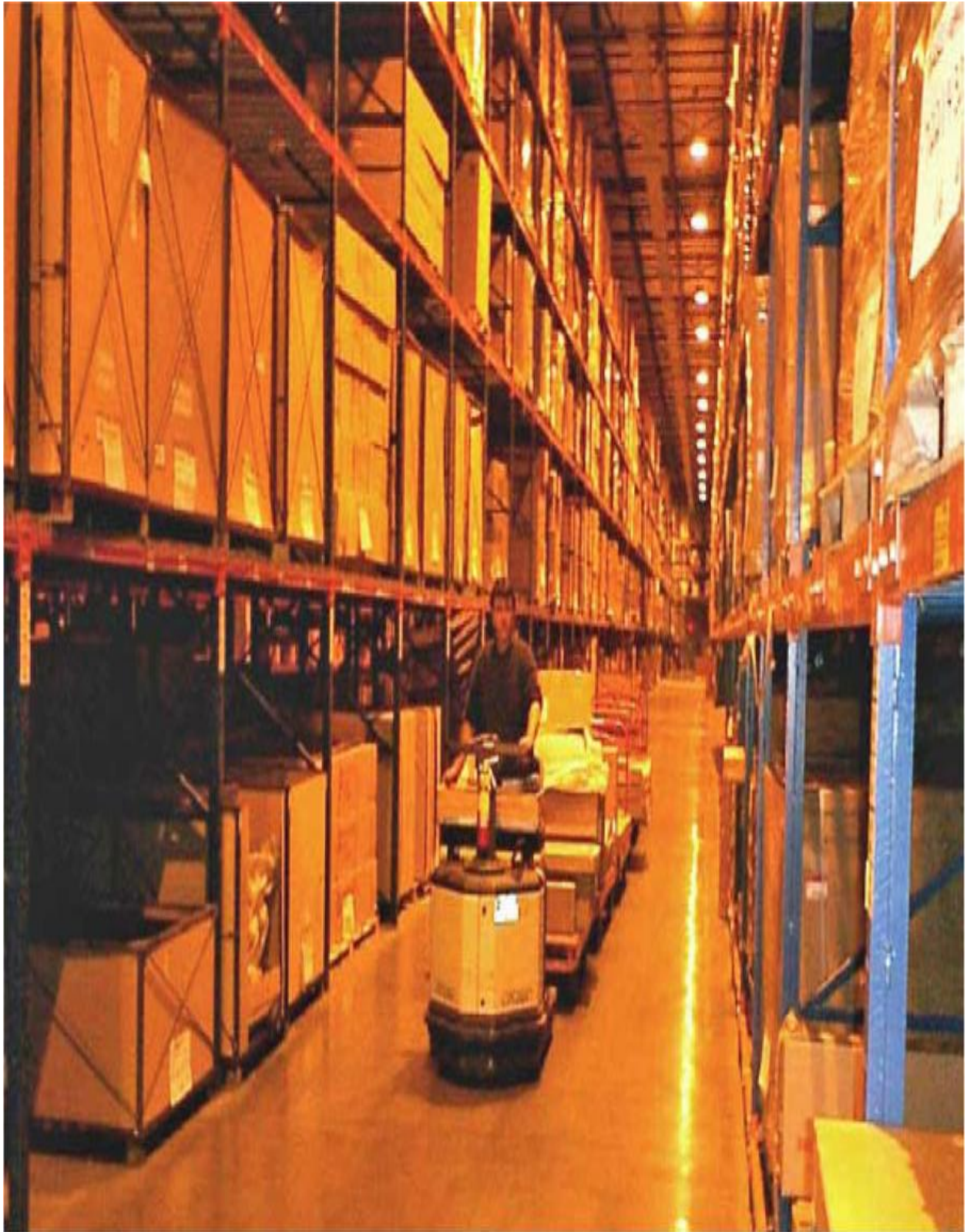


Figure 6.6 Case picking pallet trains at Happinet's retail distribution

center (Tokyo, Japan).



Figure 6.7 Automated guided pallet train (Creform).



Lift-Truck Picking Lift trucks ([Figure 6.8](#)) are often overlooked as an option for case picking operations. Lift trucks are ideally suited to many case-picking operations because the forks can be used to position the top of the pallet near the operator's waist level, to maneuver at high speed over long distances in the warehouse, and to load outbound trailers ([Figure 6.8](#)).

Figure 6.8 Lift-truck picking in Suntory's Tokyo distribution center.



Picker-Up Systems As the name implies, *picker-up systems* lift the operator to pick cases at the second pallet rack level and higher. Picker-up case picking systems include order-picker trucks and turret trucks.

Order-Picker Trucks Order-picker trucks lift an order picker off floor level as many as five levels high and are equipped with on-board forks to house picking pallets. Low-level order pickers lift the operator to the second and sometimes third levels. High-level order pickers reach the fourth and sometimes fifth levels.

Low-Level Order Pickers Low-level order pickers ([Figures 6.9 through 6.11](#)) are easy to maneuver, inexpensive, and lift case picking operators safely to the second and sometimes third levels of pallet storage. Forks move up and down on the back to permit waist-level palletizing.

Figure 6.9 Low-level order picker (Atlet).



Figure 6.10 Low-level order picker (Caterpillar).

Figure 6.11 Low-level order picker (Atlet).



High-Level Order-Picker Trucks High-level order-picker trucks ([Figures](#)

6.12 and 6.13), sometimes referred to as *stock pickers*, lift the order picker to pick locations well above floor level. Because vertical travel is much slower than horizontal travel, and because the operator must precisely position the vehicle in front of the pick location, the productivity of an order-picker truck is only in the range of 50 to 100 cases per person-hour. (The productivity can be enhanced by minimizing vertical travel through popularity-based storage and/or intelligent pick tour construction.) Hence high-level order-picker trucks are usually employed for picking slower-moving items and where high-density storage is required.

Figure 6.12 Order-picker truck at the American Cancer Society's National Logistics Center, Atlanta, Georgia.



Figure 6.13 High-level case order picking at L.L. Bean.



Turret Truck Picking Turret trucks can be used like order-picker trucks for case picking, permitting case pick operators to work in narrow aisles even six to eight levels high. While the storage density provided by turret-truck picking is high, picking productivity is fairly low, with case picking rates ranging from 25 to 75 cases per person-hour.

Figure 6.14 Turret-truck case picking.



Stock-to-Picker Systems

Though rare, automated storage and retrieval systems ([Figures 6.15 through 6.17](#)) can be used to automatically convey pallet quantities to stationary human or robotic pickers at the end of an automated storage and retrieval system aisle. The operator at the end of the aisle transfers the required number of cases from the storage pallet to the order pallet. Both pallets can be positioned such that the top of the pallet is at or near waist level. The advantages include high storage density of the storage pallets, excellent ergonomics, and high picking productivity. The disadvantages are the high degree of mechanization required and the associated capital investment and control complexities.

Figure 6.15 End-of-aisle ASRS case picking at Netto (Copenhagen, Denmark).



Figure 6.16 Robotic case picking at the end of an ASRS aisle.

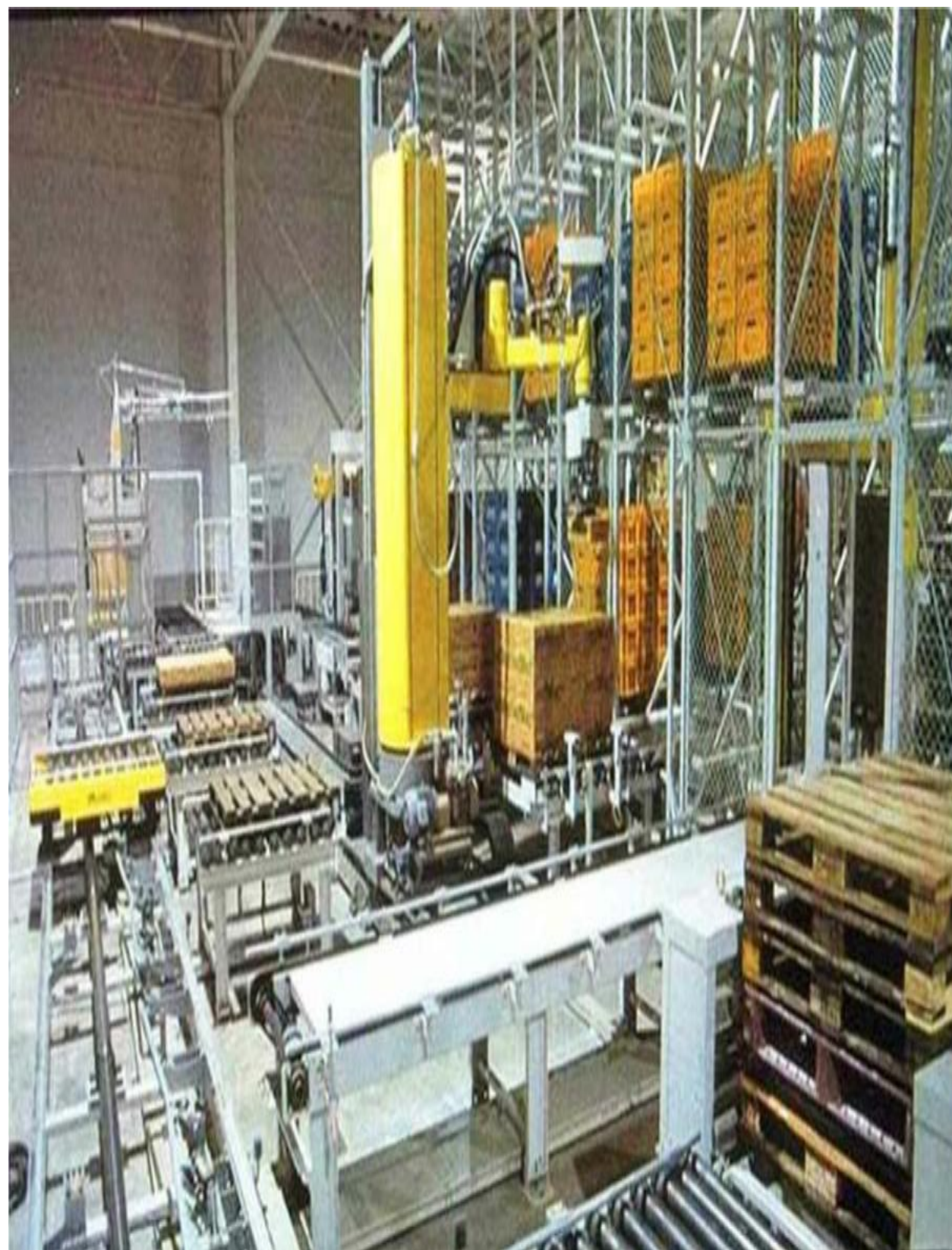
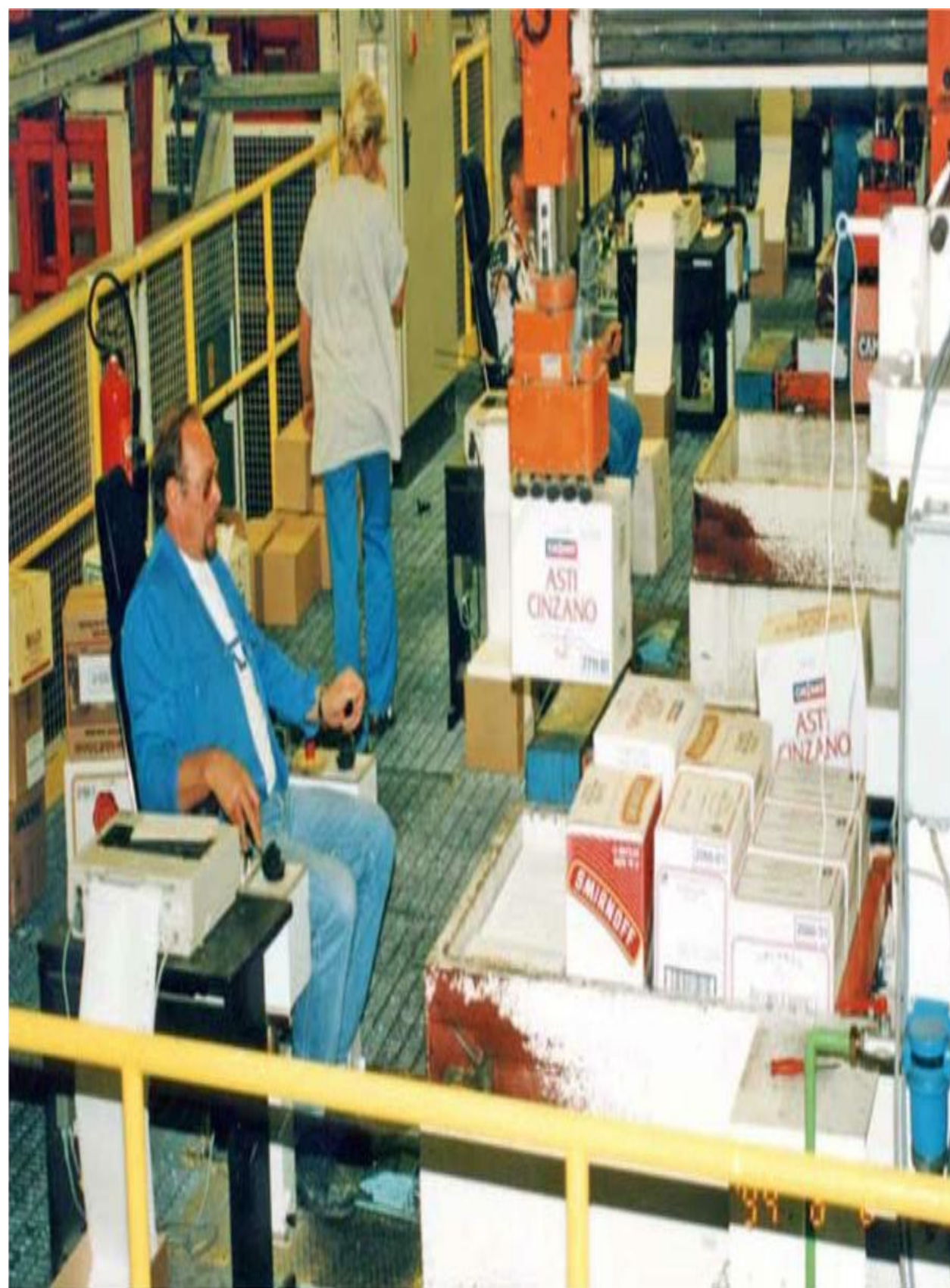


Figure 6.17 Robotic case picking and palletizing at the end of an ASRS aisle at Netto (Copenhagen, Denmark).



6.2 Zone Pick-to-Conveyor Systems

In zone pick-to-conveyor operations ([Figures 6.18](#) and [6.21](#)), a belt or roller conveyor runs the length of a case picking line, a human or robotic order pickers traverse the line removing cases from pallet storage locations and placing them on a take-away belt or roller conveyor. Typically, an operator applies a bar-code label to each case as he or she (or it) removes it from its storage location. The bar-code label is used for carton identification and downstream sorting of each case into its customer order.

Figure 6.18 Zone case pick-to-conveyor inside a case picking tunnel.



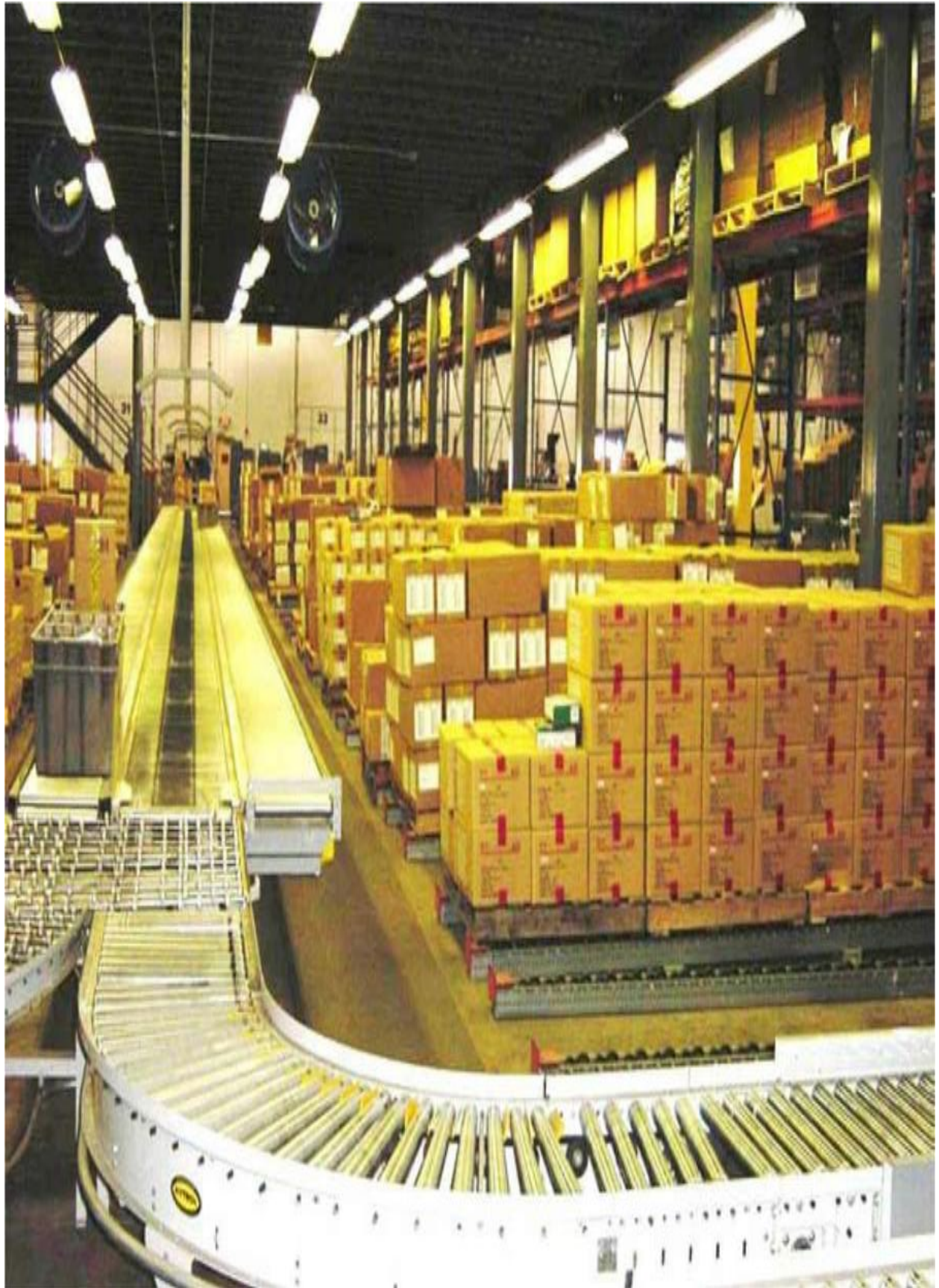
Figure 6.19 Case pick-to-conveyor operation.



Figure 6.20 Case pick to belt at a BIC finished goods distribution center.



Figure 6.21 Case pick-to-conveyor at Verizon's East Coast distribution center.



The advantage of pick-to-conveyor over pick-to-pallet operations is a substantial increase in pick face productivity, reduced travel between picks, and elimination of palletizing during picking. The disadvantage is the downstream sorting and palletizing. Hence there must be enough incremental pick face productivity to pay for the additional handling steps and mechanization.

In most pick-to-conveyor systems, cases must be sorted into outbound orders before they are palletized or loaded directly onto outbound trailers.

Pick Tunnels

Case pick-to-belt operations are often configured as *picking tunnels*—two-, three-, or four-level mezzanines built into high-bay racking configurations with belt conveyors running down the center of each mezzanine. Pallets are typically fed to the pick face along a pallet flow rack to the picking tunnel from a narrow aisle ([Figures 6.22](#) and [6.23](#)).

Figure 6.22 ASRS-fed case picking tunnels with human order pickers.

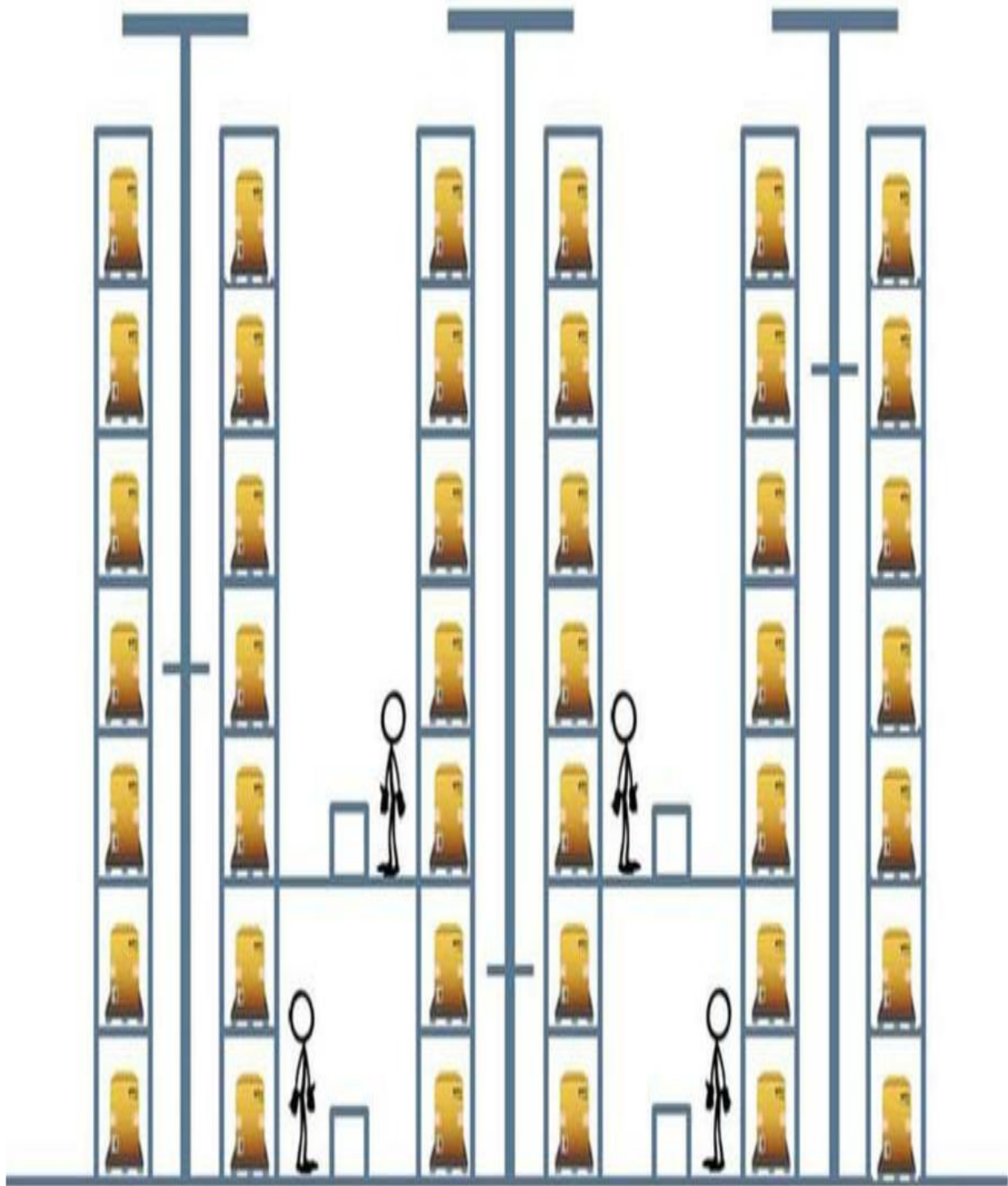
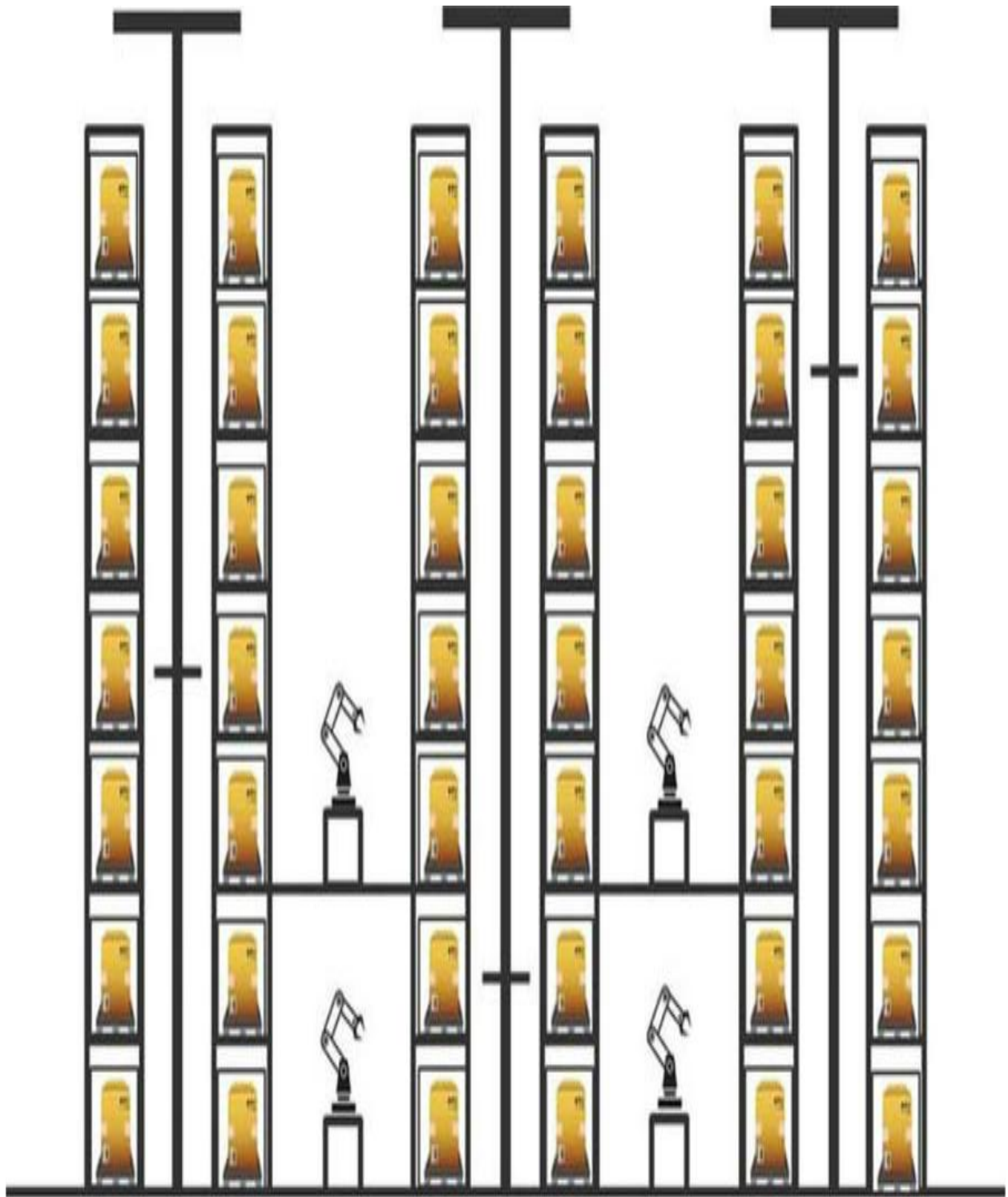


Figure 6.23 ASRS-fed case picking tunnels with robotic order pickers.



Case Sorting Systems

Sorting systems are used for merging, identifying, inducting, and separating

products for conveyance to unique destinations. Sorting systems are comprised of three subsystems—a merge subsystem consolidating an induction subsystem, and a sorting subsystem. We focus here on the sorting subsystem.

Sorting systems can be classified as manual sorting systems, diverter sorters (sweepers, rakes, and pusher bars), pop-up sorters (pop-up wheels and belts), surfer sorters, tilting sorters (trays and slats), and cross-belt sorters. They are all used in conveyor systems to divert labeled cases into their appropriate accumulation lane.

Manual Sorting In manual sorting systems ([Figure 6.24](#)), a human operator identifies cases on an accumulation conveyor and sorts them onto outbound order pallets or roll cages.

Figure 6.24 Manual sorting of outbound cartons into roll cages for store order delivery. (Tokyo, Japan)



Diverter Sorters According to the Material Handling Institute, diverter sorters are “stationary or movable arms that deflect, push, or pull a product to the desired destination.” Because the divert mechanism does not come in contact with the conveyor, it can be used with almost any flat-surface conveyor. Diverter sorters ([Figure 6.25](#)) are usually hydraulically or pneumatically operated but also can be motor driven. Diverter sorters are simple to operate, require little maintenance, and are relatively inexpensive. Diverter sorters are not recommended for fragile merchandise.

Figure 6.25 A diverter sorting system in a large industrial products distribution center.



Pop-up Sorters Pop-up sorters ([Figure 6.26](#)) are comprised of one or more rows of powered rollers, wheels or chains that pop up above the surface of a conveyor to lift product and guide it off the conveyor at an angle. Pop-up

mechanisms are lowered when products do not need to be diverted and are only capable of sorting flat-bottomed items. Pop-up rollers are generally faster than pop-up wheels.

Figure 6.26 Pop-up sorter at Nike's European distribution center. (Amsterdam, Netherlands).



Surfer Sorters Surfer sorters ([Figures 6.27](#) through [6.29](#)) employ a series of diverter slats that slide across the horizontal surface to engage product and guide it off the conveyor into its accumulation lane. Slat move from side to side as product flows in order to divert the product to either side Surfer sorters are gentle and gradually sort products.

Figure 6.27 Surfer sorter.



Figure 6.28 Surfer sorter in a large Japanese distribution center.

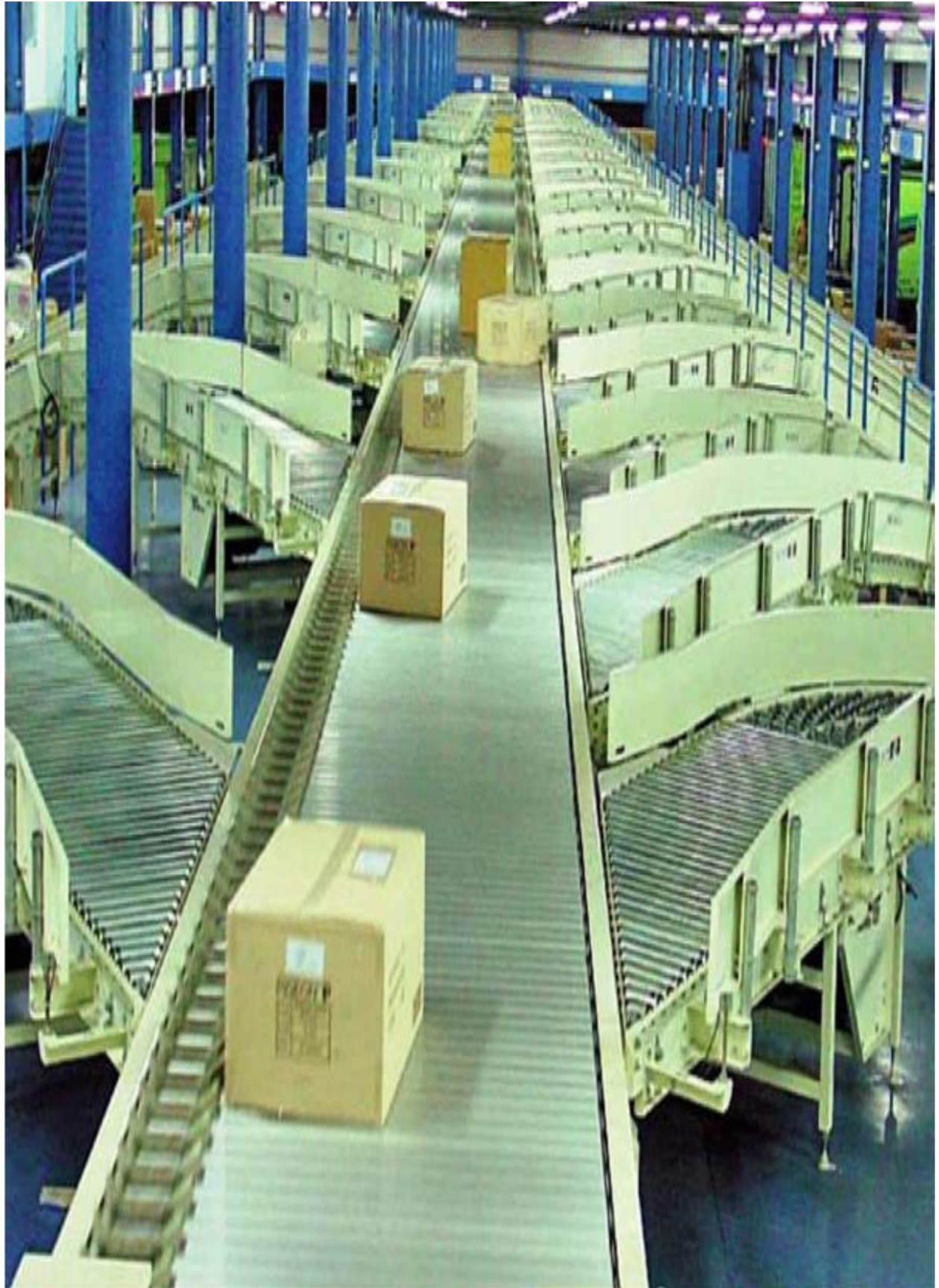


Figure 6.29 Surfer sorter in a Happinet distribution center (Tokyo, Japan).



Tilt-Tray Sorters Tilting sorters are comprised of trays or slats that provide sorting and transportation. Tilt-tray sorters ([Figure 6.30](#)) are usually designed in continuous loops in a compact layout with recirculation capability.

Figure 6.30 Tilt-tray case sorter at Netto, Copenhagen, Denmark.



Cross-Belt Sorters Each carriage on a cross-belt sorter ([Figures 6.31 and 6.32](#)) is equipped with a small belt conveyor, called a *cell*. The cell is mounted perpendicular to the direction of travel of the loop and discharges cases at their destinations. Cross-belt sorters operate in *continuous loops*, or as *trains*.

Figure 6.31 Cross-belt sorter.



Figure 6.32 Cross-belt sorter induction.



Case Sorting System Comparison and Justification Table 6.1 compares a range of sorting systems. The systems increase in complexity and expense moving from left to right in the table.

Table 6.1 Case Sorting Comparison.

Factor	Manual	Push Divert	Pull Divert	Pop-up Wheels	Pop-up Rollers	Surfer	Tilt Tray
Minimum sorts/min	15	30	30	65	15	50	65
Maximum sorts/min	25	35	40	150	20	150	300
Maximum load weight	75	75	100	300	200	200	300
Minimum distance between spurs	0	5	2	4	0	4	2
Diverter load impact	Gentle	Medium	Rough	Gentle	Gentle	Gentle	Rough
Initial cost	Lowest	Medium	High	High	Low	High	Highest
Maintenance cost	Lowest	Low	Medium	Medium	Low	High	Highest

An example sorting system justification provided for a recent e-fulfillment client is provided in Figure 6.33. This particular sorter investment was \$5 million and yielded \$3.4 million in annual savings with a payback

period of 1.47 years.

Figure 6.33 RightSort analysis for a large e-fulfillment company.

RightSort™ Justification

[edfrazee@rightchain.com](#)

File Edit View Insert Format Data Tools Add-ons Help Last edit was made on June 1 by Ed Frazee

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	A	B	C	D + F	G	H	I + K	L	M	N
1										
2		Baseline		Avg	Sorter		Avg	Year	Cash Flow	
3		ACTIVITY	Rate (upmh)	FTEs	ACTIVITY	Rate (upmh)	FTEs	0	(\$6,000,000)	
4		Replen Flow Rack	10,000	7	Case Induct	5,700	12	1	\$3,409,043	
5		Pick & Pack	376	188	Piece Induct	2,000	35	2	\$3,409,043	
6		Check	5,000	14	Pack & Seal	1,120	63	3	\$3,409,043	
7		Tray & Box Prep		5	Tray & Box Prep		12	4	\$3,409,043	
8		Returns	200	28	Returns Induction	1,200	5	5	\$3,409,043	
9					Returns Packing	550	10			
10		Maintenance		1	Maintenance		4			
11		Total FTEs		233	Total FTEs		141	Payback	1.47	
12										
13		Annual Labor Cost	\$6,995,106		Annual Labor Cost	\$4,218,876		Year	IRR	
14					Annual Savings	\$2,776,231		1	-32%	
15								2	23%	
16		Order Accuracy	96.0%		Order Accuracy	99.5%		3	48%	
17		Bad Orders Per Yr	46,875		Bad Orders Per Yr	4,688		4	57%	
18		Imperfect Order Cost	\$703,125		Imperfect Order Cost	\$70,313		5	62%	
19					Annual Savings	\$632,813				
20										
21		Square Feet	60,000		Square Feet	60,000		Year	NPV	
22		Annual Space Cost	\$334,200		Annual Space Cost	\$334,200		1	(\$4,196,667)	
23								2	(\$1,799,275)	
24		Total Annual Cost	\$8,032,431		Total Annual Cost	\$4,623,388		3	\$173,550	
25					Total Savings	\$3,409,043		4	\$1,817,572	
26								5	\$3,187,590	
27					Investment	\$5,000,000				
28										

Add 1000 more rows at bottom

Case Palletizing Systems

Once sorted into their order lanes, cases can be palletized manually, mechanically, or robotically.

Manual Palletizing Manual palletizing ([Figures 6.34](#) through [6.36](#)) is often the only technically or financially feasible palletizing alternative.

Computerized pallet loading systems are now available to instruct palletizers in the optimal configuration of pallet loads with a wide variety of carton dimensions. The best systems generate pictograms of the optimal pallet configuration. Lift and turn tables that keep the top of the shipping pallet at waist level significantly improve palletizing productivity and safety.

Figure 6.34 Manual palletizing.



Figure 6.35 Manual palletizing at Netto (Copenhagen, DENMARK).



Figure 6.36 Lift and turn table to support manual palletizing at the American Cancer Society's National Logistics Center.



Mechanical Palletizing A conveyor-based mechanical palletizing system is shown in [Figure 6.37](#). Mechanical palletizing systems are faster and safer than manual systems. They are much more expensive than manual systems and cannot work with the range of carton sizes of a manual palletizing system.

Figure 6.37 Mechanized palletizing at KAO's Iwatsuki City distribution center.



Robotic Palletizing Robotic palletizers ([Figures 6.38](#) and [6.39](#)) can service a variety of shipping pallets at a time, but they are not as fast as mechanical

palletizers.

Figure 6.38 Robotic tote palletizing at Boots Pharmacy, (London, England).



Figure 6.39 Robotic palletizing system.



Automated Case Dispensing

Automated case dispensing systems (Figures 6.40 and 6.41) fully automate single case picking. In some systems, cases are housed in gravity-flow racks. A shuttle table and a telescoping conveyor are attached to a vertical mast that travels on rails along the pick/put-away face. For put away, a transport conveyor feeds individual cases to the telescoping conveyor. The cases travel up and along the telescoping conveyor to the put-away location. The shuttle table rides up the mast to the put-away location. The telescoping conveyor feeds cases to the shuttle table, which, in turn, inserts cases in a gravity-flow rack lane. The picking process is the put-away process in reverse. The advantage of automated case dispensing is the complete elimination of human operators and the related labor and worker's compensation costs. Major drawbacks are the high maintenance requirements and the high initial investment. An automated case dispensing mechanism can dispense 500 to 700 cases per hour.

Figure 6.40 Automated case dispensing at KAO's Iwatsuki City distribution center.



Figure 6.41 Automated case dispensing ASRS at Otto's Munich distribution center.



6.3 Layer Picking Systems

Layer picking systems ([Figures 6.42 through 6.44](#)) mechanically extract an entire layer of cases from a pallet. There are a variety of mechanical approaches for layer picking, including lift-truck clamp attachments, vacuum suction, four-sided mechanical clamping, layer stripping conveyors (which literally lift up the front edge of the top layer and strip it away from the remaining layers), and gantry layer picking. The advantage of layer picking over other case picking methods is the total elimination of human handling and high case handling capacity. A typical layer picker can handle between 750 and 1,000 cases per hour. The disadvantages are the high degree of mechanization and the associated cost. As a result, layer pickers typically can be justified only when customers tend to order in high-volume layer quantities and when the cost of labor is high.

Figure 6.42 Case layer picking via lift-truck attachment in a Coca-Cola distribution center.



Figure 6.43 Gantry layer picking.

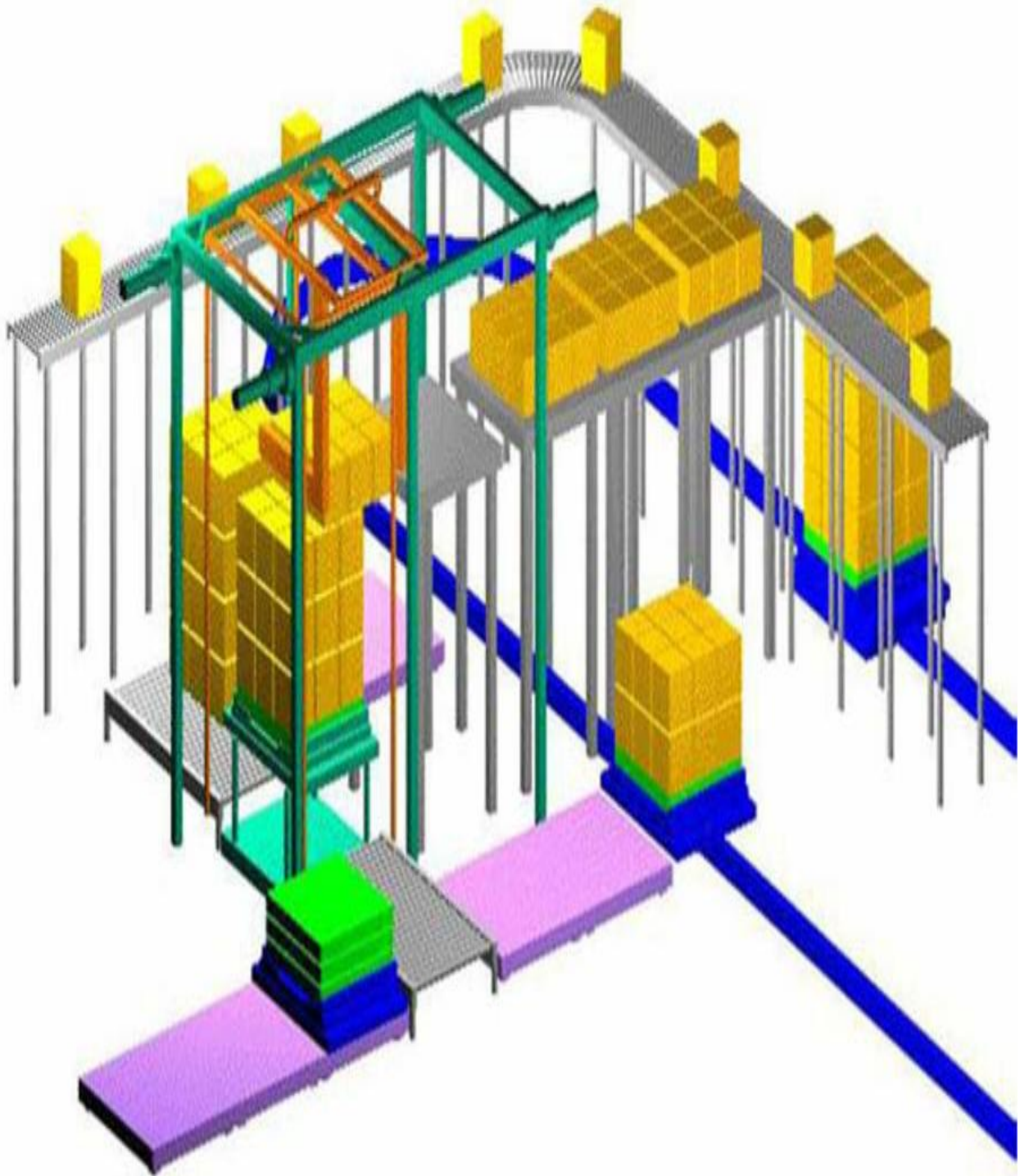
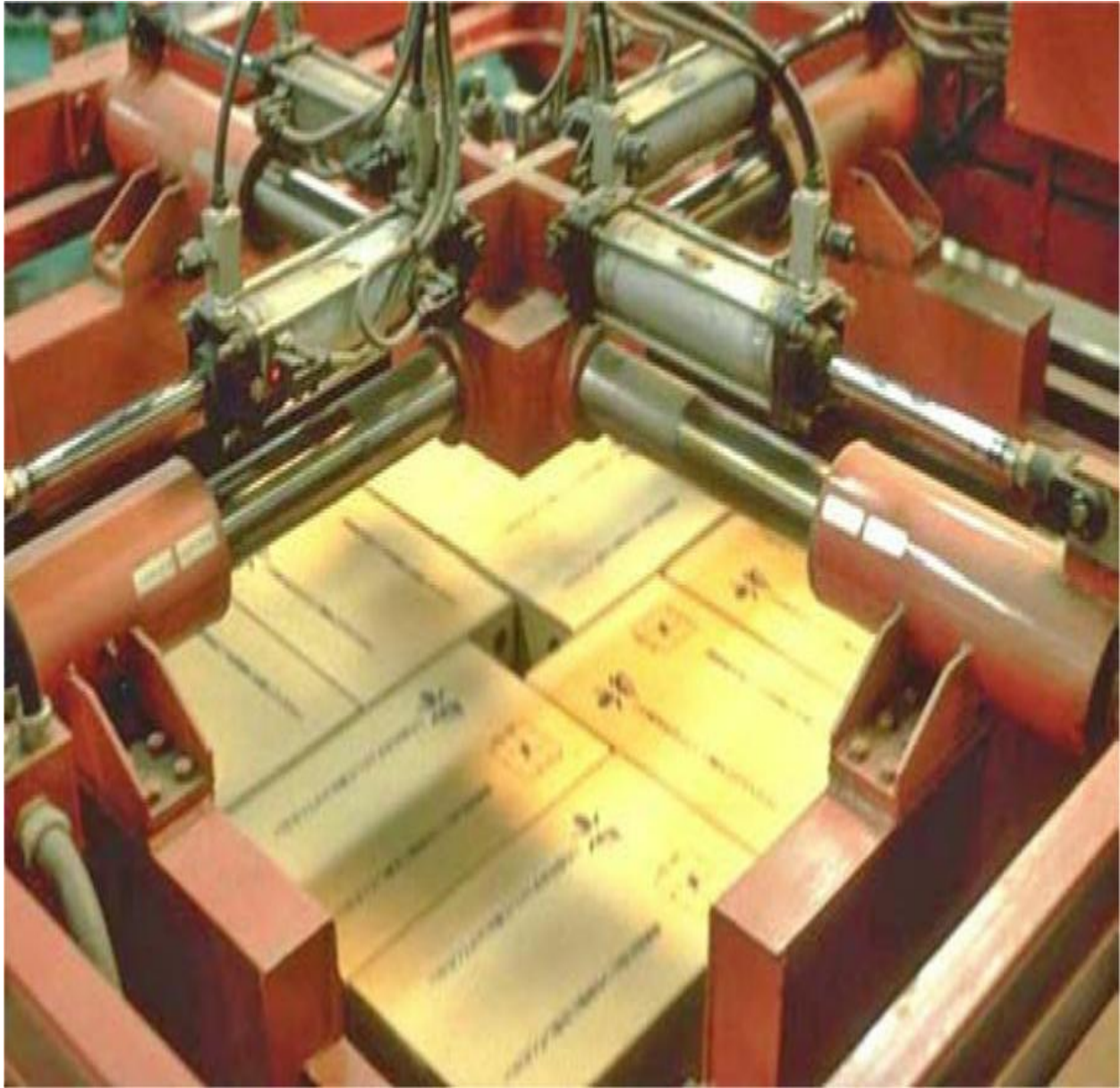


Figure 6.44 Automated clamp layer picking at KAO's Iwatsuki City distribution center.



CHAPTER SEVEN

BROKEN CASE PICKING SYSTEMS

7.1 Picker-to-Stock Systems

7.2 Stock-to-Picker Systems

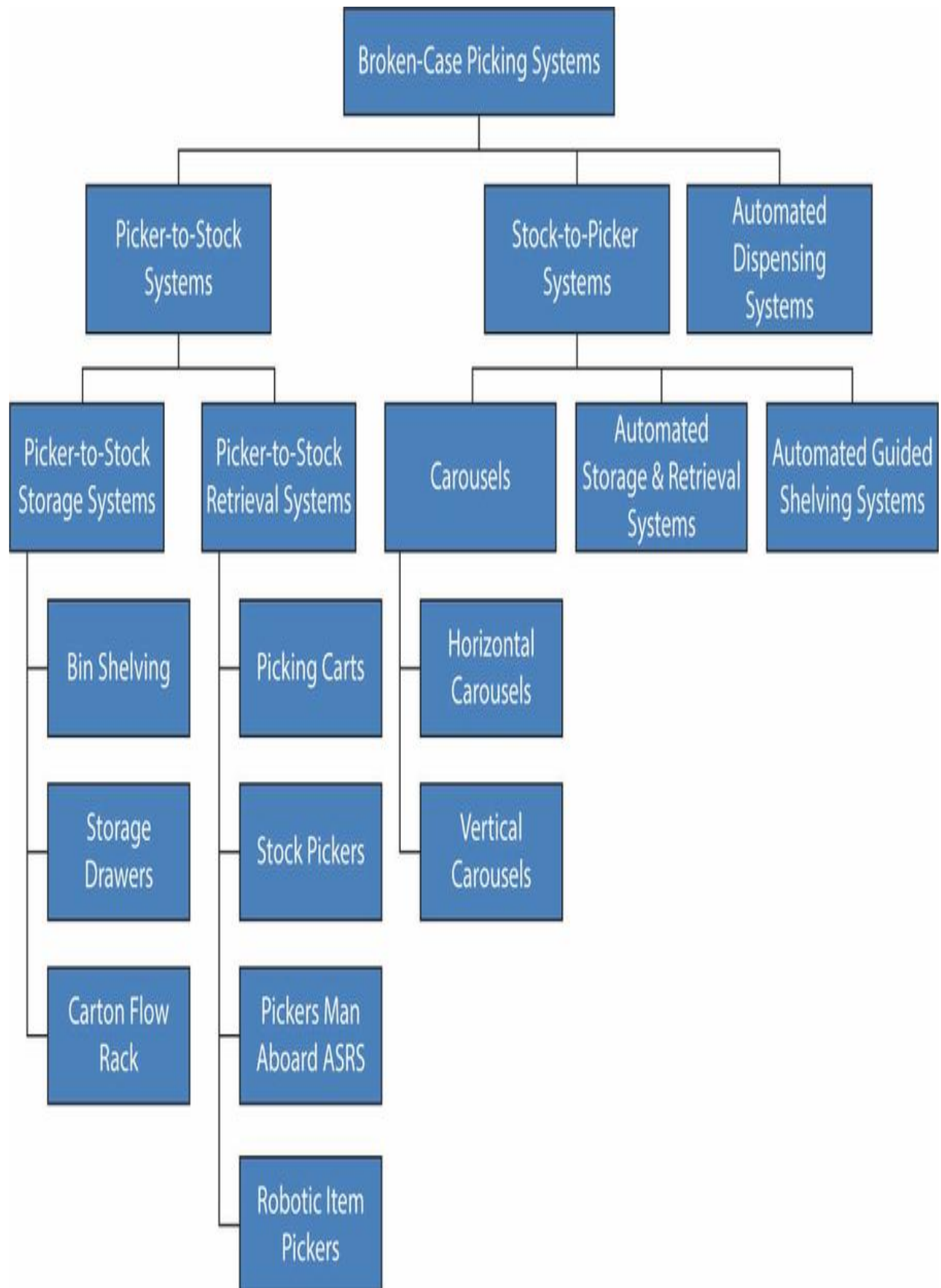
7.3 Automated Item Dispensing Systems

7.4 Broken-Case Picking Systems Comparison and Selection

Our RightHouse taxonomy ([Figure 7.1](#)) of broken-case picking systems classifies dispensing systems into picker-to-stock (PTS) systems, stock-to-picker (STP) systems, and automated item. In picker-to-stock systems, an order picker walks or rides to picking locations. In stock-to-picker systems, picking locations are mechanically transported (via carousel, automated storage and retrieval system, or AGVS) to stationary order pickers. In automated item dispensing items are automatically dispensed into shipping cartons or tote pans. This chapter describes the pros, cons, applications, and associated costs of each of these major system types. As in earlier chapters,

we will move through the system descriptions in order of increasing cost, complexity, and degree of automation. The chapter concludes with a description of the techniques for choosing from among the many equipment options for broken case picking systems.

Figure 7.1 RightHouse taxonomy of broken-case picking systems.



7.1 Picker-to-Stock Systems

In picker-to-stock systems, the order picker walks or rides to picking locations. The two subsystems that must be selected are the storage system and the item-retrieval system.

Picker-to-Stock Storage Systems

The three picker-to-stock storage systems are bin shelving, modular storage drawers, and carton-flow racks.

Bin Shelving Systems Bin shelving systems ([Figures 7.2 through 7.6](#)) are the oldest and still most popular alternative for small-parts order picking. Bin shelving is inexpensive, easily reconfigured, and requires minimal maintenance.

Figure 7.2 Typical bin shelving system.



Figure 7.3 Bin shelving system with corrugated inserts for small-parts picking.



Figure 7.4 Bin shelving with pick-to-light for video game picking in a large toy retailer's distribution center.



With bin shelving systems, savings in initial cost and maintenance may be offset by floor space requirements, labor requirements, and/or inadequate item protection.

Figure 7.5 Bin shelving with plastic inserts on a small-service-parts picking mezzanine.

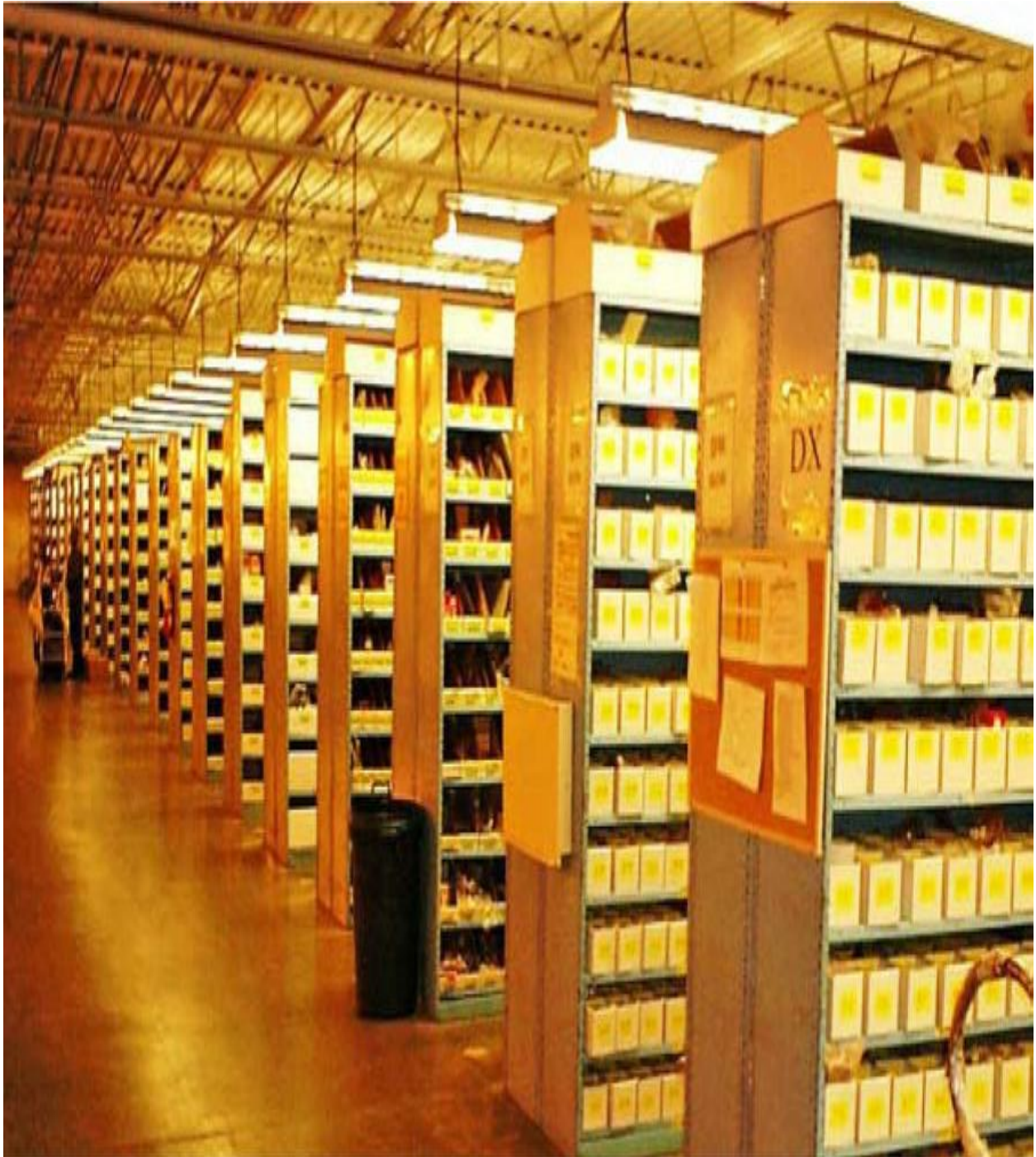
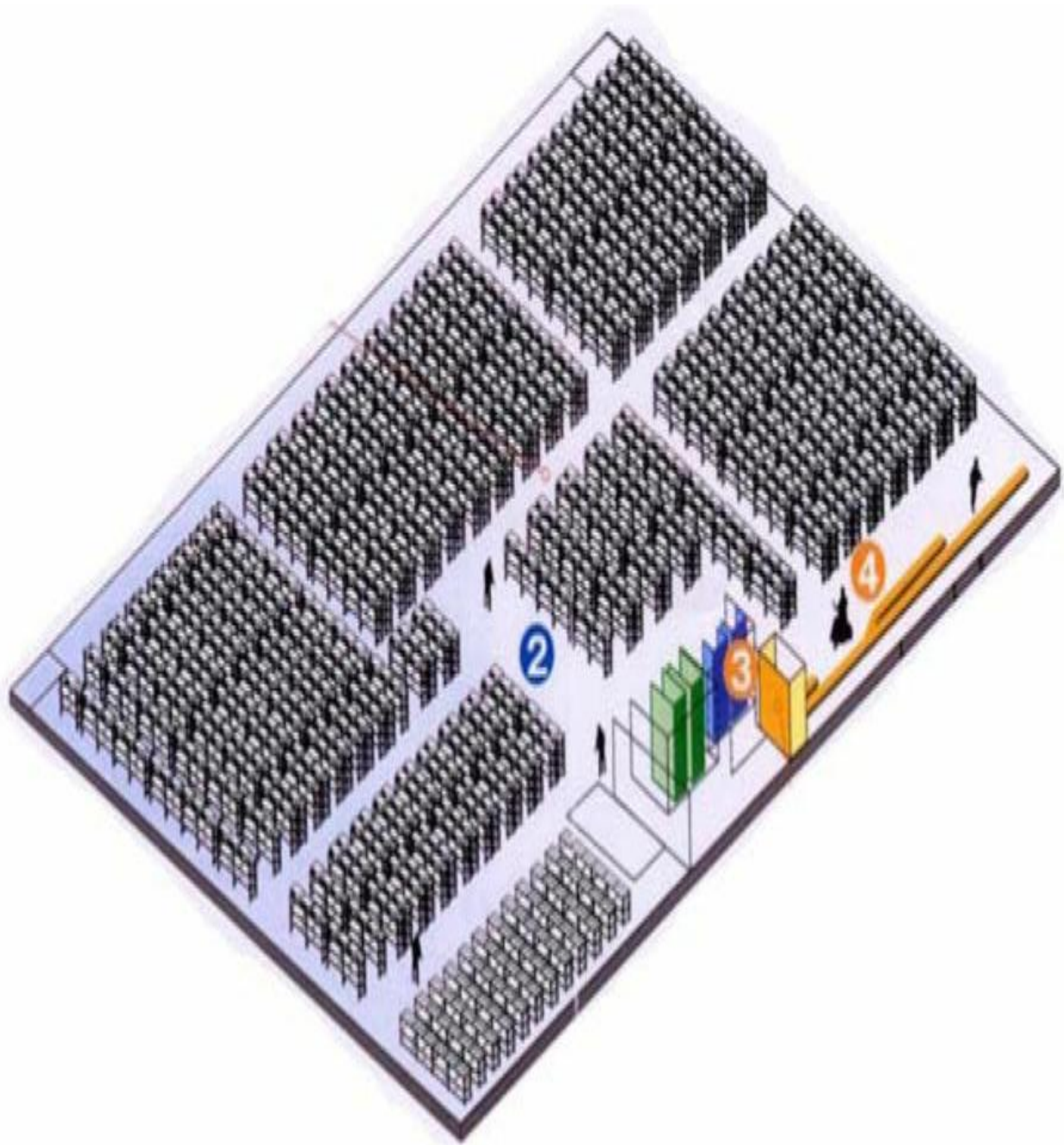


Figure 7.6 Bin shelving layout.



Space is underutilized in bin shelving systems because the full inside dimensions of a shelving unit are rarely usable. Also, the height of bin shelving units may be limited by the order picker's reaching height. As a result, the available building cube also may be underutilized.

Two additional drawbacks of bin shelving are poor supervision and item security/protection. Supervision is difficult because it is difficult to observe people through a maze of bin shelving units. Item security/protection is

difficult because bin shelving is open.

To improve building cube and/or footprint utilization, bin shelving may be mezzanined or mobilized ([Figures 7.7](#) and [7.8](#)).

Figure 7.7 Bin shelving mezzanine at Xerox's Chicago service parts distribution center.



Figure 7.8 Mobile bin shelving system at LAM Research's San Francisco service center.



Modular Storage Drawers/Cabinets Modular storage drawers/cabinets (Figures 7.9 through 7.13) are called modular because each storage cabinet houses modular storage drawers that are subdivided into modular storage compartments. Drawer heights range from 3 to 24 inches, and each drawer may hold up to 400 pounds of material.

Figure 7.9 Storage drawers in an automotive plant storage crib with a person-aboard ASRS.



Figure 7.10 Modular storage drawer configuration for military parts deployment.



Figure 7.11 Typical storage drawer configuration (Lista).



Figure 7.12 Typical storage drawer installation for maintenance parts.



Figure 7.13 Storage drawers for mining maintenance parts.



The primary advantage of storage drawers/cabinets over bin shelving is the large number of stock-keeping units (SKUs) that can be stored and

presented to order pickers in a small footprint. A single drawer can hold from 1 to 100 SKUs (depending on the size, shape, and inventory levels of the items). A typical storage cabinet can store the equivalent of two to four shelving units of material. The storage density comes from the ability to create item housing configurations within a drawer/cabinet that very closely match the cubic storage requirements of each SKU. Also, because the drawers are pulled out into the aisle for picking, space does not have to be provided above each SKU to allow room for the order picker's hand and forearm.

By housing more material in less floor space, the overall space requirement for storage drawers is substantially less than that required for bin shelving. When space is at a true premium, such as on a manufacturing floor, in an assembly area, or in an airport, or when facing the possibility of building additions, the reduction in space requirements alone can be enough to justify the use of storage drawers and cabinets.

Picking accuracy is improved over that in shelving units because the order picker looks down onto the contents of the drawer, which are illuminated by the light source for the picking aisle. Excellent item security and protection are achieved because the drawers can be closed and locked when not in use.

Because the cost per cubic foot of storage is so high, storage drawers are justifiable only for items with very little on-hand cubic inventory (typically less than 0.5 cubic feet) and for operating scenarios in which the cost of space and the need for item security and protection are very high.

As was the case with bin shelving, storage drawer systems may be mezzanined or mobilized ([Figure 7.14](#)).

Figure 7.14 Storage drawer cabinets in a mezzanine system.



Carton Flow Rack Carton-flow racks (Figures 7.15 through 7.22) are typically used for SKUs with high broken-case cube movement in uniformly sized and shaped cartons. Cartons are replenished at the back of the rack from the replenishment aisle and advance/roll toward the pick face as cartons are depleted from the front. The back-to-front movement ensures first in, first out (FIFO) turnover.

Figure 7.15 Carton-flow-rack picking operation.



Figure 7.16 Carton-flow-rack picking line at NTT's Tokyo logistics center.



Figure 7.17 Flow-rack shoe picking at Nike's European Union distribution center outside Amsterdam.



Figure 7.18 Carton flow-rack pick-to-light.



Figure 7.19 Carton flow rack in a U-shaped picking module with pick-to-light and put-to-light.



Figure 7.20 Carton-flow-rack simulation for Avon.



Figure 7.21 Carton-flow-rack bays at L.L. Bean.



Figure 7.22 Mezzanine picking operation at Verizon's Logistics East Coast distribution center.



In essence, a section of flow rack is a bin shelving unit turned

perpendicular to the picking aisle with rollers placed on the shelves. The deeper the sections, the greater is the portion of warehouse space that will be devoted to storage as opposed to aisles. Further gains in space and labor efficiency can be achieved by making use of the space over flow racks for full-pallet storage of reserve quantities of the items located below. Flow racks have very low maintenance requirements and are available in a wide variety of section and lane dimensions.

Just one carton of each SKU is located on the pick face, so that a large number of SKUs are presented to pickers along the pick line. Hence, walking and therefore labor requirements can be reduced.

Picker-to-Stock Retrieval Methods

Picker-to-stock retrieval methods include cart picking, tote picking, person-aboard systems, and robotic item picking. The pros, cons, and applications of each are described next.

Cart Picking A wide variety of picking-cart types ([Figures 7.23 through 7.34](#)) facilitate accumulating, sorting, documenting, and/or packing orders as an order picker makes a picking tour. Conventional carts provide dividers for order sorting, a place to hold paperwork and marking instruments, and a stepladder for picking at levels slightly above reaching height. Batch picking carts allow an order picker to pick multiple orders on a picking tour. More sophisticated carts automatically transport order pickers to pick locations, use light displays to direct the order picker to sort the contents of a pick, and permit mobile online communication via radiofrequency (RF) links and/or wireless local area network (LAN) links.

Figure 7.23 Batch picking cart with one tote per dealer order in a Honda parts distribution center.



Figure 7.24 Batch picking cart for health and beauty aids.



Figure 7.25 Batch picking cart for service parts equipped with onboard computing and packaging in a Caterpillar parts distribution center, Georgia.



Figure 7.26 Pick face pick-pack cart for service parts and hardware at the U.S. Defense Logistics Agency.



Figure 7.27 Monorail picking cart in a large book distribution center in Gutersloh, Germany.



Figure 7.28 Batch picking cart equipped with onboard scales, onboard labeling, and onboard computing.



Figure 7.29 Pick-to-light batch picking cart at Shisheido.



Figure 7.30 Batch wave picking carts at L.L. Bean.



Figure 7.31 Batch picking cart.



Figure 7.32 Batch wave picking cart releasing poly-bagged garments into

tilt-tray sorter.



Figure 7.33 Light picking cart.



Figure 7.34 Automated guided vehicle (AGV) picking cart. (Creform)



Tote (or Carton) Picking In tote picking systems ([Figure 7.35](#)), conveyors transport tote pans (or shipping cartons) through successive picking zones. Order pickers may walk one or more totes through a single picking zone, partially completing several orders at a time, or an order picker may walk one or more totes through all picking zones, thus completing one or more orders on each pass through the picking zones. Tote picking rates range from 150 to 300 lines per person-hour. The improvement over cart picking must be sufficient to justify the additional investment in conveying and sorting

systems.

Figure 7.35 Tote picking system.



Person-up Systems In the systems described thus far, the operator remains at floor level. To improve storage density order pickers can ride up on an order-picker truck or a person-aboard ASRS machine to locations as high as 40 to 50 feet ([Figures 7.36 through 7.39](#)). The operation of order-picker

trucks was explained in [Chapter 6](#). The operation of a person-aboard ASRS is described next.

Figure 7.36 Stock picker truck at the American Cancer Society's National Logistics Center.



Figure 7.37 Stock picker truck.



Figure 7.38 An order picker headed for a batch picking run of slow-moving items in high-bay storage at L.L. Bean's distribution center.



Figure 7.39 High-bay picking area for slow-moving items at L.L. Bean's distribution center.



A person-aboard ASRS ([Figure 7.40](#)), as the name implies, is an automated storage and retrieval system in which the picker rides aboard a storage/retrieval machine to the pick locations.

Figure 7.40 Person-aboard ASRS picking operation in an HP distribution center.



Typically, the order picker leaves from the front of the system at floor level and visits several pick locations during a picking tour.

The key to achieving good picking productivity is intelligent slotting and pick tour sequencing.

Person-aboard systems typically are appropriate for slow-moving items where space is fairly expensive.

Robotic Item Picking Robotic picking vehicles ([Figures 7.41](#) and [7.42](#)) travel automatically through a sequence of picking locations, receiving power and communication from rails in the floor and ceiling. Picking robots are equipped with a small carousel to permit order sorting, accumulation, and containment. The carousel travels up and down a mast on the robot as it traverses the picking aisle(s). The robot can automatically extract a storage drawer from a storage location onto the picking vehicle. The robot's arm is guided by an onboard vision system to direct item picking from a specific storage compartment in a storage drawer. Only in rare instances are robotic item picking systems justifiable.

Figure 7.41 Robotic item picking.



Figure 7.42 Robotic item picking for single bottles of consumer products.



7.2 Stock-to-Picker Systems

The three major types of stock-to-picker systems are carousels, miniload automated storage/retrieval systems, and automated guided shelving systems. Each system type is described in the following subsections. The major advantage of stock-to-picker systems over picker-to-stock systems is elimination of the travel time for the order picker. When wage rates are high, the labor savings can be sufficient to justify the investment in the mechanical and control systems required in stock-to-picker systems. If a stock-to-picker system is not designed properly, an order picker may remain idle waiting on

the system to present the next picking transaction. In such cases, productivity actually can be worse than in picker-to-stock systems.

Another advantage of stock-to-picker systems is supervision. In stock-to-picker systems, the picking takes place at the end of an aisle. Hence all the operators should be visible to a supervisor in one quick glance down a picking line.

Carousels

Carousels, as the name implies, are mechanical devices that house and rotate items for order picking. Horizontal and vertical carousels are popular for order picking applications.

Horizontal Carousels A horizontal carousel ([Figures 7.43 through 7.46](#)) is a linked series of rotating bins with adjustable shelves driven on the top or the bottom by a drive-motor unit. Bins rotate about an axis perpendicular to the floor at a rate of 80 to 200 feet per minute.

Figure 7.43 Horizontal carousel system at Ford's parts distribution center.

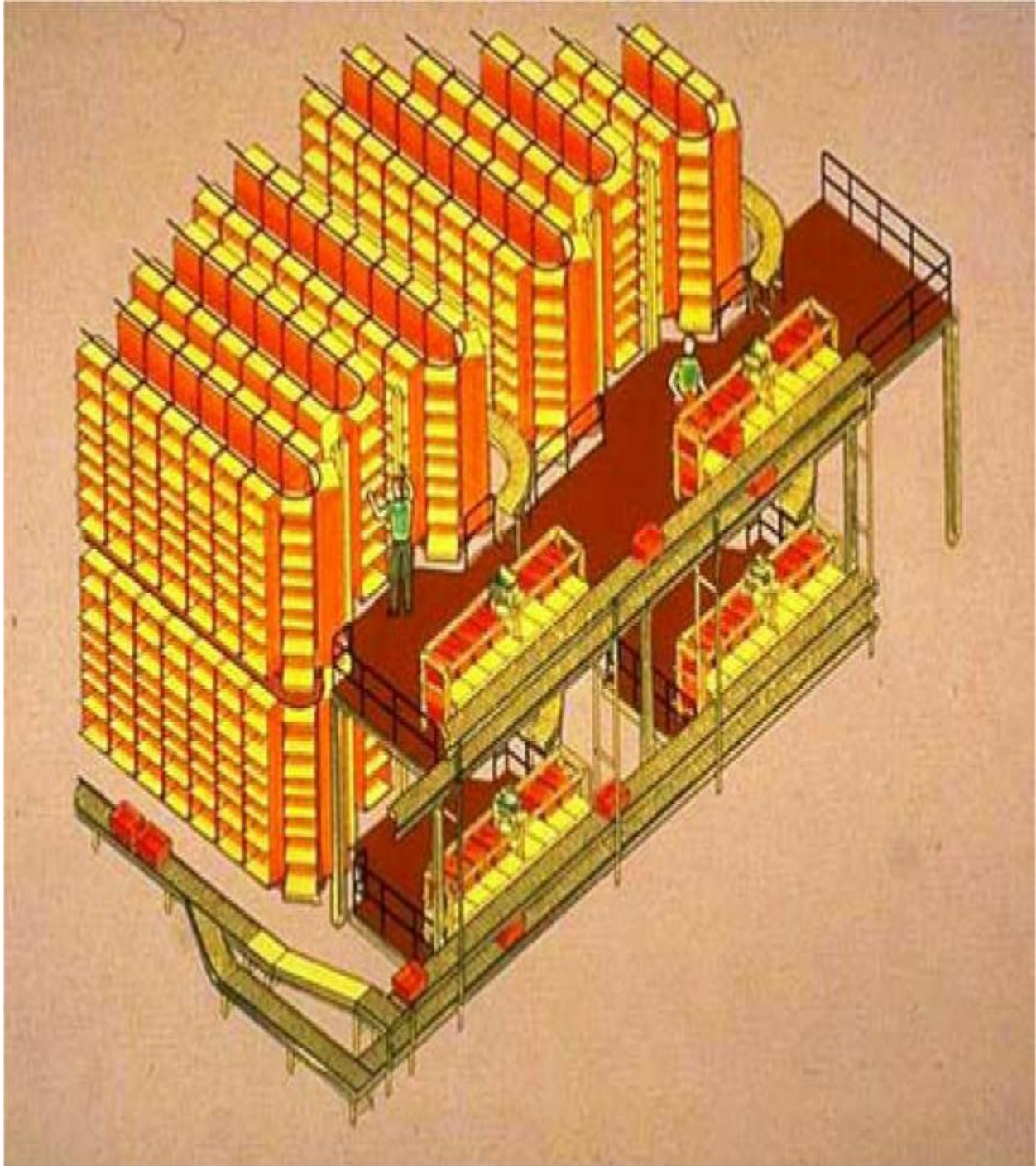


Figure 7.44 Pick-by-light, put-to-light horizontal carousel picking at Swagelok.



Figure 7.45 Horizontal carousel system with automated outfeed and loop front end at Witt.



Figure 7.46 Horizontal carousel storage and retrieval system with

robotic extractor for tote staging.



Order pickers may be responsible for controlling the rotation of the carousel. Manual control is achieved via a keypad that tells the carousel which bin location to rotate forward and a foot pedal that releases the carousel to rotate. Carousels are normally computer controlled, in which case the sequence of pick locations is stored in a computer and brought forward automatically.

The assignment of order pickers to carousels is flexible. If an order picker is assigned to one carousel unit, he or she must wait for the carousel to rotate to the correct location between picks. If an order picker is assigned to two or more carousels, he or she may pick from one carousel while the other is rotating to the next pick location.

Horizontal carousels vary in length from 15 to 100 feet and in height from 6 to 25 feet. The length and height are dictated by the pick rate requirements and building restrictions. The longer the carousel, the more time is required, on average, to rotate the carousel to the desired location. Also, the taller the carousel, the more time is required to access items. Heights over 6 feet require the use of ladders, lift platforms, or robotic arms on vertical masts to access items.

One drawback of horizontal carousels is that the throughput capacity is limited by the rotation speed of the motor drive. Another drawback is the high initial investment per carousel unit. Consequently, items with high cube movement should not be housed in carousels because the carousel may not be able to rotate fast enough to permit sufficient access to those items and because those items would occupy a large and expensive envelope of space in the carousel.

Vertical Carousels A vertical carousel ([Figures 7.47 through 7.49](#)) is a horizontal carousel turned on its end and enclosed in sheet metal. As with horizontal carousels, an order picker operates one or multiple carousels. The carousels are indexed either automatically via computer control or manually by the order picker working a keypad.

Figure 7.47 Vertical carousel installation.



Figure 7.48 Vertical carousel picking at a large dental supply distribution center.



Figure 7.49 Vertical carousel installation at NASA.



Vertical carousels range in height from 8 to 35 feet. Heights (as lengths were for horizontal carousels) are dictated by throughput requirements and building restrictions. The taller the system, the longer it will take, to rotate the desired bin location to the pick station.

Vertical carousels always present at an order picker's waist level. This eliminates stooping and reaching reduces search time, and promotes more accurate picking.

Additional benefits include excellent item protection and security. In vertical carousels, only one shelf is exposed at a time, and the entire contents of the carousel can be secured.

Vertical carousels are much more expensive than horizontal carousels with cost increasing with the number of shelves, weight capacity, and special features. The additional cost of vertical over horizontal carousels is a result of the sheet-metal enclosure and the extra power required to rotate against the force of gravity.

Miniload Automated Storage and Retrieval Systems

In miniload automated storage/retrieval systems ([Figures 7.50 through 7.56](#)), an automated storage/retrieval machine travels horizontally and vertically simultaneously in a storage aisle, transporting storage containers to and from an order picking station located at one end of the system. The order picking station typically has two pick positions. As an order picker picks from the container in the one position, the storage/retrieval machine returns the container from the other pick position back to its location in the rack and returns with the next container.

Figure 7.50 Miniload ASRS.

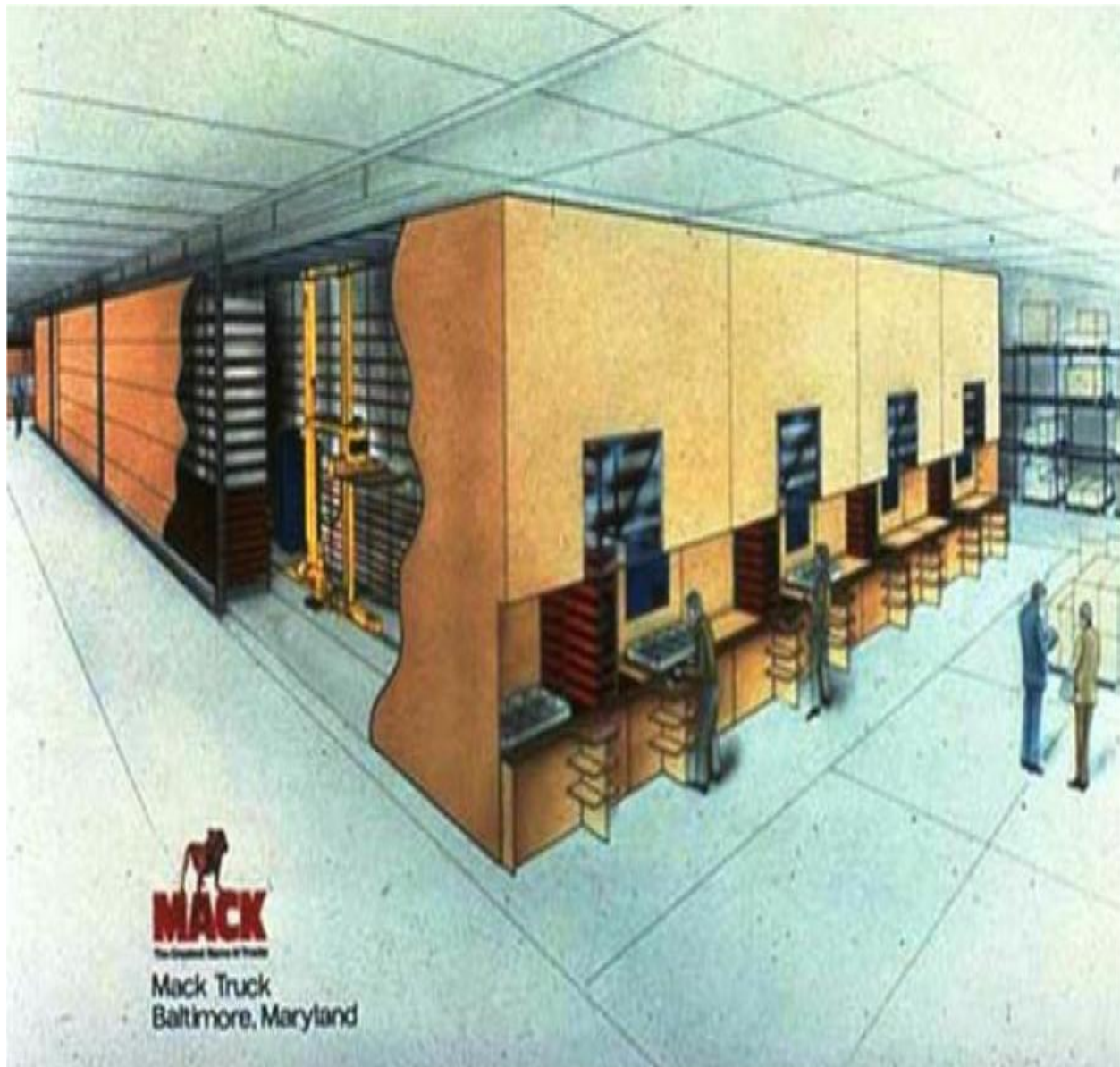


Figure 7.51 Miniload ASRS front-end picking with a loop conveyor (Daifuku).



Figure 7.52 Even miniload systems can be configured with mobile aisles, as is the case in this installation.



Figure 7.53 Inside a miniload ASRS at NASA.

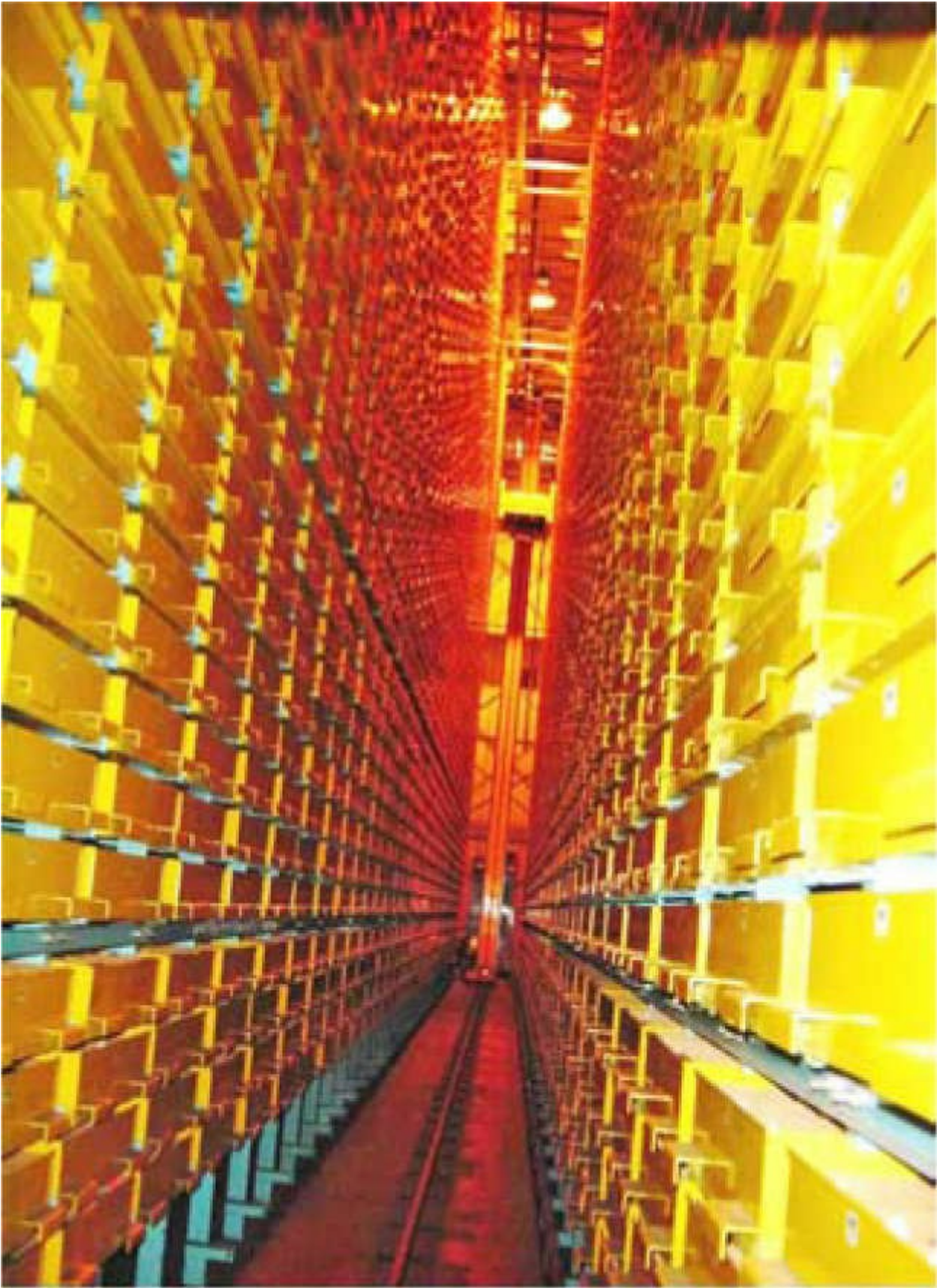


Figure 7.54 Multi-shuttle miniload ASRS.



Figure 7.55 Miniload ASRS for mining maintenance parts.



Figure 7.56 Miniload with picking display and batch picking (Opex).



The sequence of containers can be determined manually (the order picker keying in the desired line-item numbers or rack locations on a keypad) or automatically by computer control. Miniload systems vary in height from 8 to 70 feet and in length from 40 to 300 feet. As is the case with carousels, the height and length of the system are dictated by the throughput requirements and building restrictions. The longer and taller the system, the longer is the travel time. However, the longer and taller the system, the fewer are the aisles and storage/retrieval machines that will have to be purchased.

Miniload floor space requirements are small because of the ability to store material up to 50 feet high, the ability to size and shape the storage containers and the subdivisions of those containers to very closely match the storage-volume requirements of each SKU, and aisle widths that need only accommodate the width of a storage container.

Because this is the most sophisticated of the system alternatives described thus far, it should come as no surprise that the miniload system carries the highest price tag of any of the order picking system alternatives. Another result of its sophistication is the significant engineering and design time that accompanies each system. Most systems require between 6 and 18 months for design, delivery, and installation. Finally, greater sophistication leads to greater maintenance requirements. It is only through a disciplined maintenance program that miniload suppliers are able to advertise uptime percentages of between 97 and 99.5 percent.

Automated Guided Shelving Systems

Automated guided shelving systems are small automated guided vehicles that transport bin shelving units to stationary order pickers ([Figure 7.57](#)).

Figure 7.57 Automated guided shelving systems operating at an Amazon distribution center.



7.3 Automated Item Dispensing Systems

Automated item dispensing systems ([Figures 7.58 and 7.59](#)) act much like vending machines for small items. Each SKU is allocated one or more dispensers ranging from 2 to 6 inches wide and from 3 to 5 feet tall. (The width of each dispenser is easily adjusted to accommodate variable product sizes.) The dispensing mechanism kicks the unit of product at the bottom of the dispenser onto a conveyor running between two rows of dispensers configured as an A-frame over a belt conveyor.

Figure 7.58 Automated item dispensing system at Boots Pharmacy (London, ENGLAND).



Figure 7.59 Automated item dispensing system at Avon Products.



Virtual order windows begin at one end of the conveyor and pass by each dispenser. If an item is required in the order window, it is dispensed onto the conveyor. Merchandise is accumulated at the end of the belt into a tote pan or carton. A single dispenser can dispense at a rate of up to 6 units per second. Automatic item dispensing systems are popular in industries with high throughput for small items of uniform size and shape, such as cosmetics, wholesale drugs, compact discs, videos, publications, and poly-bagged garments.

Replenishment is performed manually from the back of the system. The manual replenishment operation significantly cuts into the potential savings in picking labor requirements. Nonetheless, typical picking rates are in the range of 1,500 to 2,000 picks per person-hour. Typical picking accuracy is 99.97.

7.4 Broken-Case Picking Systems Comparison and Selection

As is the case with all the systems selections and justifications described so far, a picking-mode economic analysis should be conducted to assign each item to its most economically attractive storage mode. This analysis should consider the activity and inventory profile of each item and the storage and handling characteristics of each storage mode. The economic analysis should recommend the appropriate storage mode for each SKU based on matching each item's requirements to a storage mode's capabilities. Our RightStore Optimization automates this selection process. The optimization calculates the picking, restocking, space, equipment, and error costs for each item in each potential storage mode and assigns each SKU to its optimal storage mode and allocation of space ([Table 7.1](#) and [Figures 7.59 through 7.61](#)).

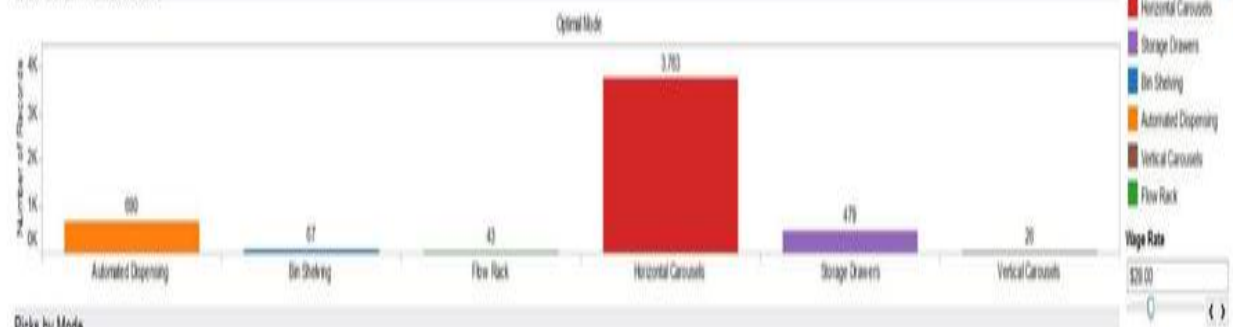
Table 7.1 Summary Characteristics of Alternative Broken-Case Picking Systems

						Picking Rates (lines/person hour)				
Method	Feet Cubic Feet of Inventory of Inventory Housed per Square Foot of Floor Space	Main-tenance Require-ments	Item Security and Protection	Reconfi-guration Flexibility	Ergono-mics	General	Cart	Tote	ASRS	Wave
Bin shelving	1.0–1.2	Low	Low	High	Low	15–500	20–100	80–250	15–80	200–500
Carton flow rack	0.7–0.9	Low	Low	High	Low	20–600	2–125	100–300	20–100	300–600
Storage drawers	1.8–2.5	Low	High	High	Medium	10–150	15–80	60–150	10–50	N/A
Horizontal carousels	0.8–1.3	Medium	Low to medium	Medium	Medium	50–250	N/A	N/A	N/A	N/A
Vertical carousels	5.0–7.0	Medium	Very high	Low	High	35–200	N/A	N/A	N/A	N/A
Miniload ASRS	4.0–5.0	Very high	Very high	Low	High	30–150	N/A	N/A	N/A	N/A
Automated dispensing	—	Very high	Medium	Low	Medium	500–2000	N/A	N/A	N/A	N/A

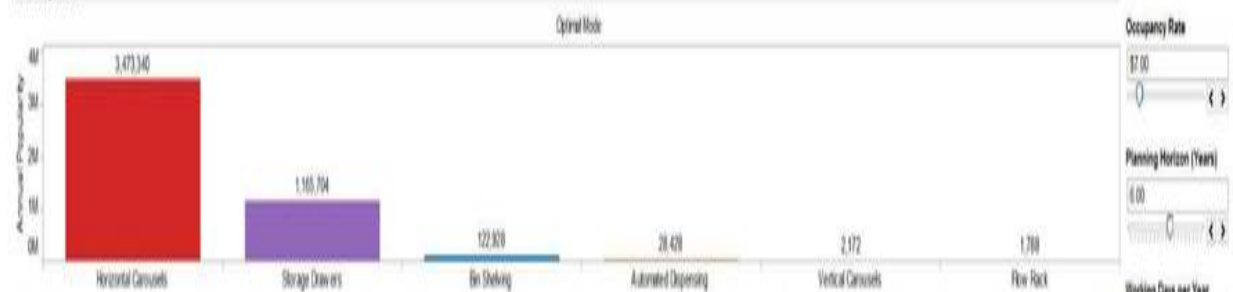
Figure 7.60 RightStore broken-case picking storage mode optimization.

[SOLUTION](#)
[RightClick™ Savings](#)
[X=Popularity Y=CM](#)
[X=Turnover Y=Popularity](#)
[Mid-Global DGLs](#)
[Bin Shelving](#)
[Automated Dispensing](#)
[Flow Rack](#)
[Horizontal Carousels](#)
[Miniload](#)
[Storage Drawers](#)
[Vertical Carousels](#)
[Optimization](#)
[Optimization 2](#)

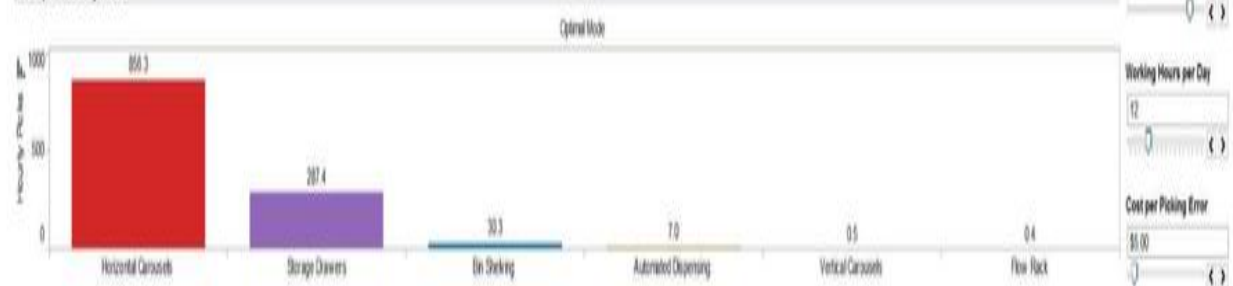
SKUs by Optimal Picking Mode



Picks by Mode



Picks per Hour by Mode



Floor Space by Mode

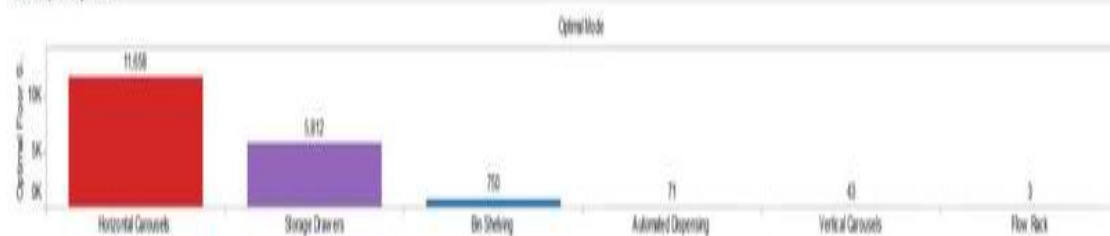
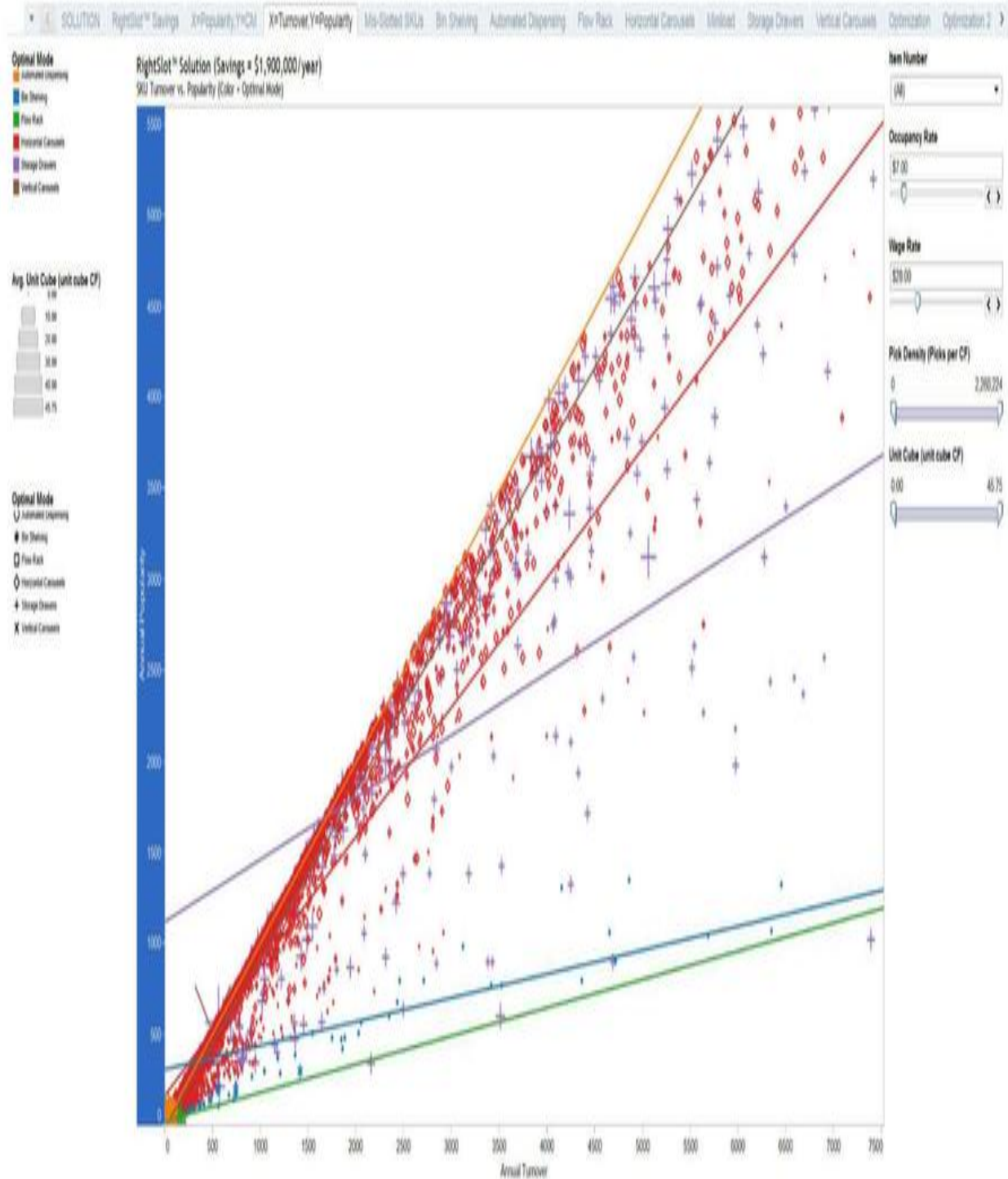


Figure 7.61 RightStore preference regions.



CHAPTER EIGHT

ORDER PICKING AND SHIPPING

8.1 Minimize, Simplify, and Combine

8.2 Order Picking Schemes

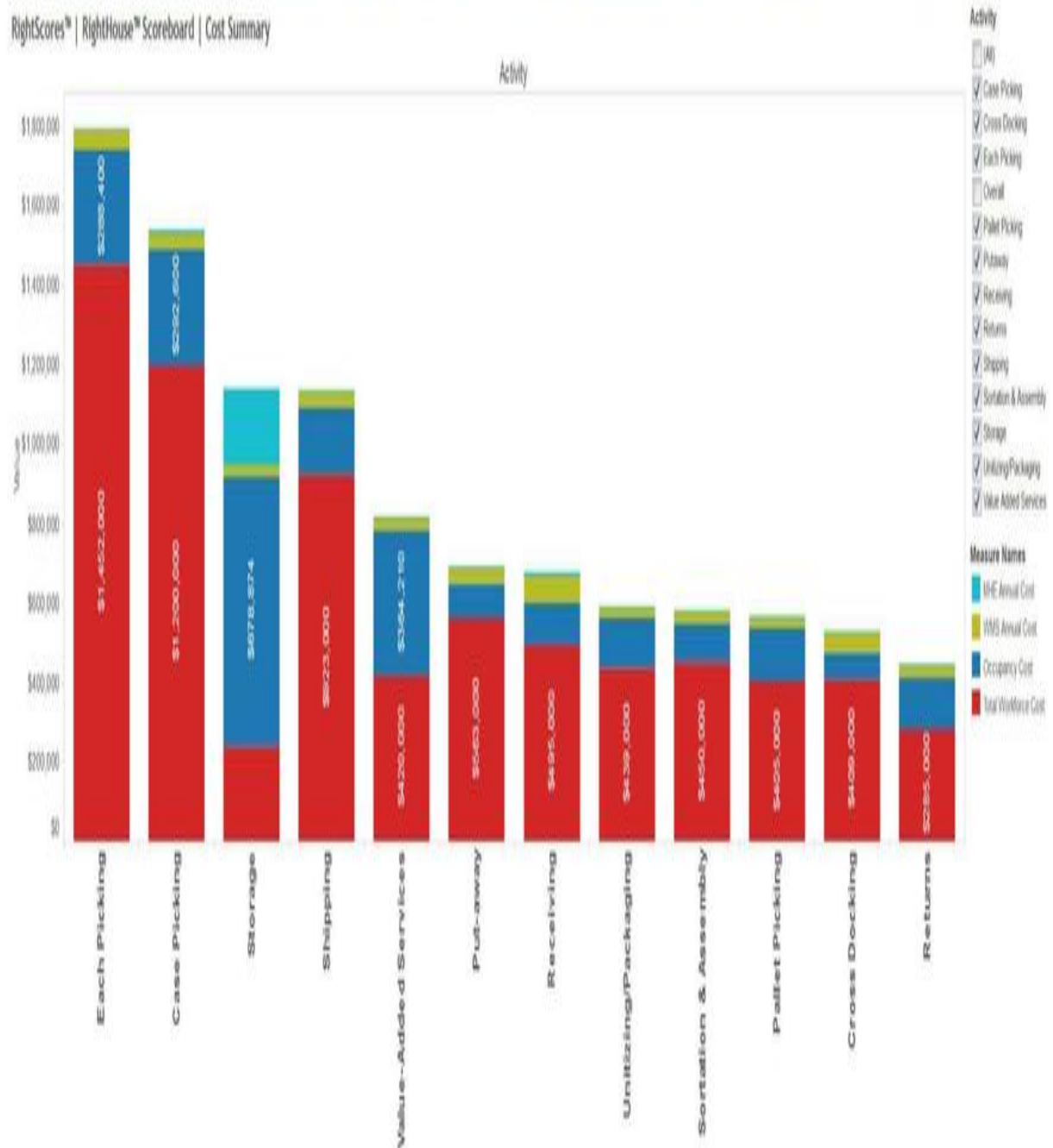
8.3 Slotting Optimization

8.4 Pick-Tour Sequencing

Order picking and shipping are typically the highest priority activities for warehouse operations improvement. There are several reasons. Order picking and shipping are the most costly activities in a typical warehouse ([Figure 8.1](#)). Order picking and shipping are the most labor-intensive functions in the warehouse. To combat the labor intensity, most of the material- and information-handling systems in warehousing are devoted to the outbound activities. Many of the decision-support systems and engineering projects in a warehouse in picking and shipping. Most of the errors made in warehousing are made in order picking and shipping.

Figure 8.1 Operating cost distribution in a typical warehouse.

RightScores™ | RightHouse™ Scoreboard | Cost Summary



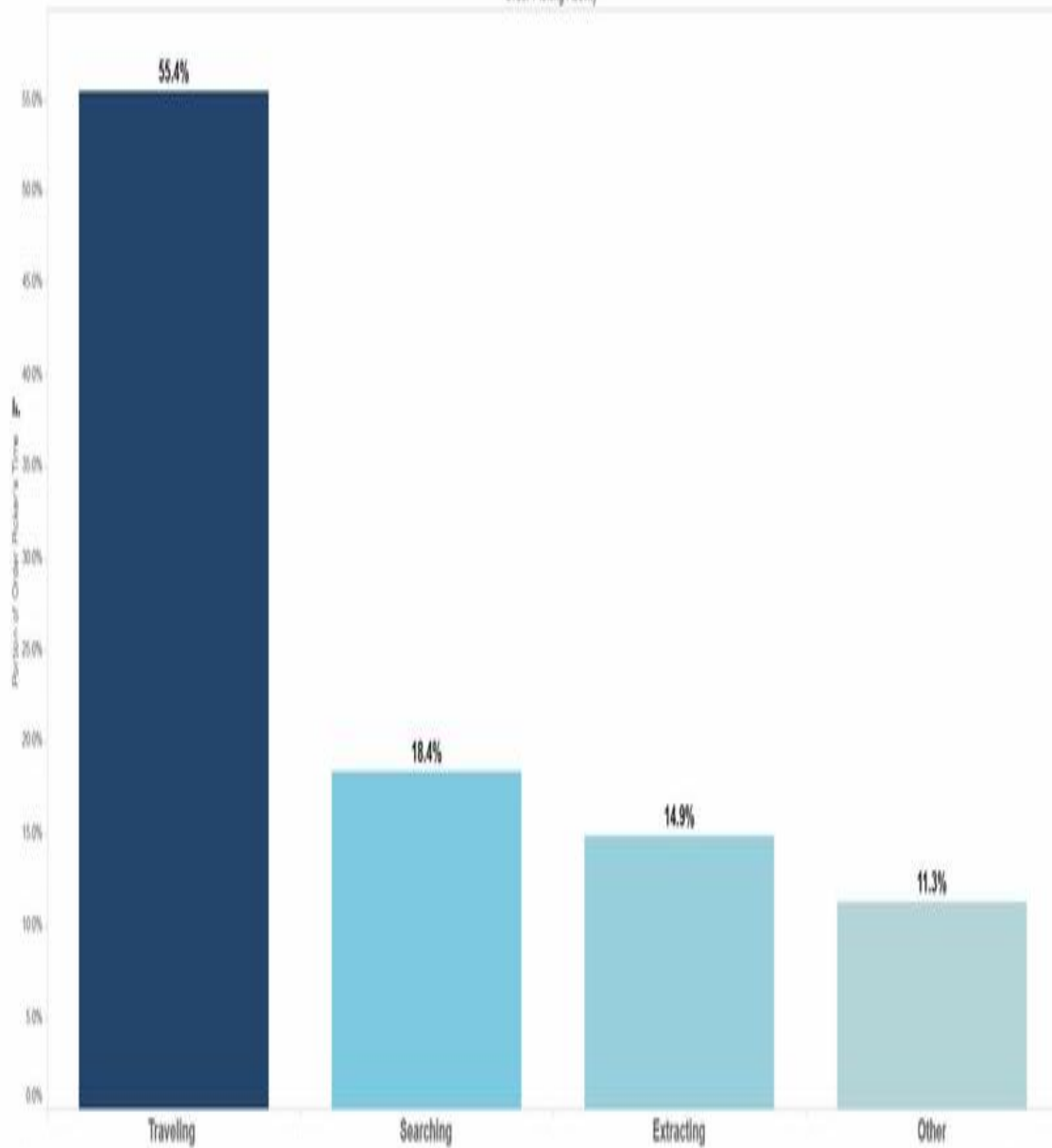
Order picking has become increasingly difficult to manage. The difficulty arises from the introduction of new operating programs such as *just-in-time* (JIT), *lean*, *cycle-time reduction*, *quick response*, and new marketing strategies such as *micromarketing* and *megabrand* strategies. These programs require smaller orders delivered more frequently and more accurately, and more stock-keeping units in the order picking system. As a result, throughput, storage, and accuracy requirements have increased dramatically.

The conventional responses to these increased requirements—to hire more people or to invest in more automated equipment—are often stymied by labor shortages and high hurdle rates. Fortunately, there are a number of ways to improve order picking productivity without increasing staffing or making significant investments in highly automated equipment. The most effective of those improvement strategies are described and illustrated in this chapter. The strategies are aimed at reducing the amount of time order pickers spend in their most time-consuming tasks ([Figure 8.2](#)).

Figure 8.2 Typical distribution of an order picker's working time.

Order Picking Activity

Portion of Order Picker's ...

11.3% 55.4%


8.1 Minimize, Simplify, and Combine

The RightHouse first option is always to minimize work content. When work content cannot be eliminated, we work to simplify it. When it cannot be simplified, we work to combine work elements. This approach to order picking is presented in the next three subsections.

Optimize Issue Packs

By encouraging customers to order in full-pallet quantities or by creating quarter- and/or half-pallet loads, much of the counting and manual physical handling of cases can be avoided both in your warehouse and in your customers' warehouses. In similar fashion, by encouraging customers to order in full-case quantities, much of the counting and extra packaging in loose case picking can be avoided.

Simplify Pick Tasks

The work elements in order picking include *traveling* to, from, and between pick locations; *searching* for pick locations; *extracting* items from pick locations; *reaching and bending* to access pick locations; *documenting* picking transactions; *sorting* items into orders; and *packing*. Each of those work elements may be eliminated with process changes and/or technology ([Table 8.1](#)).

Table 8.1 Pick task simplification approaches.

Work Element	Method of Elimination	Enablers
Traveling to, from, and between pick locations	Transport picking locations to the picker	Stock-to-picker systems including carousels and automated storage and retrieval systems
	Optimize slotting	Slotting statistics, system, and methodology
	Batch orders to reduce the distance between successive picks	Batch picking carts
Searching for pick locations	Transport picking locations to the picker	Stock to picker via carousels or automated storage and retrieval systems (ASRS)
	Transport the picker to the picking locations	Person-aboard guided vehicles
	Illuminate picking locations	Pick-to-light
Extracting	Eliminate operator extracting	Automated dispensing
Center in cell Documenting	Automate information flow	Radiofrequency (RF) terminals, voice headsets, pick-to-light
Center in cell Bending and reaching	Present items at waist level	Slot for waist-level picking. Vertical carousel or ASRS to present locations at waist level
Counting	Count by weight	Scales in line and/or on picking carts
	Count by inner packs	Prepackage in issue increments
Packing	Eliminate operator packing	Autopack

Combine Work Elements

When work elements cannot be eliminated, they can often be combined to improve order picking productivity.

Traveling and Extracting Items Stock-to-picker (STP) systems such as carousels and automated storage/retrieval systems should keep order pickers busy while a mechanical device travels to, from, and between storage locations, bringing pick locations to the order picker.

Figure 8.3 In-line order weight checking in book distribution (Gutersloh, Germany).



Traveling and Documenting Because a person-aboard storage/retrieval machine is programmed to automatically transport the order picker between

successive picking locations, the order picker is free to document picking transactions, sort material, or pack material while the storage/retrieval machine is moving.

Picking and Sorting Picking carts equipped with dividers or totes allow the picker to sort material during the course of a picking tour.

Picking, Sorting, and Packing When an order is small, say, less than the size of a shoe box, the order picker can sort directly into a packing or shipping container ([Figure 8.4](#)). Packing or shipping containers must be set up ahead of time and placed on picking carts equipped with dividers and/or totes.

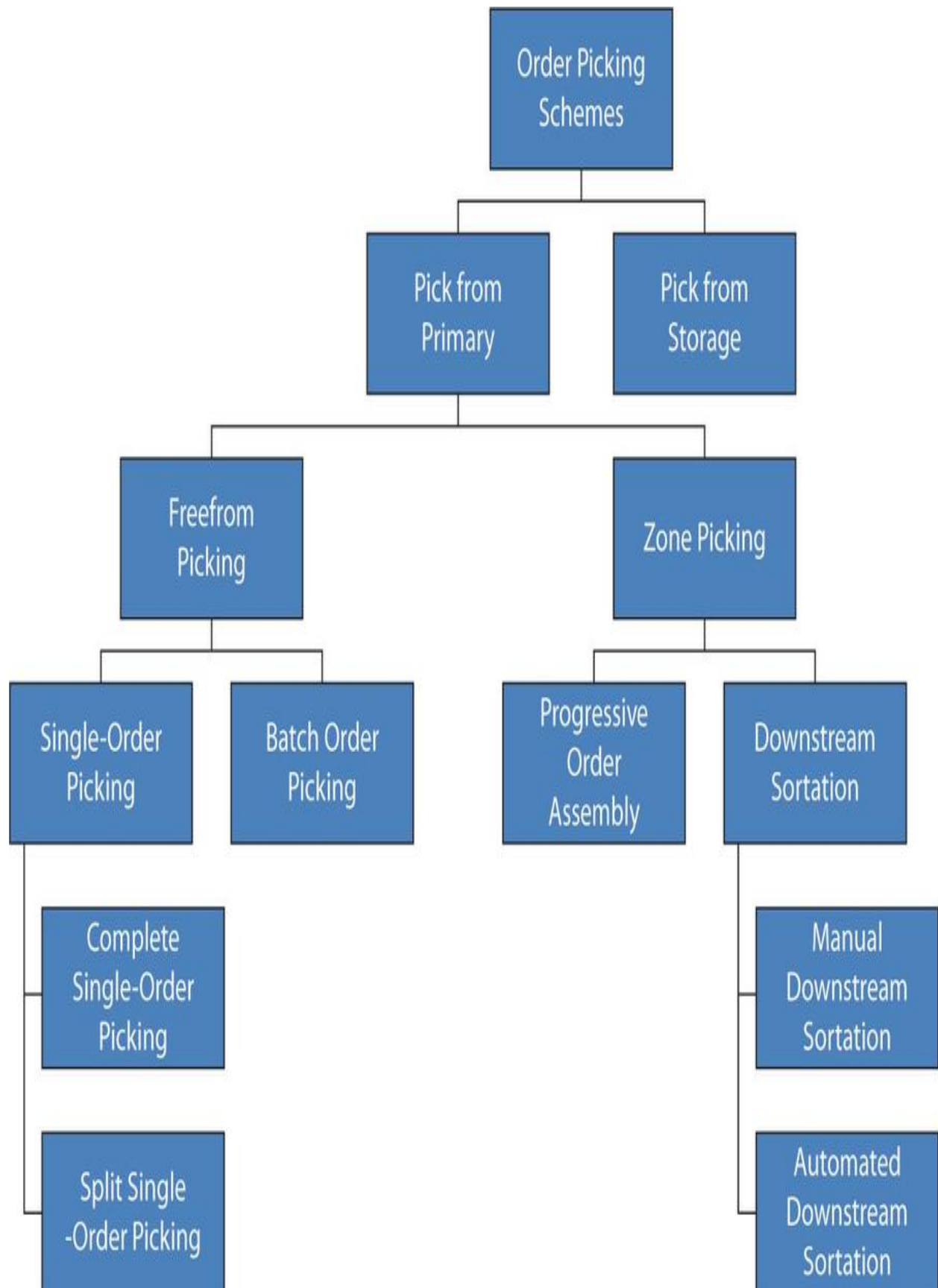
Figure 8.4 Pick and pack at Avon Products.



8.2 Order Picking Schemes

In our RightPick taxonomy of picking schemes ([Figure 8.5](#)), the first decision is whether to pick from primary or secondary/reserve storage locations.

Figure 8.5 RightPick taxonomy of picking schemes.



Pick from Primary

Once we have decided to pick from primary pick locations, the next decision is whether or not to organize order picking by assigning operators to picking zones. A *picking zone* is a portion of an aisle, multiple aisles, or machines (e.g., carousels and ASRS machines) assigned to an operator for picking. The key distinguishing feature is that the operator is dedicated to a zone, and no other operator works in that zone. In zone picking operators do not have order-completion accountability because the lines on an order will be filled from different zones and hence by different order pickers.

The opposite zone picking is *free-form picking*. In free-form picking, order pickers are responsible for picking every line on each order assigned to them, and they are free to move to any aisle in the warehouse. The advantages of zone picking are enumerated in [Table 8.2](#).

Table 8.2 Zone Picking Advantages.

Zoning Pros	Notes and Comments
Operator travel time is reduced because operators are assigned to small, dedicated work areas.	I always prefer to play zone defense in basketball because I do not have to chase anyone around the court and because I do not have responsibility for an opposing player's scoring outbursts!
Operators become familiar with the products and locations in their zone.	Product familiarity should yield improved picking productivity and picking accuracy (see the section "Xerox Service Parts").
Congestion is minimized because not more than one operator is in an aisle at a time.	Minimizing congestion is the most important justification for zone picking. In some operations, the volume is so great that free-form picking creates gridlock-like bottlenecks.
There is operator-zone accountability.	The order picking performance (productivity, accuracy, and housekeeping) can be recorded and posted by zone. The tradeoff is the loss in accountability for orders (see the section "True Value Hardware").
It minimizes excessive socializing.	Because operators are assigned alone to dedicated work zones, there is little or no opportunity during a pick wave for excessive socializing. Some socializing is healthy, but zone picking helps to control and monitor it.

Xerox Service Parts I recently toured a Xerox service parts distribution center outside Chicago. I spent nearly an hour observing the picking operation.

I especially enjoyed meeting the top-performing order picker. She had been with Xerox for over 20 years and had worked the same two aisles in the

warehouse for five years. The housekeeping, productivity, and accuracy in her zone were the highest in the warehouse. I could not help but comment to her about the excellent performance record she had and on the neatness of her work area. During the conversation, I noticed that the merchandise in the bin closest to the front of her zone and next to the take-away conveyor was not nearly as neatly arranged as the other bins. It was so unusual compared with other bins in her zone that I asked her about the arrangement of that particular bin. She told me that the bin contained merchandise that customers were going to order that day. How did she know? She did not have ESP or claim to function as the world's greatest forecasting system. The items in that bin were A-movers that had not been properly reslotted. The order picker grew tired of traveling to the end of her zone for those popular items. She simply moved some of the inventory for those items close to the front of the zone. This simple process improvement would have been impossible without the product and location familiarity that comes with zone picking.

True Value Hardware At True Value Hardware, each of its small-item order picking areas is configured in single-aisle zones. A take-away belt conveyor runs down the center of each zone, allowing an operator to make one pass through the zone during a pick wave. During a pass, each operator works with a roll of picking labels. The labels present items in location sequence to the order picker, who picks an item, places a bar-code label on the item, places the labeled item on the belt conveyor, and moves to the next location. The take-away belt conveyor feeds a downstream sorting system that sorts the items coming from each zone into retail-store orders. At the end of each zone, the performance statistics, including picking productivity, picking accuracy and housekeeping for the zone, are posted. Talk about public accountability!

The benefits of zone picking—reduced travel time, minimal congestion, product-location familiarity, and operator-zone accountability—may or may not pay for the associated costs and inherent control complexities presented by zone picking. [Table 8.3](#) describes some of those costs and control difficulties.

Table 8.3 Zone Picking Costs and Control Complexities

Zone Picking Costs and Control Challenges	Notes and Comments
Order assembly	The major difficulty and cost factor in zone picking is the need to assemble orders across order picking zones. The two methods for order assembly—progressive assembly by passing the contents of the order from zone to zone and wave picking with downstream sorting—can be excessively expensive. They can also reduce the operating flexibility of the warehouse and significantly increase the level of sophistication of warehouse control systems.
Workload imbalances can create bottlenecks, gridlock, and low worker morale.	It is nearly impossible to perfectly balance the workload between zones on a daily basis. To do so requires advanced slotting techniques or, as is the case with highly sophisticated zone picking schemes, dynamic floating zones. In those operations, the size of the zone varies as a function of the associated workload. In either case, the controls are an order of magnitude more complex than those used in free-form picking.

Free-Form Picking

As described earlier, in free-form picking, order pickers are free to operate outside the confines of picking zones. In free-form picking, the toughest decision is whether the order picker should work on a single order or multiple orders during a picking tour.

Single-Order Picking In single-order picking, each order picker completes one order at a time. In picker-to-stock (PTS) systems, single-order picking is

like going to a grocery store and accumulating the items on your grocery list in your cart. Each shopper is only concerned with his or her list.

The major advantage of single-order picking is that order integrity is never jeopardized. The major disadvantage is that the order picker is likely to traverse a large portion of the warehouse to pick a single order. Consequently, the travel time per line item picked is high if the order does not contain several line items. (For large orders, a single order may yield an efficient picking tour.) However, in some systems, response-time requirements do not allow orders to build up in queue to create efficient batches for order picking. For an emergency order, the customer-service motivation should override the efficiency motivation, and we should pick the single emergency order without batching.

Batch Picking Batch picking can be thought of as going to a grocery store with your shopping list and those of some of your neighbors. In one traversal of the grocery store, you will have completed several orders. As a result, the travel time per line item picked will be reduced by approximately the number of orders per batch. For example, if an order picker picks one order with two items while traveling 100 feet, the distance traveled per pick is 50 feet. If the picker picked two orders with four items, the distance traveled per pick is reduced to 25 feet.

Single-line orders are a natural group of orders to pick together. Single-line orders can be batched by small zones in the warehouse to further reduce travel time.

The major disadvantages of batch picking are the time required to sort line items into customer orders and the potential for picking errors ([Figure 8.6](#)).

Figure 8.6 Picking two orders, one per pallet, with a double-pallet jack is a classic example of free-form batch picking.



Zone Picking

The major decision in zone picking is how to establish order integrity for orders with lines picked in multiple zones. The two options are progressive order assembly and downstream sorting.

Progressive Order Assembly In *progressive assembly* (or pick-and-pass) systems, the contents of an order are passed by hand, conveyor, or vehicle from one zone to the next until the order is completely assembled ([Figure 8.7](#)). Sophisticated progressive order assembly systems employ zone

skipping, transporting an order's container to a zone only if there is an SKU for the order in that particular zone.

Figure 8.7 Progressive order assembly.



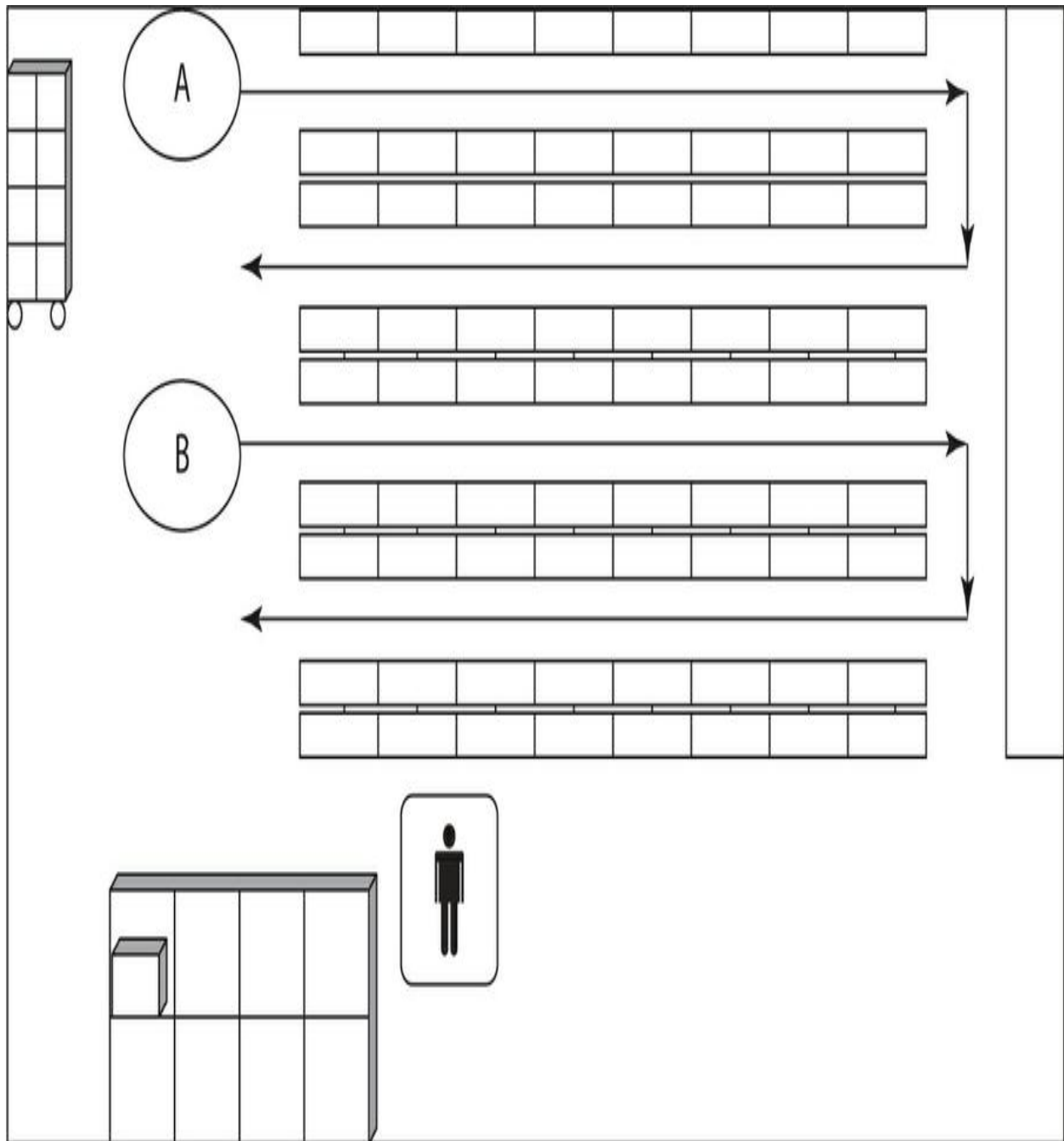
Downstream Sorting In zone picking with downstream sorting. Order pickers work in parallel, making full passes of their pick zone during a wave.

Product is typically bar-code labeled as it is picked and placed into a large cart or onto a conveyor belt that passes alongside the pick line. The contents of the cart and/or the items on the take-away conveyor are inducted into a sorting system that sorts the merchandise into customer orders.

The cost of downstream sorting systems can run into the millions of dollars. Hence, the incremental benefits of zone picking with downstream sorting compared with progressive order assembly must be sufficient to justify the incremental investment. The incremental benefits are primarily picking productivity benefits. The incremental cost is the difference between the cost of the material- and information-handling systems required for downstream sorting versus that required for passing orders from zone to zone.

Manual Downstream Sorting: Lanier Worldwide is a multibillion-dollar distributor of copiers, fax machines, and dictation equipment. A major portion of its revenue comes from service parts and supplies that support its installation base. Parts and supplies are stored in traditional bin shelving. Operators are assigned to zones comprised of two aisles of shelving ([Figure 8.8](#)). Orders are released to the picking floor in 20-minute waves, just long enough to allow efficient picking tours and just short enough to maintain the attention and sense of urgency of the order pickers. Each order picker pushes a specially designed picking cart through his or her zone. Each picking cart is subdivided into eight compartments. Before each picking tour, an empty tote labeled with that zone and operator's identification is placed in each of the eight containers. At the beginning of each wave, an order picker is given a pick list that walks the operator through his or her zone in location sequence. On each line on the pick list is the location, the item ID, the quantity to pick, and the number of the compartment (one to eight) on the cart into which to place the item. At the end of a tour, each order picker brings his or her cart to a large storage rack that is subdivided into (you guessed it) eight compartments. Each operator puts his or her number one tote in the number one compartment, his or her number two tote in the number two compartment, and so on. Standing on the other side of the storage compartment is an operator whose job is to sort the merchandise in each compartment into orders, check the orders for accuracy, and pack the orders for shipping. This operation yields manual picking productivity in excess of 120 lines per person-hour and exceptionally high picking accuracy.

Figure 8.8 Lanier's manual wave picking concept.



Automated Downstream Sorting Scroll's mail-order distribution center outside of Nagoya, Japan, is an excellent example of zone picking with automated downstream sorting ([Figure 8.9](#)).

Figure 8.9a Zone picking with automated downstream sorting.

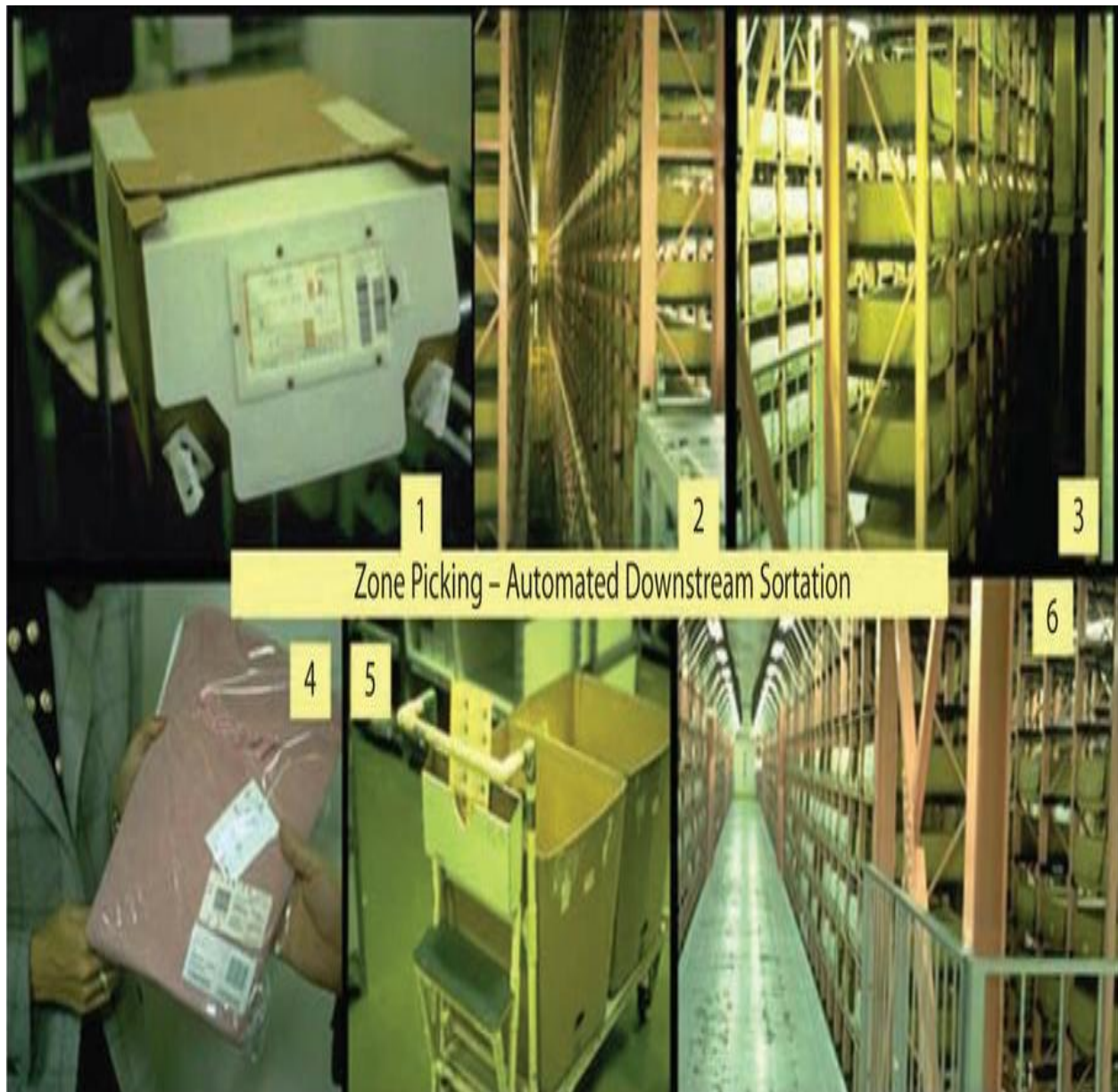
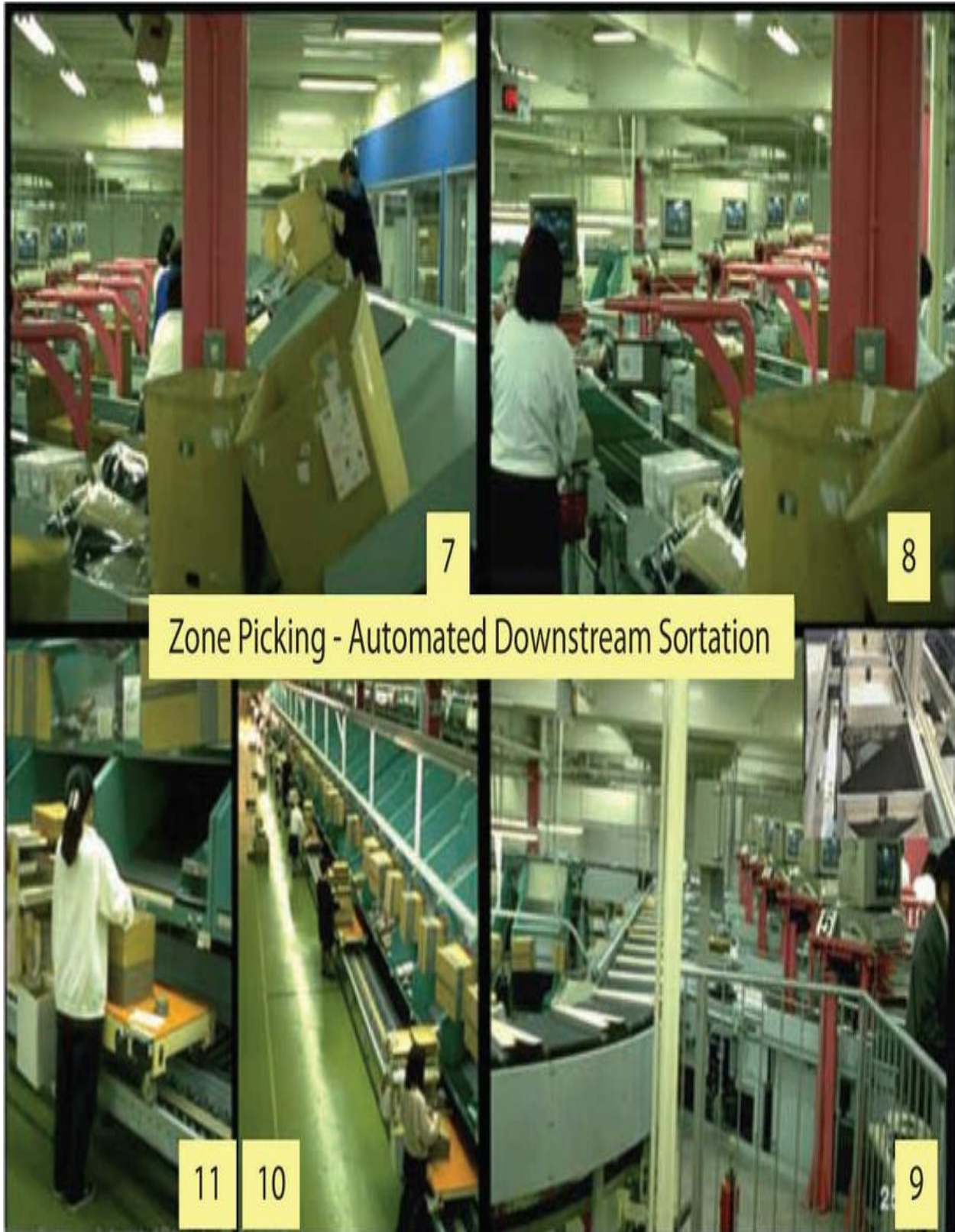


Figure 8.9b Zone picking with automated downstream sorting.



1. A returnable carton is used as a physical *kanban* indicating that a

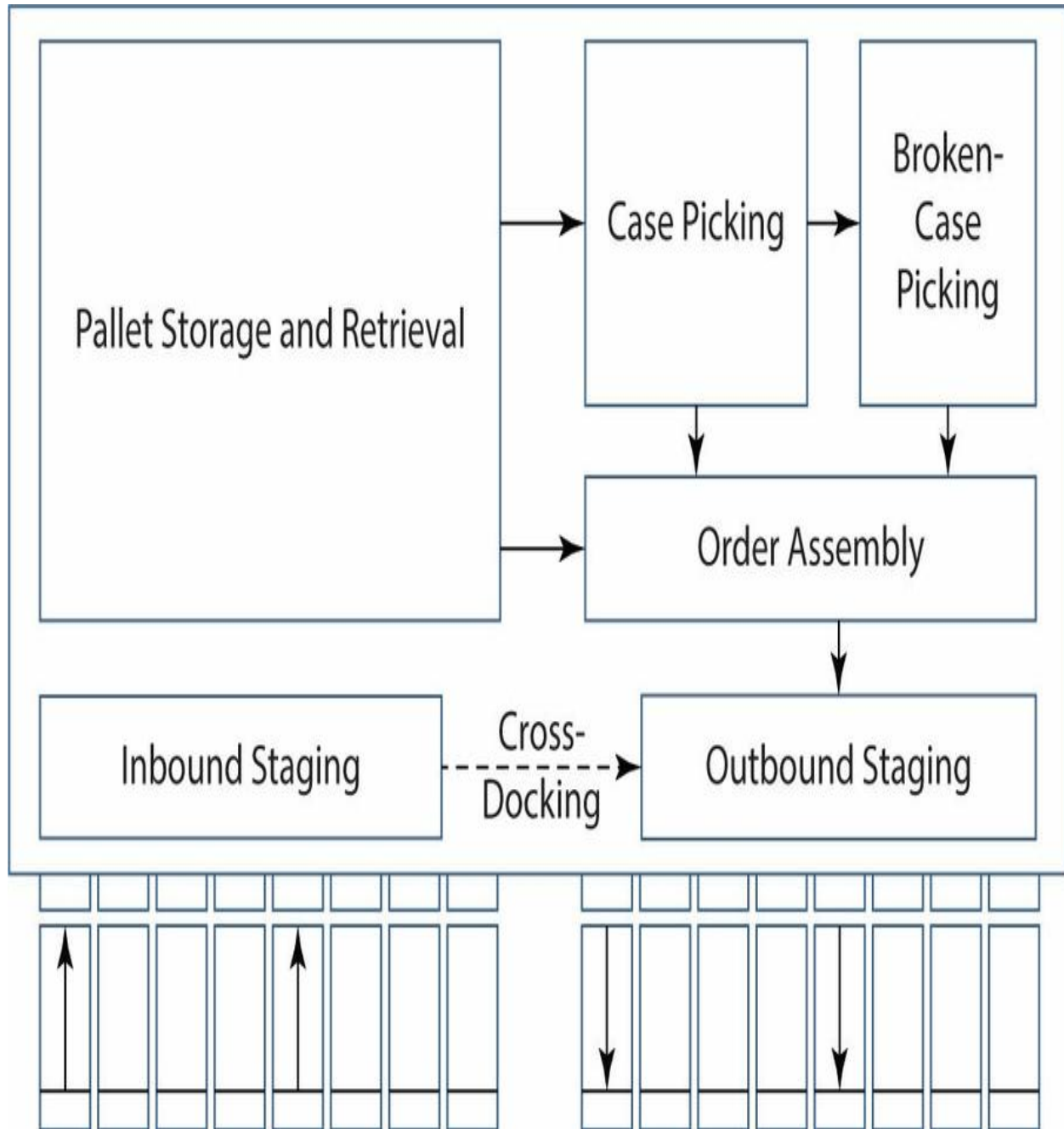
replenishment is required from a supplier, the inbound shipping container, and the picking carton.

2. Inbound cartons flow directly from inbound trailers into a miniload ASRS.
3. Picking aisles are on mezzanines on the opposite side of storage/retrieval aisles. Picking occurs during two shifts. During the third shift, the ASRS machine reconfigures the entire pick line for the next day's picking activity.
4. Pickers apply a bar-code label to each poly-bagged garment as it is picked into a picking cart.
5. A simple batch picking cart holds two corrugated totes.
6. Order pickers work in dedicated picking zones—one aisle is one zone.
7. Once full, each completed corrugated tote is conveyed to a sorter induction station. The contents of each tote are spilled into an induction station.
8. Induction operators orient each piece to be read by an overhead bar-code scanner, which assigns each piece to a cell on a cross-belt sorter.
9. The cross-belt sorter conveys each piece to its assigned packing lane and diverts it down the lane.
10. Packers move among the three or four lanes assigned to them, sort pack, and place product on an outbound shipping conveyor running below the bottom of the sorting lane.
11. A mobile packing station makes it easy to move between sorting lanes.

Pick from Storage

A traditional U-shaped warehouse layout ([Figure 8.10](#)) includes receiving docks, receiving staging, receiving inspection, put-away to reserve storage, reserve pallet storage and pallet picking, case pick-line replenishment from pallet storage, case picking, broken-case pick-line replenishment from case storage, broken-case picking, packing, accumulation, shipping staging, and shipping docks.

Figure 8.10 Traditional U-shaped warehouse configuration.



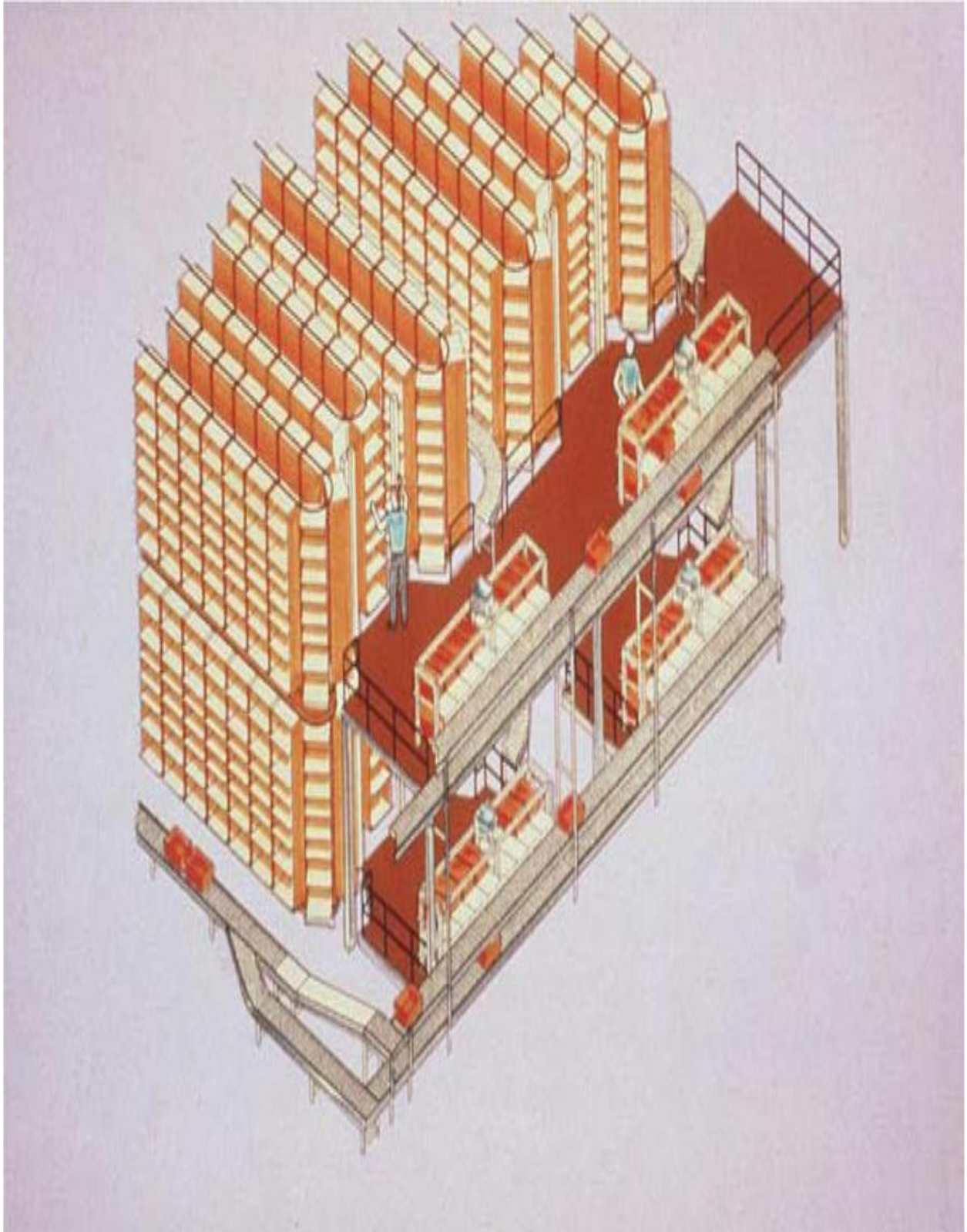
Why do we need so many different storage and picking areas? Why do we need separate forward areas for case and broken-case picking? The reason is that broken- and full-case picking productivity from a large reserve pallet storage area is low. The forward areas are small and compact, are uniquely configured for the picking task, and may have specialized equipment. As a

result, the picking productivity in these forward areas is much greater than the productivity in a large reserve storage area. The forward picking productivity gain is almost always so great compared with picking from reserve storage locations that the incremental cost for replenishing the forward areas and the incremental space required for these areas are rarely considered.

Now suppose that we could achieve forward picking rates from a reserve storage area. We can have our cake and eat it too—excellent picking productivity, no forward-area replenishment, and no extra space set aside for forward areas. Is this possible? It is in Ford's service parts distribution centers.

Ford Service Parts At Ford's service parts distribution centers ([Figure 8.11](#)), receipts arrive by rail in wire baskets, each identified with a bar-code license plate. The wire baskets are moved by a lift-truck operator to an automated receiving station. At the receiving station, the receiving operator scans the bar code to let the warehouse management system know that the item and cage are on site. The system then directs the operator to distribute the contents of the cage into one or more tote pans, each with a bar-code license plate. Each tote is, in turn, assigned to and conveyed to one of 54 horizontal carousels for put-away by the carousel operator. The carousel operators each work a pod of three carousels. A real-time warehouse management system interleaves the put-away and picking tasks. All picking is light directed, and the operator is also light directed to distribute each pick into order totes housed in flow racks adjacent to the carousels.

Figure 8.11 Pick-from-storage order picking concept.



Is this picking from storage? Yes, because the 54 carousels act as the

reserve storage area. The entire inventory for an item is housed in the carousel system, but not necessarily in the same carousel location. There is no replenishment within the system, and there is no space set aside for reserve stock.

This operating concept gives Ford a significant competitive advantage in service parts logistics. The concept requires a highly sophisticated logistics information system (i.e., random storage, intelligent slotting, activity balancing, and dynamic wave planning), a high degree of mechanization (to move the reserve storage locations to the order picker), and a disciplined workforce. This operating philosophy is not meant for every situation, but when the operating volumes are large enough and the necessary resources are available, the pick-from-storage concept can yield tremendous productivity gains.

Shiseido Because most of a typical order picker's time is spent traveling and/or searching for pick locations, one of the most effective means for improving picking productivity and accuracy is to bring the reserve storage locations to the picker. Shiseido recently installed systems that bring reserve storage locations to stationary order picking stations for batch picking of partial-case quantities and direct induction into a cross-belt sorting system ([Figure 8.12](#)). In so doing, order picking travel time has been eliminated. In addition, the same system can transfer storage locations to/from receiving, prepackaging, and inspection operations, virtually eliminating human travel throughout the warehouse. Though expensive, the systems may be justified by increased productivity, storage density and accuracy.

Figure 8.12 Pick-from-storage concept for health and beauty aids.



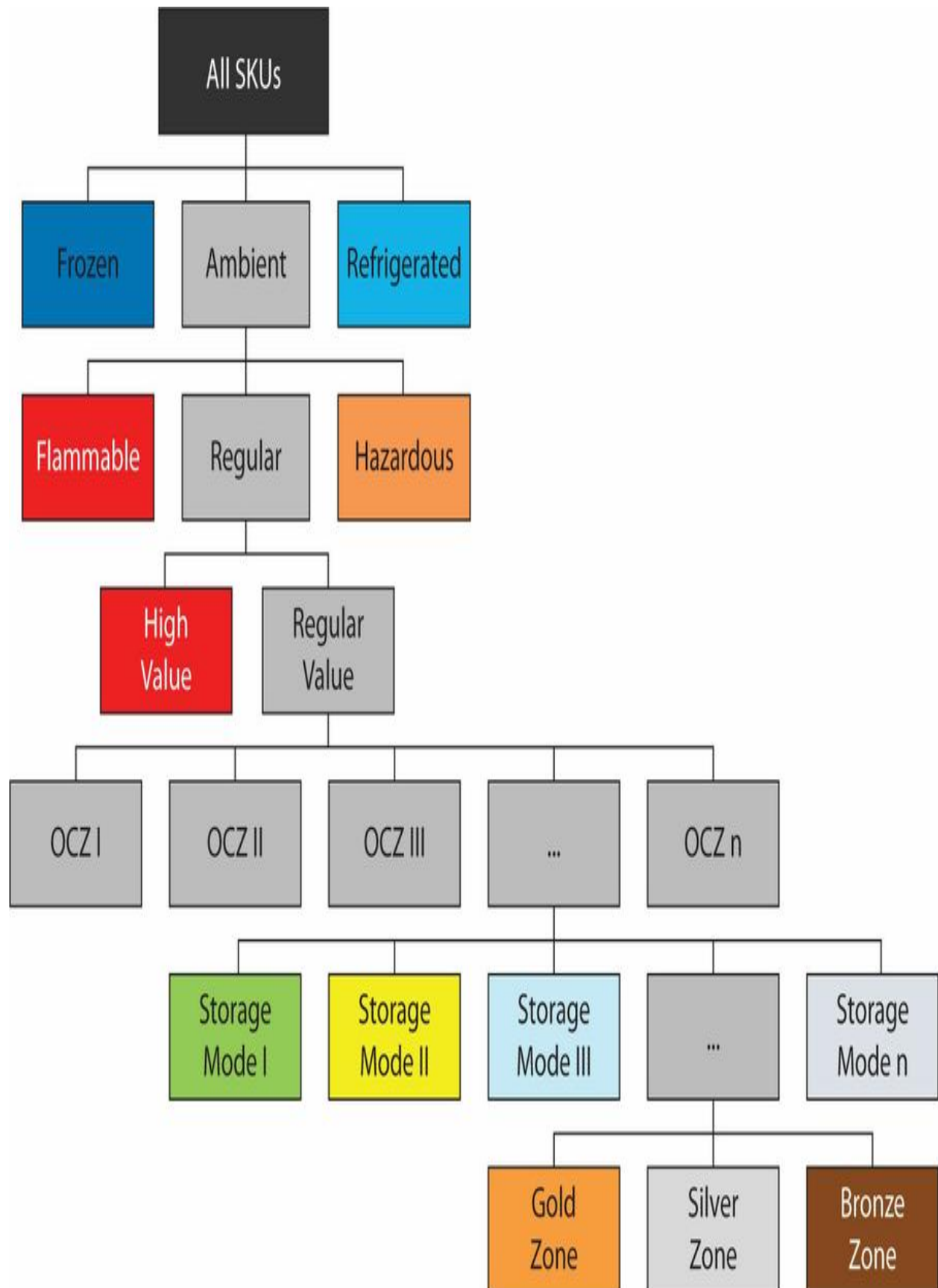
8.3 Slotting Optimization

In *slotting*, we determine for each item its (1) optimal storage mode, (2) optimal allocation of space, and (3) optimal storage location in its appropriate storage mode. As a result, slotting has a significant impact on all the warehouse key performance indicators—productivity, shipping accuracy,

inventory accuracy, dock-to-stock time, warehouse order cycle time, storage density, and level of automation. Few decisions have more impact on the overall performance of a warehouse than slotting. Yet, when we begin our RightSlot projects, we typically find that fewer than 15 percent of items are slotted correctly. Most warehouses are spending 10 to 30 percent more per year than they should because the warehouse is mis-slotted.

Our RightSlot methodology ([Figure 8.13](#)) is based on 25+ years of slotting projects. After looking back on all those projects and all those different types of items—cans, bottles, rolls of carpet backing, brake parts, spools of yarn, computer hardware, vials of nuclear medicine, automotive service parts, paper products, frozen food, and chainsaws—I identified the common denominators of the projects and developed this 10-step slotting methodology and supporting tool to assist in slotting projects.

Figure 8.13 RightSlot decision tree.



Populate the Slotting Database

Fortunately, the number of data elements required for slotting is not overwhelming. For each item, we need the following data:

- Item number
- Item description
- Material type
- Storage environment (i.e., frozen, refrigerated, flammable, hazardous, etc.)
- Shelf life
- Dimensions (length, width, and height)
- Item unit cube
- Weight
- Units per carton
- Cartons per pallet

This information should be readily available from the product or item master file. Just the process of evaluating the accuracy and availability of the data is helpful as a data-integrity audit.

For each customer order, we need the customer ID, the unique items requested on the order and the quantities of each, and order date and time. This information should be available from the sales and/or order-history file. The sample size required depends heavily on the seasonality of the industry. If there are large annual surges of demand, such as in the mail-order and retailing industries, then a 12-month sample is necessary. If the demand is fairly stable over the course of a year, as in automotive service parts, then a three- to six-month sample will be appropriate.

Compute Slotting Statistics

Once the raw data are captured, the computation of slotting statistics is fairly straightforward ([Table 8.4](#)).

Table 8.4 RightSlot Statistics and Formulas

Slotting Statistic	Symbol	Unit(s) of Measure	Notes and Comments
Slotting period	R	Time (year, quarter, month, week, day)	The time period for slotting calculations
Popularity	P	Requests per period	Sometimes referred to as the <i>hits</i> on an item; used with volume to determine assignment to a storage mode and location within the storage mode
Turnover	T	Units shipped per period	Sometimes referred to as the <i>demand</i> for an item; used with unit cube to compute cube movement for storage-mode assignment and space allocation
Unit cube	C	Cubic feet per unit	Measures the physical size of one unit of a unique item; the information may already be in a database; if not, C can be computed by measuring the size of the outer container for the item (e.g., pallet, case, tote, bag, etc.) and dividing by the number of units in the container
Cube movement	$V = T \times C$	Cubic feet per period	Sometimes referred to as the <i>volume</i> ; used to determine the appropriate storage mode and the allocation of space in the storage mode
Pick density	$D = P/V$	Requests per cubic foot	Used in golden zoning; the items with the highest pick density should be assigned to the most accessible picking locations
Demand increment	$I = T/P$	Units per request	—
Demand correlation	DC_{ij}	—	The probability that item i will appear on an order when item j does
Standard deviation of demand	S	—	Measure of the daily standard deviation of demand

These statistics appear on the surface to be self-explanatory. However, there are some subtle but critical issues surrounding the interpretation of each statistic. For example, popularity is often incorrectly measured in dollar or unit sales. The popularity P of an item, like the popularity of a song on a jukebox, should be measured by the number of times it is requested. This indicator is critical because it is a measure of the number of potential times an operator will visit the location for a particular item. Because most of the work in a warehouse is traveling to, from, and between warehouse locations, knowledge of the potential location visits for individual and families of items is critical to success in managing the overall work content in the warehouse.

Unfortunately, many warehouse managers stop with popularity for slotting criteria. Popularity is used singly to assign items to storage modes, to allocate space in storage modes, and to locate items within storage modes. Let's consider the example of golden zoning a section of bin shelving. The objective is to maximize the amount of picking activity at or near waist level. Assume that 7 cubic feet of space is available in the golden zone. Suppose that there are three items we are considering for slotting. The slotting statistics for the three items are recorded in [Table 8.5](#).

Table 8.5 Bin-Shelving Slotting Example

Item ID	Popularity	Cube Movement	Pick Density
A	140 requests/month	7 ft ³ /month	20 requests/ft ³
B	108 requests/month	4 ft ³ /month	27 requests/ft ³
C	75 requests/month	3 ft ³ /month	25 requests/ft ³

Suppose that we decide to store a month's supply of material in bin shelving. Item A requires 7 cubic feet, item B requires 4 cubic feet, and item C requires 3 cubic feet. Suppose that we rank the items based on popularity alone to determine the order of preference for assignment into the golden zone. (Remember, the golden zone has only 7 cubic feet of capacity.) With popularity ranking, item A will be assigned to (and will exhaust the available space in) the golden zone. There will be 140 visits to the golden zone per

month. (Remember, we are trying to maximize the number of trips to the golden zone.) Is this the best we can do? Absolutely not! Suppose that we assign items B and C to the golden zone. There will be 183 trips to the golden zone. Had we used pick density as the criterion for preference ranking, we would have maximized the activity in the golden zone. This is why it is so important to utilize all the slotting statistics.

Assign Items to Environmental Families

Assign items to *storage-environment families* based on requirements for storage temperature (e.g., frozen, refrigerated, and ambient), flammability, toxicity, and security. These storage-environment families will specify the need for special building requirements, special racking requirements, and special material-handling zones.

Assign Items to Order-Completion Zones

Within each storage environment, assign items to *order-completion zones* based on the order-completion and demand correlation analysis completed in warehouse activity profiling. These order-completion zones will create warehouses within the warehouse for highly efficient order picking.

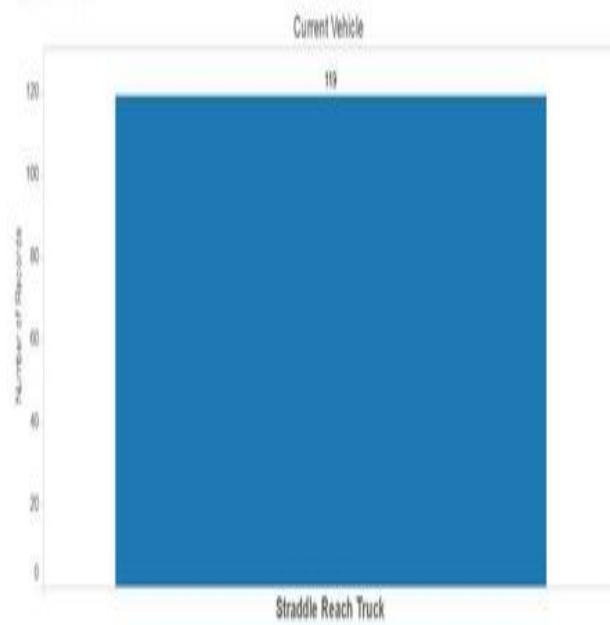
Assign Items to Storage-Mode Families

Based on productivity, storage density, picking error rates, and system investment requirements, a storage-mode economic analysis should determine the least-cost storage mode for each item. The items assigned to a particular storage mode become the members of that storage mode's family. Our Right-Store optimization computes the annualized cost of assigning each item to each storage mode. The least-cost mode and optimal space allocation are recommended for each item. Example output illustrates ([Figures 8.14](#) and [8.15](#)) the assignment of item-activity families to storage-mode families.

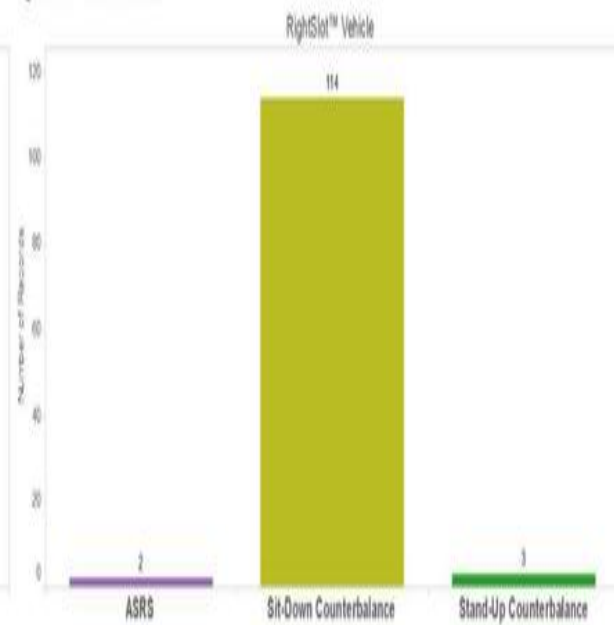
Figure 8.14 RightStore pallets optimization.

RightStore™ | Storage Mode Optimization | Pallets

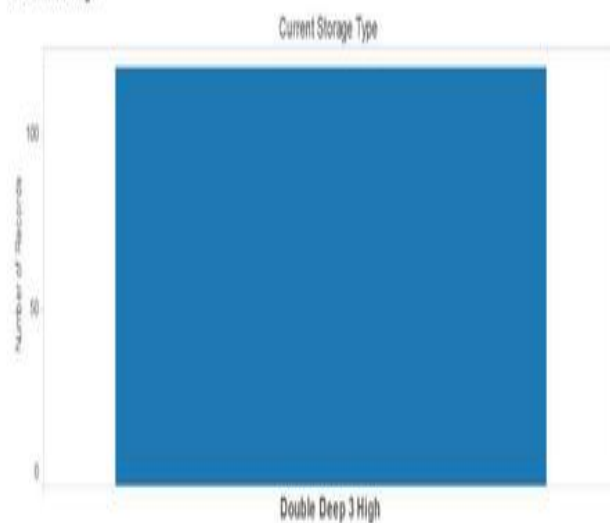
Current Vehicles



RightStore™ Vehicle Solution



Current Storage



RightStore™ Storage Solution

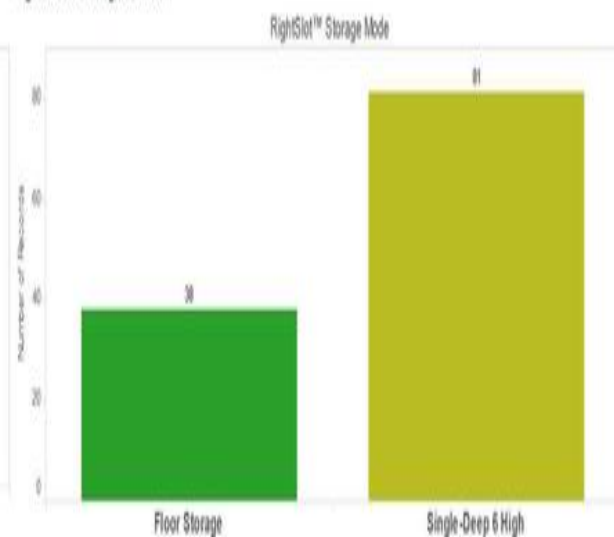
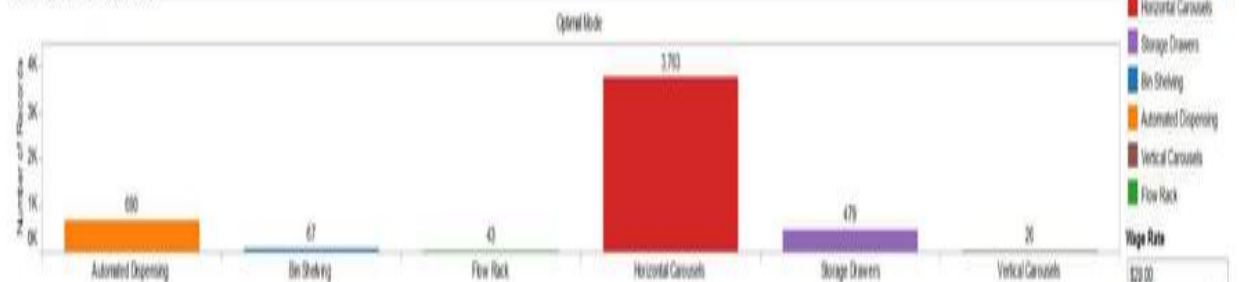


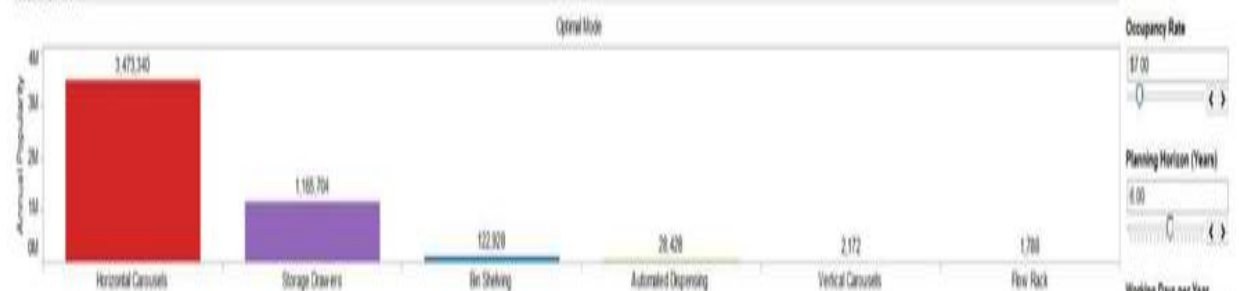
Figure 8.15 RightStore eaches optimization.

[SOLUTION](#)
[RightClick™ Savings](#)
[X-Popularity Y-CM](#)
[X-Turnover Y-Popularity](#)
[Mis-Sorted SKUs](#)
[Bin Shelves](#)
[Automated Dispensing](#)
[Flow Rack](#)
[Horizontal Carousels](#)
[Unload](#)
[Storage Drawers](#)
[Vertical Carousels](#)
[Optimization](#)
[Optimization 2](#)

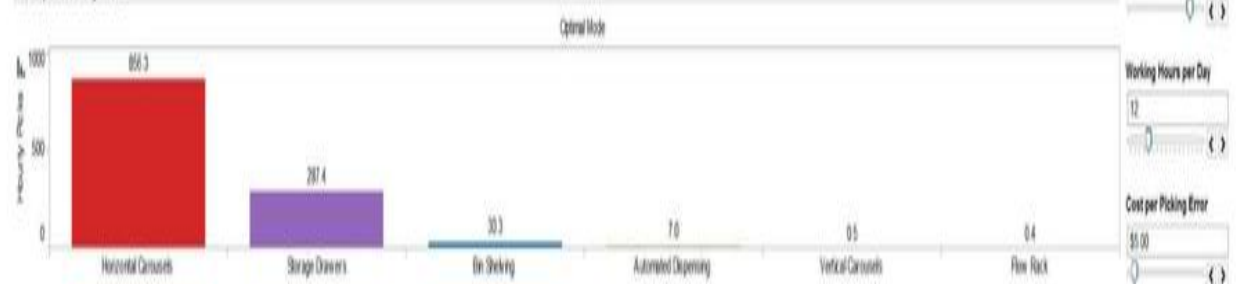
SKUs by Optimal Picking Mode



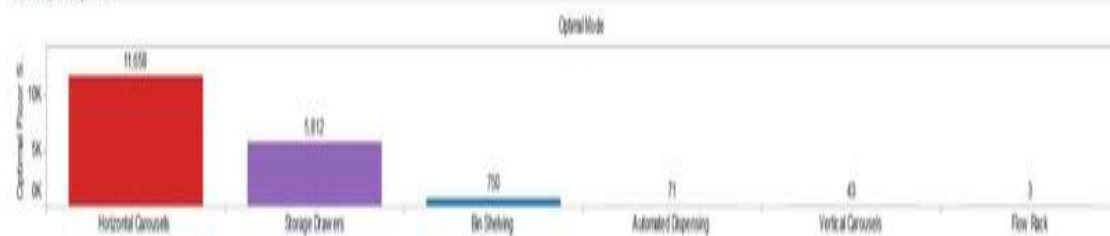
Picks by Mode



Picks per Hour by Mode



Floor Space by Mode



Rank Items Based on Pick Density

Rank items from highest to lowest based on picking density ([Figure 8.16](#)). In Bertelsmann's book distribution center, a worn place in the carpeted picking floor is a good indicator that pickers are most often working near the center of the picking zone.

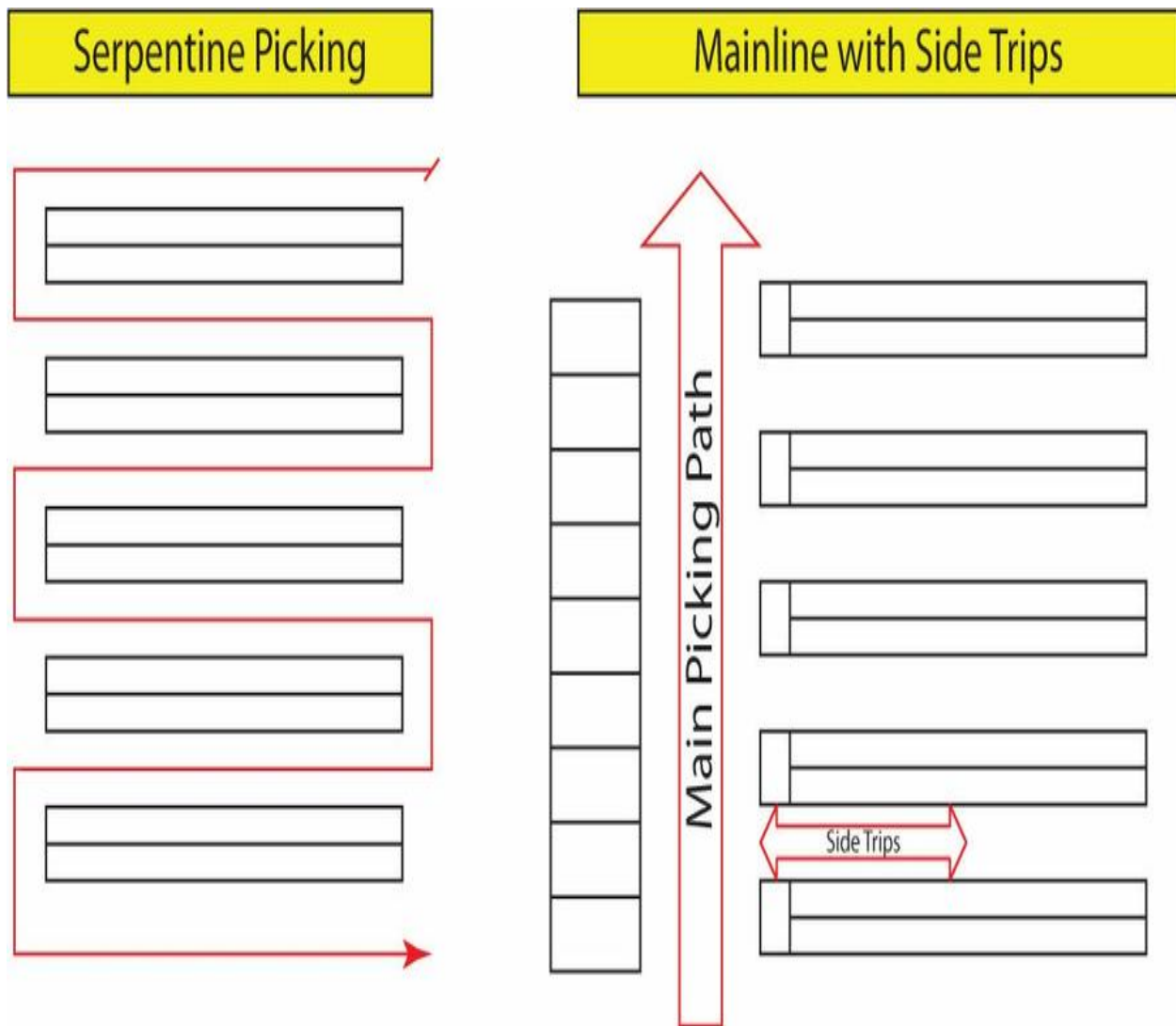
Figure 8.16 Pick-density-based storage at Bertelsmann's Gutersloh distribution center.



Map Individual Warehouse Locations Within Each Storage Mode into Picking-Activity Zones

The first step is to plot the pick path through each storage mode. Once the pick path has been determined, the definition of the activity zones is fairly straightforward. The two most popular pick paths are the *serpentine* and *mainline with side trips* (Figure 8.17).

Figure 8.17 Serpentine and mainline picking with side trips.



In serpentine picking, order pickers travel down each aisle and by each location. Hence, to designate an A-activity zone near one end of the pick line will not reduce travel time. In fact, it may create congestion. Instead, the A-activity zone should be the locations that are at or near waist level for broken-case picking and at or near floor level for case picking from pallet racks.

In mainline picking with side trips, the objective is to minimize the number and length of the side trips. Hence the A-activity zone should be the locations along the mainline.

Follow the Map to Slot

Simply stated, the principle of golden zoning is to slot the most popular items in the most accessible locations. In RightSlot we rank each location by accessibility and rank each item by pick density. We slot the item with the highest pick density in the location with the greatest accessibility. We slot the item with the second highest picking density in the location with the second greatest accessibility. We continue until all the items have been slotted and the locations occupied.

Develop Reslotting Statistics

Almost as soon as an item is properly slotted, its activity profile changes. For example, in the mail-order industry, changes in catalogs yield major changes to the warehouse activity profile and major changes to the slotting requirements. Hence, slotting must be continually updated to maintain the productivity and storage-density gains achieved under the initial slotting program.

Based on the initial slotting, reslotting rules should be defined to suggest if and when a particular item should be reslotted. The rules can be developed with the help of a simple *from-to chart* that computes the potential cost savings of moving an item from its current mode and zone to every other mode and zone. This savings is compared with the cost to move the item. If the savings-to-cost ratio exceeds a predetermined threshold, the item is recommended for reslotting. An example reslotting from a recent client engagement is provided in [Figure 8.18](#). The tool prioritizes reslotting based on the degree of mis-slotting.

Figure 8.18 RightSlot reslotting analysis for a single SKU. In this case, the recommendation is to relocate the SKU from storage drawers to horizontal carousels, yielding an annual savings of \$28.35 and a move cost of \$1.86 for a four-week payback period.

	Item Number/Item Description/Category/Current Mode/Optimal Mode 11098 Downy Sheets April Fresh Stationery Storage Drawers Horizontal Carousels
Annual popularity	972.00
Annual turnover	984.00
Current Annual Operating Cost	\$532
Optimal Annual Operating Cost	\$505
Unit Cube (unit cube CF)	0.42
Cube Movement	414.56
Demand Increment (Eaches per Pick)	1.01
Cube Increment (CF per Pick)	0.43
Pick Density (Picks per CF)	2,307.16
RightSlot™ Savings (\$/year)	\$27.35
Current Cost (% of Sales)	8.98%
Optimal Cost (% of Sales)	8.52%
Move Cost	\$1.86
Payback Period (Years)	0.07

Develop and Implement a Reslotting Program

Perhaps a more difficult question is the timing of a general reslotting of the entire warehouse. Unfortunately, there is very little science to go on here.

Most warehouses have a natural demand rhythm. For example, L.L. Bean, the mail-order catalog operator, drops four main catalogs a year—winter, spring, fall, and summer. It is natural in their case to reslot the warehouse every season. Avon Products has 26 promotional campaigns a year. The warehouse has to be reslotted 26 times a year.

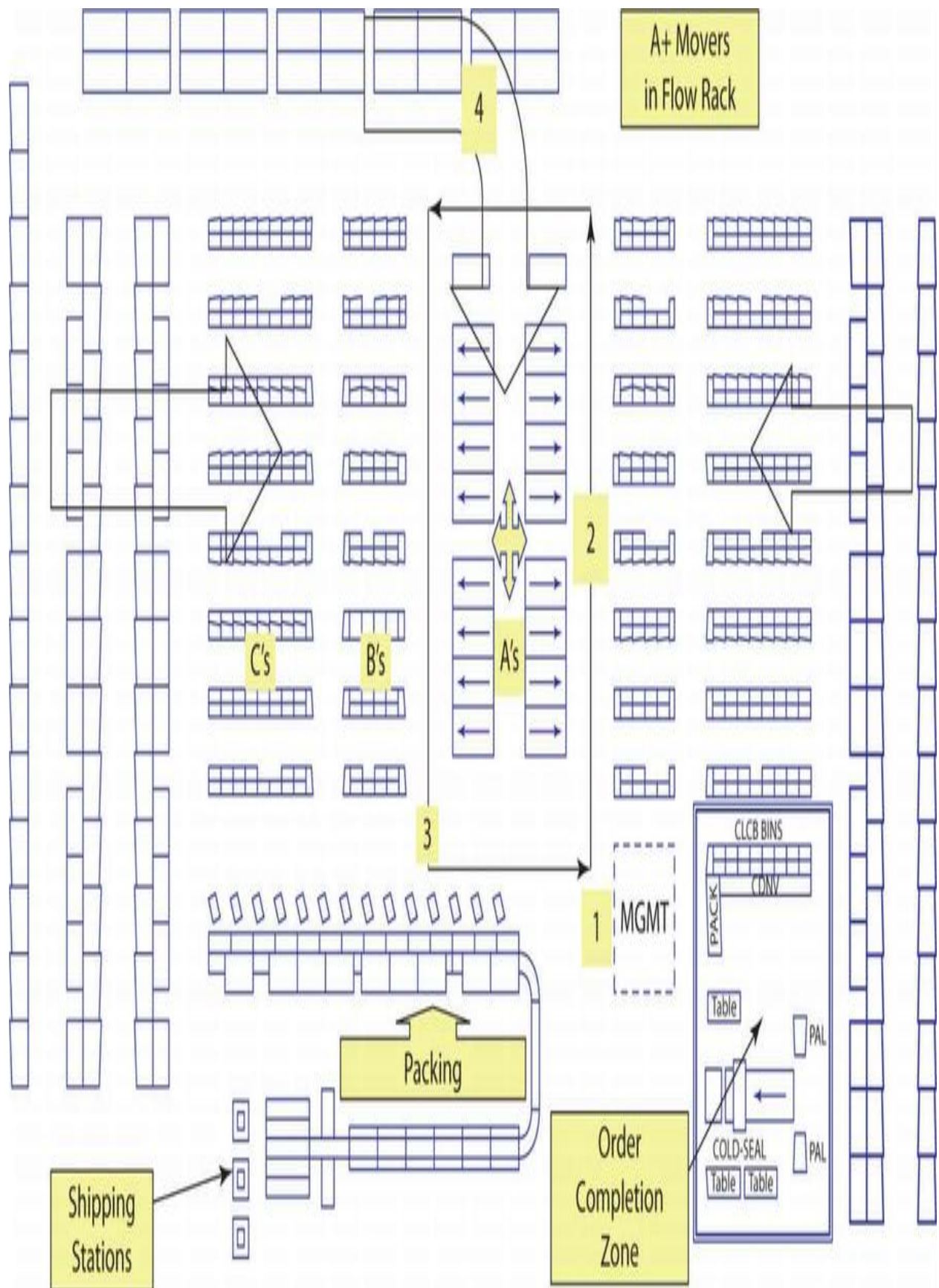
Lifeway Christian Resources

Lifeway Christian Resources publishes and distributes Christian media (i.e., books, periodicals, cassette tapes, CDs, videos, etc.) and gift items to bookstores (retail distribution), churches (church distribution), and individuals (mail order) all over the United States. More than 15,000 items are housed in its 600,000-square-foot distribution center in downtown Nashville. The reserve inventory for each business unit is centralized and housed in high-bay random locations. The forward picking inventory is housed in dedicated locations on separate low-bay picking floors for each business unit. Because the business is a low-margin, there is little or no capital available for highly mechanized systems. Hence, the design strategy is to eliminate and streamline as much work content as possible.

The slotting and layout plan for the retail picking floor is illustrated in [Figure 8.19](#). Note the main horseshoe-shaped pick line in the center of the warehouse. While traversing this pick line, order pickers pick approximately 20 orders per pass. A specially designed cart organized to hold 24 orders allows pickers to quickly and efficiently sort individual picks into orders. Items with the highest cube movement are housed in carton flow rack in the center of the layout. Because each picking tour will pass each flow-rack bay, the picking activity is purposefully distributed evenly along the flow-rack pick line. The most popular flow-rack items are located at or near waist level. The remainder of the items falls naturally into bin shelving. To minimize travel time, the bin-shelving items with the greatest pick density are assigned to locations along or near the pick line. This slotting scheme alleviates any congestion problems and allows nearly 75 percent of the picks to be executed along the main pick line. The reserve stock for the carton flow rack is housed in double-deep pallet racks along the back wall. Batched replenishments are executed along the back of the flow lanes. Reserve stock for the bin shelving is conveniently located in single-deep pallet racks along the sidewalls. This slotting and operating scheme yielded a 100 percent improvement in

productivity and response time with minimal capital investment and risk.

Figure 8.19 Lifeway Christian Resources order-picking layout.



8.4 Pick-Tour Sequencing

In both picker-to-stock and stock-to-picker systems, pick location sequencing reduces travel time and increases picking productivity. For example, the travel time for a person-aboard ASRS picking tour can be reduced by 50 percent simply by dividing the rack into upper and lower halves and visiting pick locations in the lower half in increasing distance from the front of the rack on the outbound leg and in decreasing distance in the upper half of the rack during the inbound leg ([Figures 8.20 and 8.21](#)).

Figure 8.20 Picking tour prior to pick sequencing

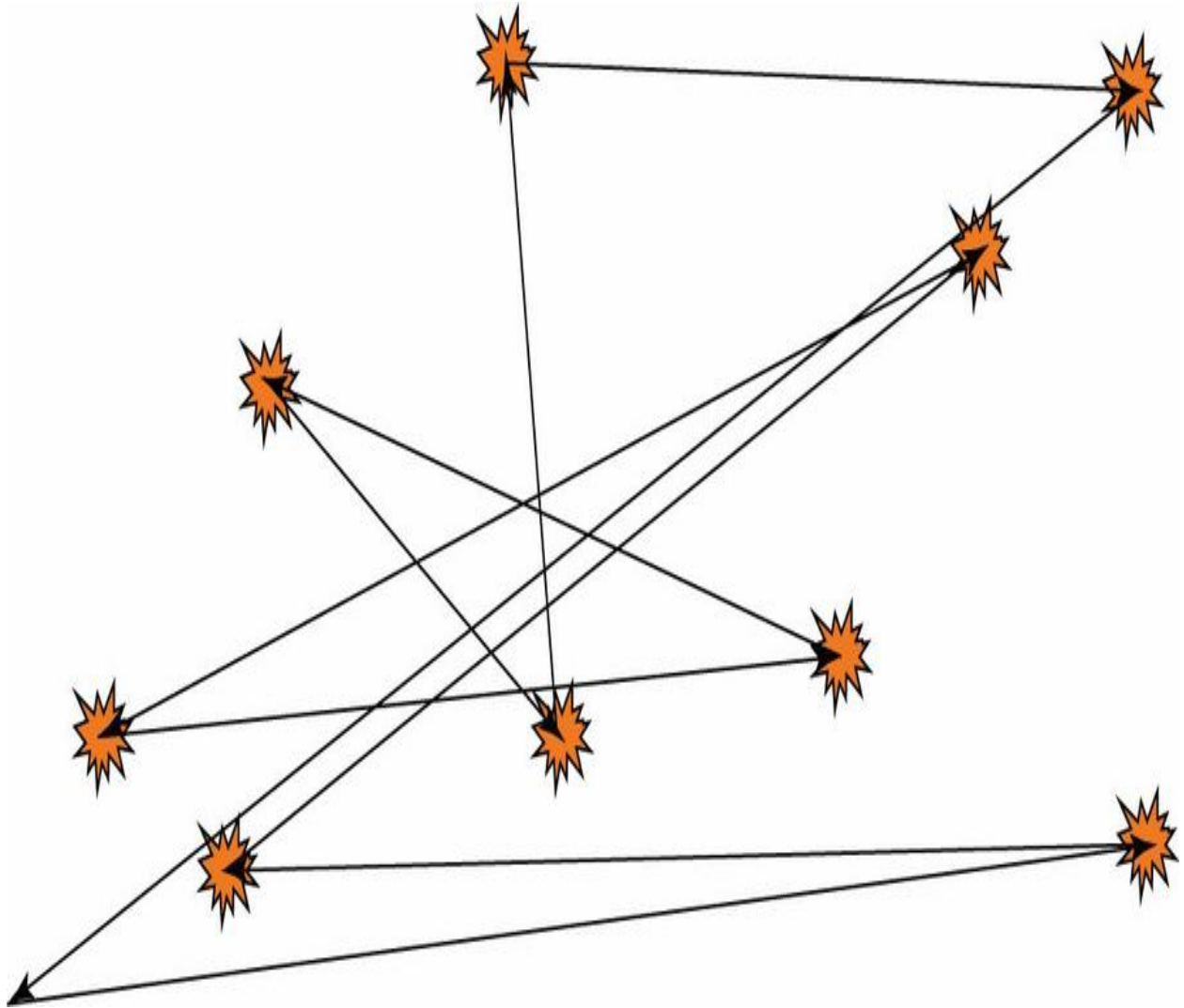
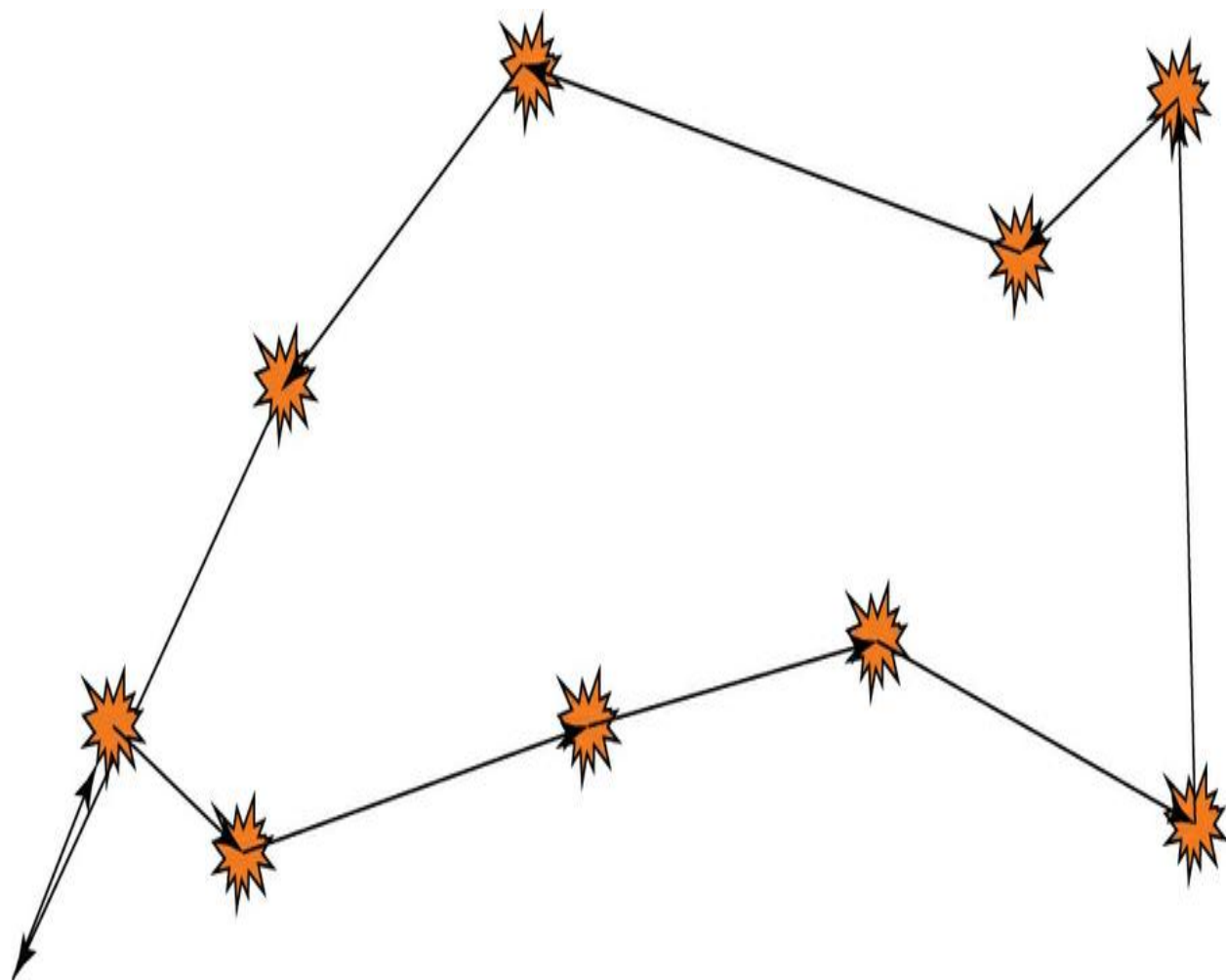


Figure 8.21 Picking tour after pick sequencing



CHAPTER NINE

WAREHOUSE LAYOUT OPTIMIZATION

- 9.1 Space Requirements Planning**
- 9.2 Adjacency Optimization**
- 9.3 Material Flow Planning**
- 9.4 Bay Matching**
- 9.5 Material-Handling Equipment**
- 9.6 Maximize Space Efficiencies**
- 9.7 Expansion/Contraction Planning**

Warehouse layout is much like puzzle piecing. The puzzle pieces are the warehouse activities of receiving, receiving staging, pallet storage and retrieval, case picking, piece picking, packing, order assembly, shipping staging, and so on. As with a puzzle, it is impossible to complete until all the individual pieces have been shaped and sized. The individual shaping and sizing of those individual pieces were completed in previous chapters, where

we selected equipment and determined space requirements for each activity. Our seven-step RightPaths methodology for putting those activities together into an efficient warehouse layout is the subject of this chapter.

1. Determine space requirements for all warehouse functions.
2. Locate functions with high adjacency requirements close to one another.
3. Assign activities with high storage requirements to high-bay space and labor-intensive processes in low-bay space.
4. Determine flow paths.
5. Assign the optimal material-handling method to each flow path.
6. Minimize space requirements.
7. Develop and document expansion/contraction strategies.

9.1 Space Requirements Planning

Warehouse layouts should be based primarily on the space requirements for and the interrelationships between warehouse activities. The first step in laying out a warehouse is to *determine the overall space requirements for all warehouse activities*. The Space Requirements Optimization from our RightHouse Layout Optimization System optimizes and summarizes long-term space requirements ([Figure 9.1](#)).

Figure 9.1 Warehouse space requirements optimization.

RightHouse™ Layout Optimization System

edward@rightchain.com

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Comments

Views



Activity

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10					
2	Receiving Staging	20,000	20,600	21,218	21,855	22,510	23,185	23,881	24,597	25,335	26,095					
3	Receiving Inspection	10,000	10,300	10,609	10,927	11,255	11,593	11,941	12,299	12,668	13,048					
4	Putaway Staging	15,000	15,450	15,914	16,391	16,883	17,389	17,911	18,448	19,002	19,572					
5	Pallet Storage	120,000	123,600	127,308	131,127	135,061	139,113	143,286	147,585	152,012	156,573					
6	Case Picking	30,000	30,900	31,827	32,782	33,765	34,778	35,822	36,896	38,003	39,143					
7	Piece Picking	10,000	10,300	10,609	10,927	11,255	11,593	11,941	12,299	12,668	13,048					
8	Order Assembly	40,000	41,200	42,436	43,709	45,020	46,371	47,762	49,195	50,671	52,191					
9	Packing	15,000	15,450	15,914	16,391	16,883	17,389	17,911	18,448	19,002	19,572					
10	Shipping Staging	20,000	20,600	21,218	21,855	22,510	23,185	23,881	24,597	25,335	26,095					
11	Returns	12,000	12,360	12,731	13,113	13,506	13,911	14,329	14,758	15,201	15,657					
12	Sub Total 1	292,000	300,760	309,783	319,076	328,649	338,508	348,663	359,123	369,897	380,994					
13	Main Aisles	43,800	45,114	46,467	47,861	49,297	50,776	52,299	53,868	55,485	57,149					
14	Sub Total 2	335,800	345,874	356,250	366,938	377,946	389,284	400,963	412,992	425,381	438,143					
15	Offices	18,000	18,540	19,096	19,669	20,259	20,867	21,493	22,138	22,802	23,486					
16	Restrooms	6,000	6,180	6,365	6,556	6,753	6,956	7,164	7,379	7,601	7,829					
17	TOTAL	359,800	370,594	381,712	393,163	404,958	417,107	429,620	442,509	455,784	469,457					
18																
19																
20																

Storage Requirements Planning

One of the most difficult decisions to make in storage-space planning is the portion of the peak storage requirements to accommodate. If the duration of the peak is short-lived and the peak-to-average storage ratio is high, then outside warehousing and/or trailer storage should be considered to accommodate the peak storage requirements ([Figure 9.2](#)). If the duration of the peak is for an extended period and the peak-to-average storage ratio is low, then the storage area should be sized at or very near peak requirements ([Figure 9.3](#)).

Figure 9.2 Storage capacity requirements with a short-lived high peak-to-average storage ratio.

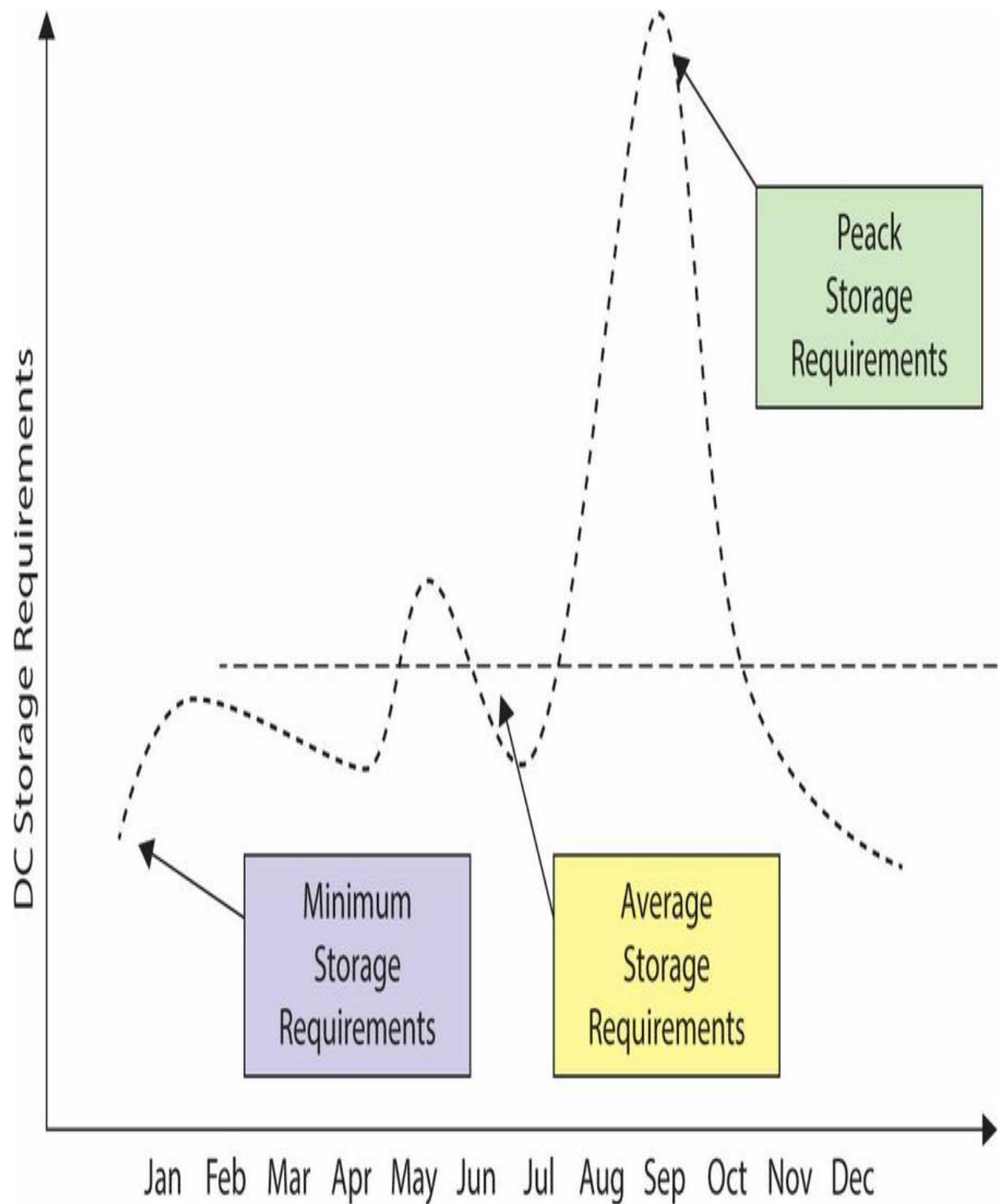
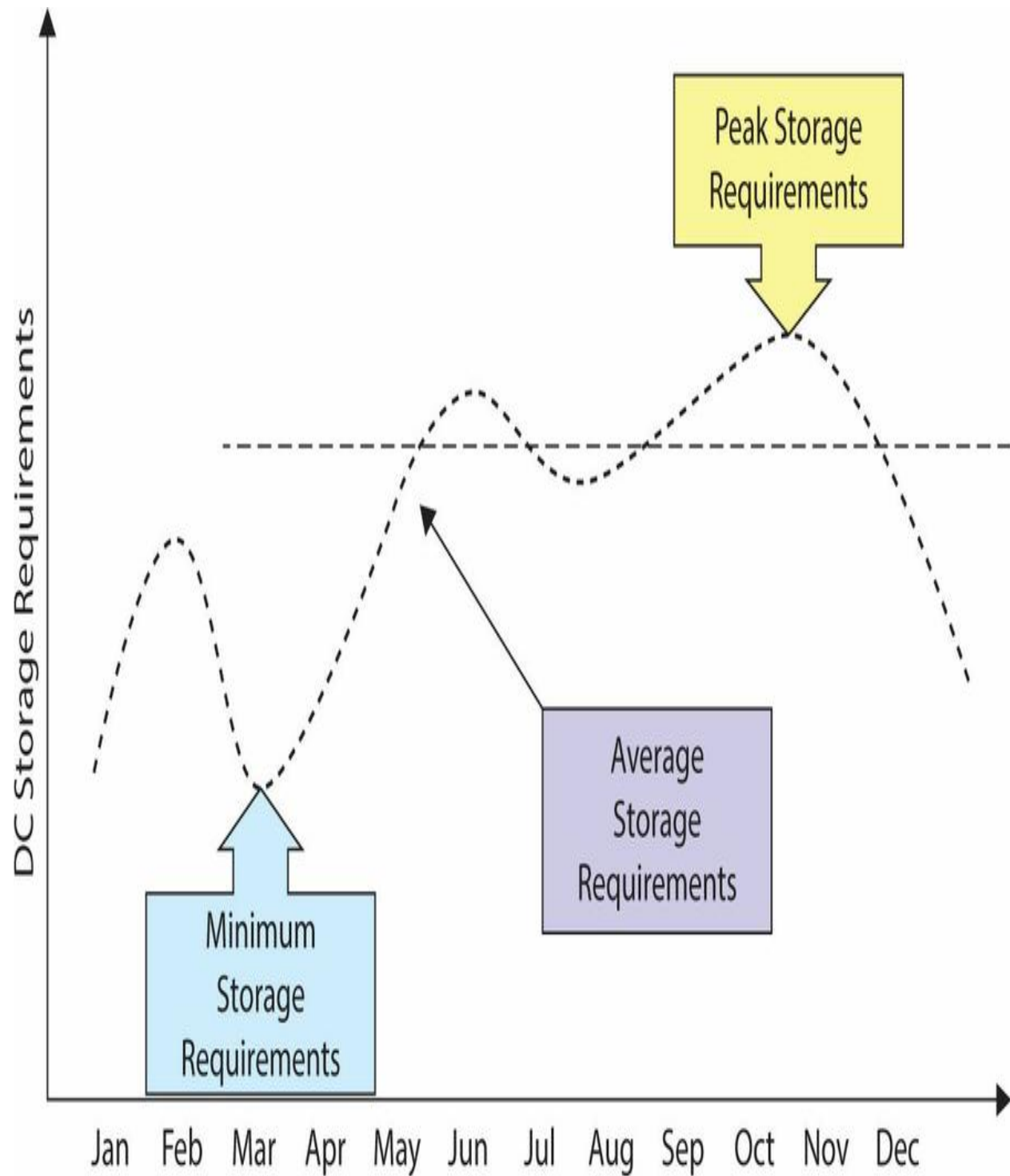


Figure 9.3 Storage capacity requirements over time with a low peak-to-average storage ratio.

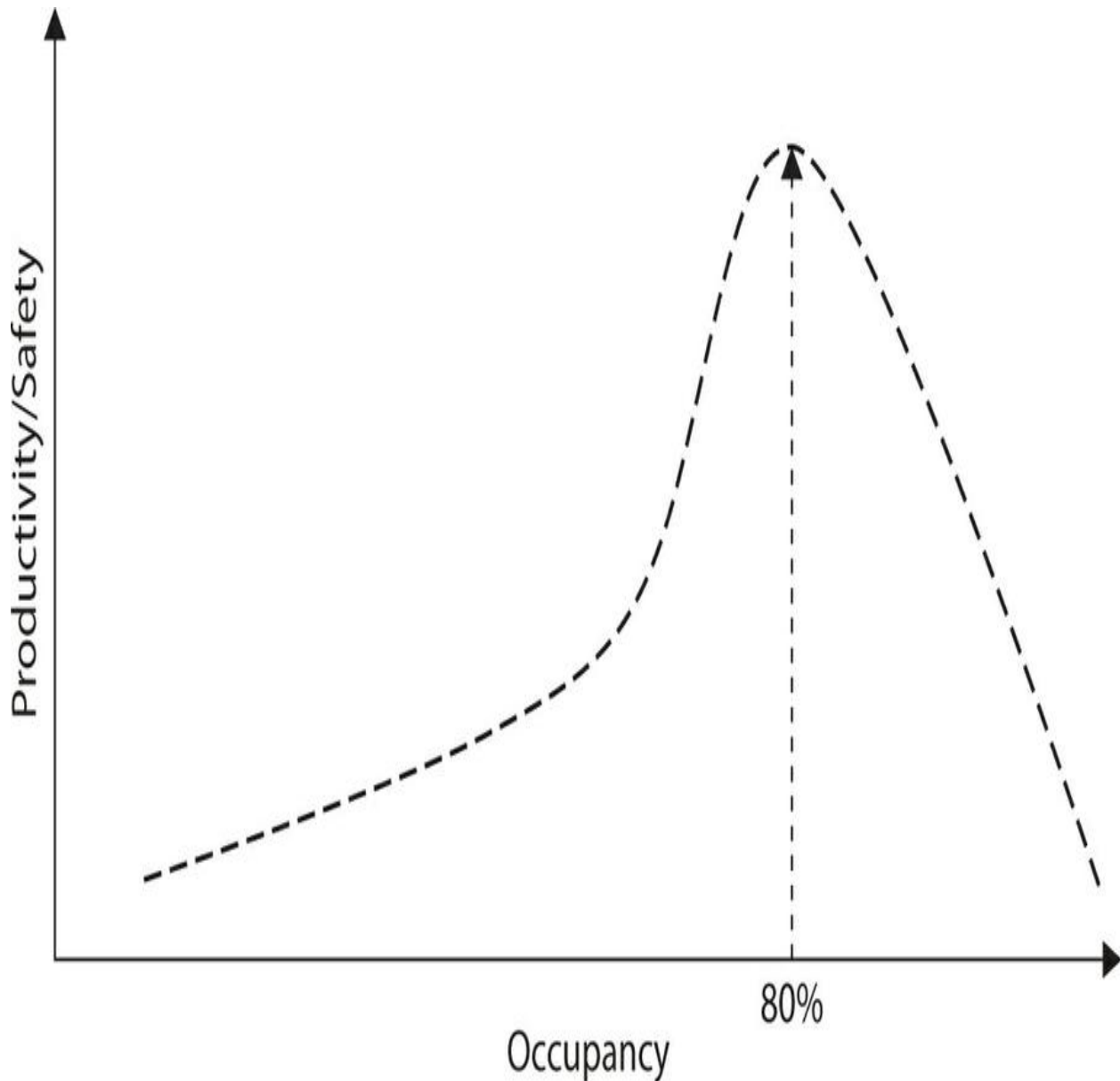


Occupancy versus Productivity

Another important consideration in storage space requirements planning is the portion of warehouse locations that will be occupied for planning

purposes. As the utilization of storage locations exceeds 85 percent in non-real-time warehouses and 90 percent in real-time warehouses, the productivity and safety of the operations decline dramatically ([Figure 9.4](#)).

Figure 9.4 Warehouse productivity versus warehouse occupancy.



Stihl Corporation

Stihl Corporation recently asked us to assist them in projecting their long-term warehouse space requirements. Because pallet storage occupies the most space, we began by computing the storage-space requirements for pallets. The computations and scenarios are described next and illustrated in [Figure 9.5](#).

Figure 9.5 Storage requirements optimization.

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Scenario	Year	Forecasted Unit Growth Rate	Forecast Demand (units)	Forecasted Unit Turn Rate	Average Inventory Level	Units per Pallet	Average Pallets On Hand	Average Inventory Ratio	Percent of Peak for Planning	Maximum Pallet Location Utilization	Required Pallet Positions	Aisle Width (Feet)	Storage Levels	Storage Density (Square Feet per Pallet Position)	Floorspace Requirements (Square Feet)	Cost per Square Foot	Annual Occupancy Cost
Baseline	Year 1	3.00%	275,620	6.2	44,456	43	1,034	108%	92%	80%	1,517	12	3	20	30,342	\$7.85	\$238,183
	Year 2	5.00%	289,410	6.4	45,220	40	1,131	109%	92%	80%	1,674	12	3	20	33,485	\$8.00	\$287,861
	Year 3	6.00%	306,775	7.1	43,208	38	1,137	110%	93%	80%	1,681	12	3	20	33,622	\$8.15	\$274,022
	Year 4	7.00%	328,240	7.2	45,590	38	1,200	112%	93%	80%	1,806	12	3	20	36,121	\$8.25	\$298,000
	Year 5	8.00%	354,509	7.3	48,563	35	1,368	115%	94%	80%	2,122	12	3	20	42,437	\$8.50	\$360,716
	Year 6	8.00%	362,870	7.5	51,049	35	1,459	115%	94%	80%	2,230	12	3	20	44,610	\$8.75	\$390,337
	Year 7	5.00%	402,014	7.5	53,602	30	1,787	120%	95%	80%	2,821	12	3	20	56,423	\$9.00	\$507,807
	Year 8	5.00%	422,114	7.5	56,262	30	1,876	120%	95%	80%	2,962	12	3	20	59,244	\$9.25	\$548,008
	Year 9	4.00%	438,999	7.5	58,533	30	1,951	125%	96%	80%	3,176	12	3	20	63,513	\$9.50	\$603,370
	Year 10	4.00%	456,559	7.5	60,875	30	2,029	125%	96%	80%	3,303	12	3	20	66,053	\$9.75	\$644,018
Tunnel	Year 1	3.00%	275,620	6.2	44,456	43	1,034	108%	92%	87%	1,385	6.5	5	8	11,160	\$7.85	\$87,697
Trucks	Year 2	5.00%	289,410	6.4	45,220	40	1,131	109%	92%	87%	1,640	6.5	5	8	12,316	\$8.00	\$98,531
	Year 3	6.00%	306,775	7.1	43,208	38	1,137	110%	93%	87%	1,546	6.5	5	8	12,367	\$8.15	\$100,790
RF	Year 4	7.00%	328,240	7.2	45,590	38	1,200	112%	93%	87%	1,681	6.5	5	8	13,286	\$8.25	\$109,609
	Year 5	8.00%	354,509	7.3	48,563	35	1,368	115%	94%	87%	1,951	6.5	5	8	15,609	\$8.50	\$132,677
	Year 6	8.00%	362,870	7.5	51,049	35	1,459	115%	94%	87%	2,051	6.5	5	8	16,408	\$8.75	\$143,072
	Year 7	5.00%	402,014	7.5	53,602	30	1,787	120%	95%	87%	2,584	6.5	5	8	20,753	\$9.00	\$186,780
	Year 8	5.00%	422,114	7.5	56,262	30	1,876	120%	95%	87%	2,724	6.5	5	8	21,791	\$9.25	\$201,566
	Year 9	4.00%	438,999	7.5	58,533	30	1,951	125%	96%	87%	2,920	6.5	5	8	23,361	\$9.50	\$221,929
	Year 10	4.00%	456,559	7.5	60,875	30	2,029	125%	96%	87%	3,037	6.5	5	8	24,295	\$9.75	\$236,880

1. Divide forecasted unit sales by annual inventory turns to compute the average unit inventory.
2. Divide the average unit inventory by the average units per pallet to compute the average pallet inventory.
3. Multiply the average pallet inventory by the ratio of peak-to-average inventory to compute the peak pallet inventory.
4. Multiply the peak pallet inventory by the portion of peak inventory used for storage planning purposes to compute the effective pallet storage capacity.
5. Divide the effective pallet storage capacity by the location utilization factor (typically 85 percent for single-deep pallet storage) to compute the required number of pallet storage locations.
6. Multiply the required number of pallet storage locations by the storage density (square feet per pallet computed as a function of the aisle width and storage height) to compute the floor-space requirements.
7. Apply the annual occupancy cost rate to estimate the annual occupancy costs.

9.2 Adjacency Optimization

Based primarily on material flow patterns, *activities with high adjacency requirements should be located close to one another*. For example, reserve storage should be located near receiving. The same can be said for receiving and cross-docking, cross-docking and shipping, case picking and pallet storage, case picking and broken-case picking and picking shipping. If we decide to locate receiving and shipping near one another, then these natural flow relationships lead to a U-shaped flow design.

We use warehouse activity relationship charting to document adjacency requirements. It is used to suggest the location of processes and functions relative to one another in a block layout. In the example in [Figure 9.6](#), we simply record under each interprocess relationship the importance of locating

the processes adjacent to one another. For example, it is critical that reserve storage be adjacent to receiving staging for efficient put-away ([Figure 9.7](#)). Computer-aided facility layout tools take these adjacency requirements, the floor-space requirements of each process, and the location of fixed objects as inputs and compute an optimal block layout for a facility. [Figure 9.8](#) illustrates conversion of our adjacency optimization into a block layout for a Honda parts distribution center. Computer-aided design tools allow us to convert the block layout into a detailed facility design. [Figure 9.9](#) illustrates our conversion of the block layout for the Honda parts distribution center into a detailed distribution center layout.

Figure 9.6 Adjacency optimization from the RightHouse Layout Optimization System.

RightHouse™ Layout Optimization System

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Comments

Font

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	From/To	Receiving Docks	Unloading	Returns Processing	Receiving Staging	Receiving Sorting	Pulaway Staging	Pallet Storage	Case Picking	Small Parts Storage	Picking Staging	Picking Sortation	Order Merge & Sortation	Shipment Preparation	Loading	Shipping Docks		
2	Receiving Docks		2	1	2	1	1	1	1	1	2	2	0	1	1	2		
3	Unloading	2		1	0	0	0	2	1	0	2	1	2	0	2	0		
4	Returns Processing	2	-1		0	2	0	2	1	0	2	1	2	0	2	0		
5	Receiving Staging	2	-1	1		2	0	2	1	0	2	1	2	0	2	0		
6	Receiving Sorting	2	-1	1	0		0	2	1	0	2	1	2	0	2	0		
7	Pulaway Staging	2	-1	1	1	1		2	1	0	-1	1	2	0	2	0		
8	Pallet Storage	2	-1	1	1	1	0		1	0	2	1	1	0	2	0		
9	Case Picking	2	-1	1	1	1	0	2		0	2	1	2	0	2	0		
10	Small Parts Storage	2	-1	1	2	1	0	2	2		2	1	2	0	2	0		
11	Picking Staging	-1	-1	1	1	1	0	2	1	0		1	2	0	2	0		
12	Picking Sortation	-1	-1	1	1	1	0	2	1	-1	2		2	0	2	0		
13	Order Merge and Sortation	0	-1	1	1	1	0	2	1	0	1	1		0	2	0		
14	Shipment Preparation	-1	-1	1	2	1	0	1	1	0	2	1	2		2	0		
15	Loading	-1	-1	1	1	1	0	2	1	0	2	1	2	0		0		
16	Shipping Docks	2	-1	1	1	1	0	2	1	0	2	1	2	0	2			
17																		
18																		
19																		
20	Adjacency Priority																	
21	2	Very Important to Locate Near One Another																
22	1	Important to Locate Near One Another																
23	0																	
24	-1	Important to Locate Away from One Another																
25	-2	Very Important to Locate Away from One Another																
26																		
27																		
28																		

Figure 9.7 Block layout from the RightHouse Layout Optimization System.

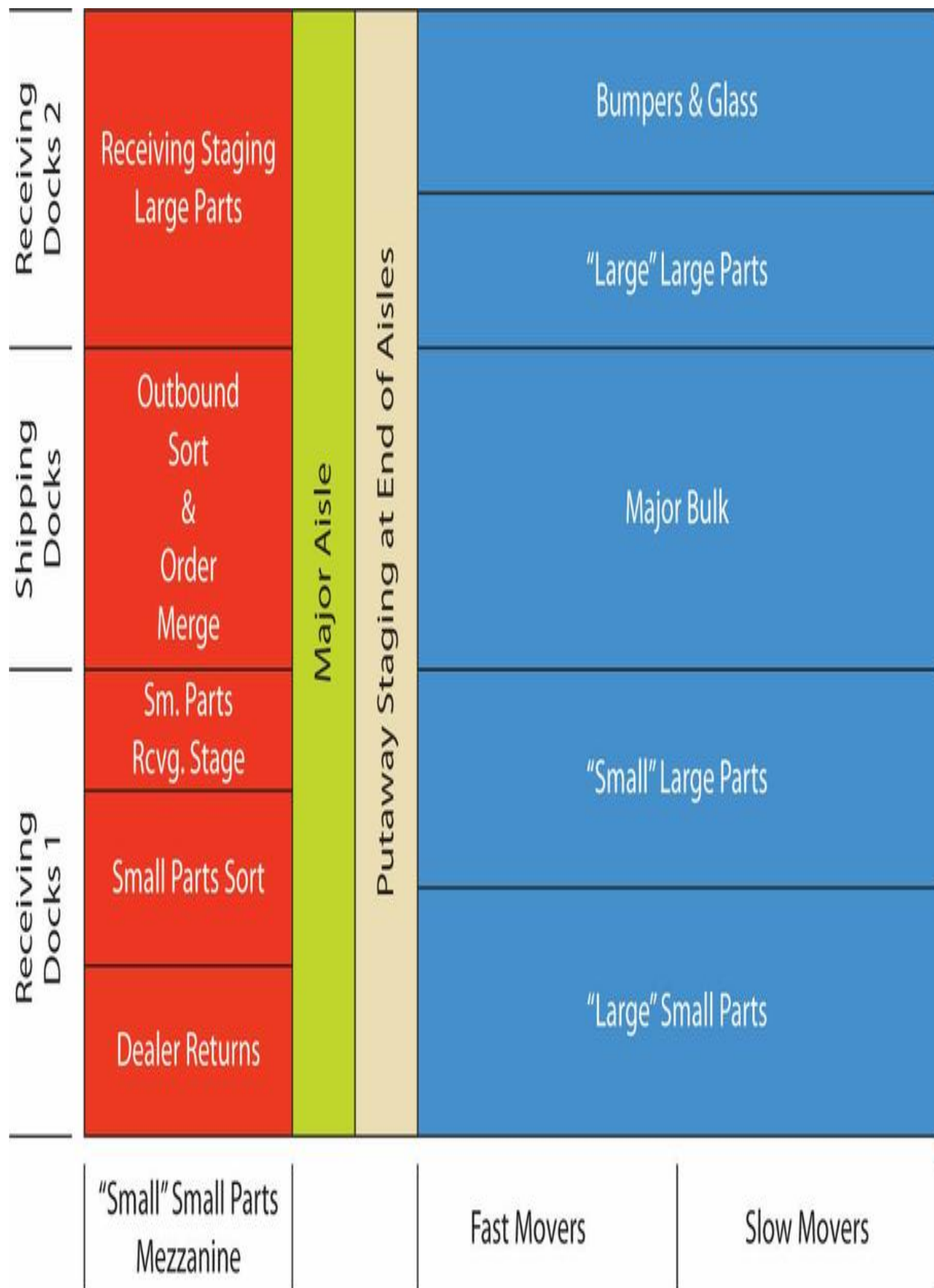


Figure 9.8 Detailed layout for a Honda parts distribution center.

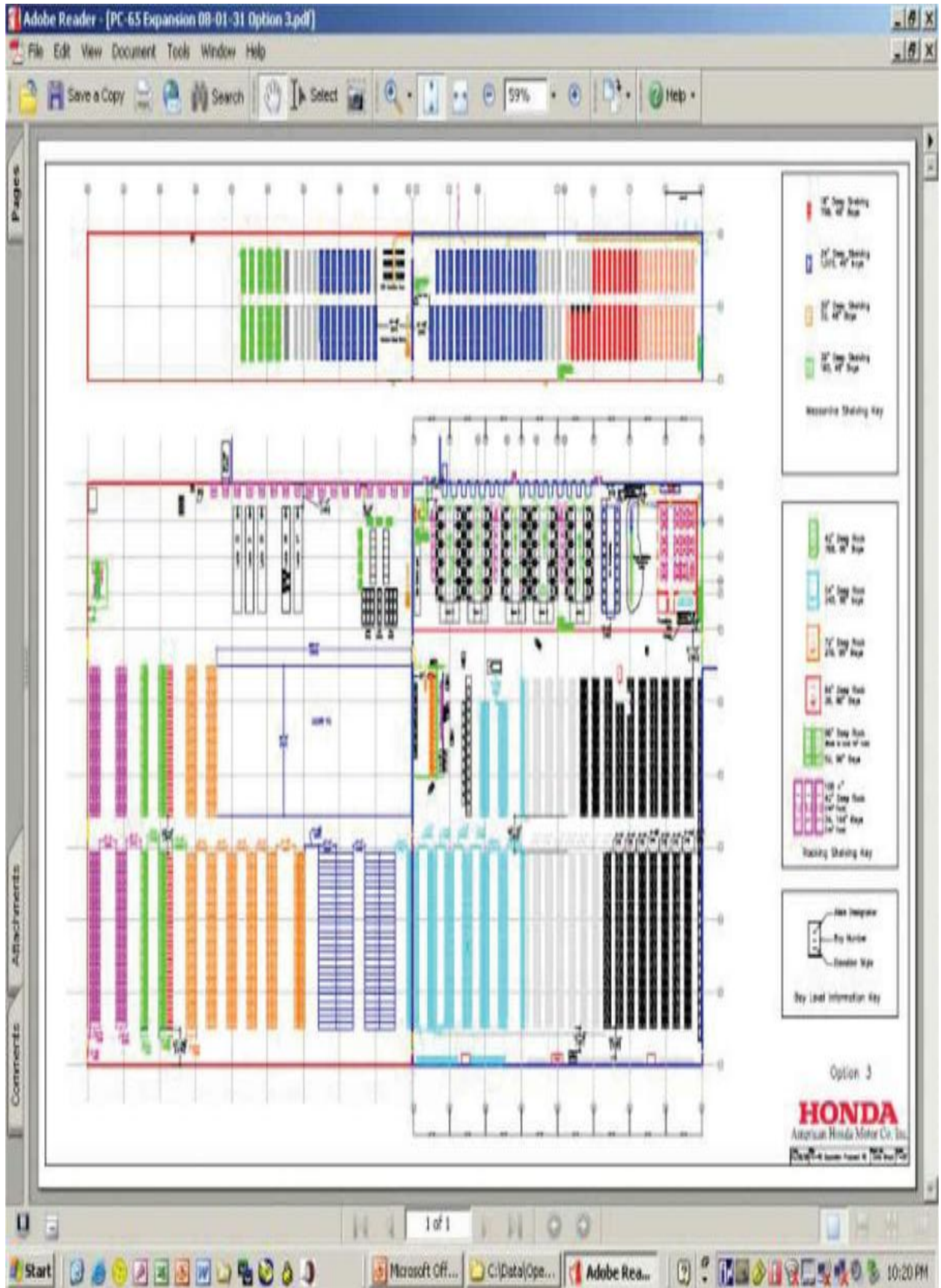
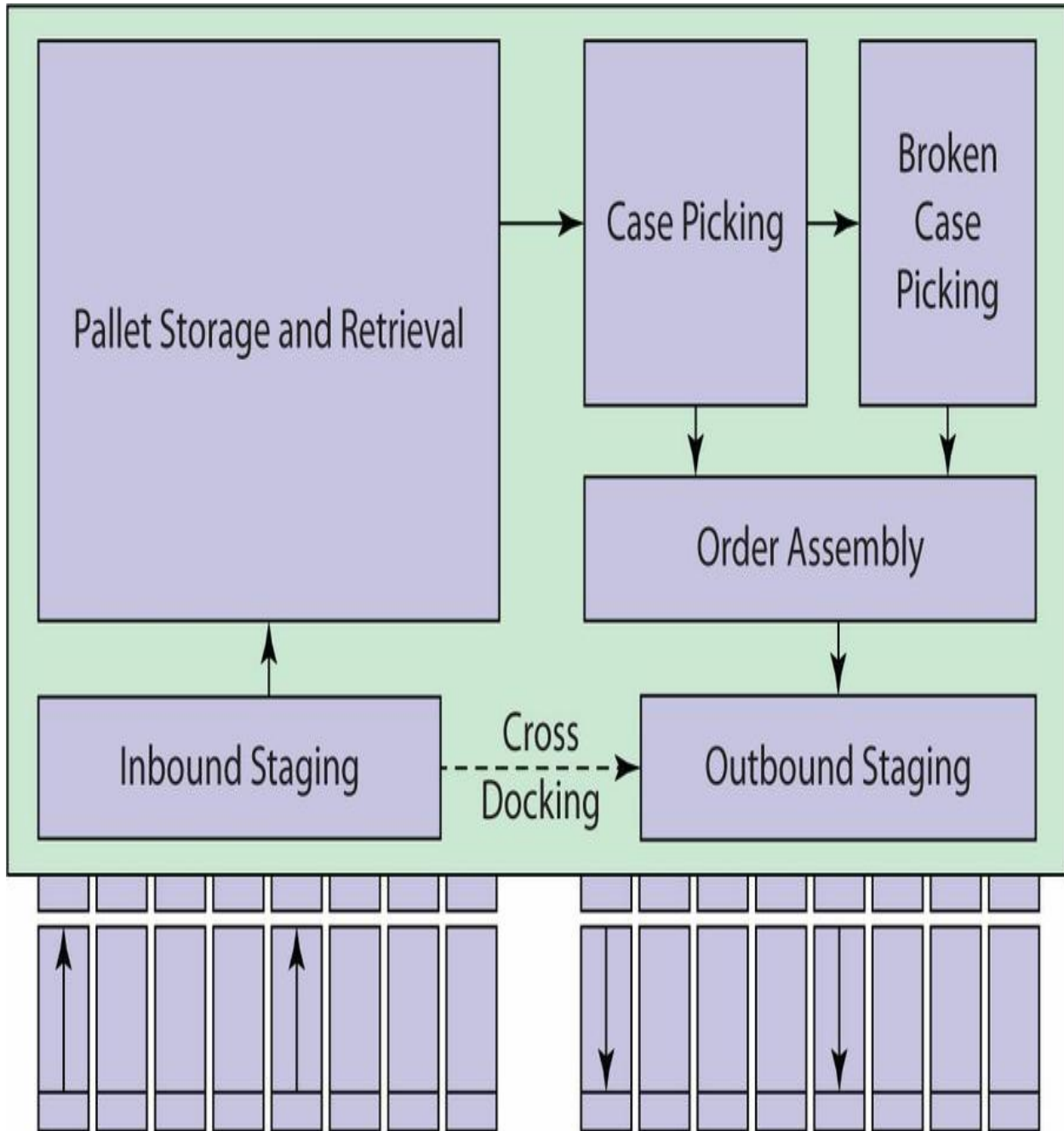


Figure 9.9 Typical U-shaped flow pattern.



9.3 Material Flow Planning

U-shaped, straight-through, modular-spine, and multi-story flow paths work in isolation or in conjunction with one another to form the large majority of warehouse flow paths.

U-Shaped Flow

An example U-shaped warehouse flow design is shown in [Figure 9.9](#). Products flow in at receiving and move to receiving staging, pallet storage, case picking, broken-case picking, order assembly, and shipping.

A U-shaped flow design has a number of advantages over other flow designs, including the following:

- It yields high utilization of dock resources (i.e., dock doors, dock equipment, dock space, dock operators, and dock supervisors) because the receiving and shipping processes can share dock doors.
- It facilitates cross-docking because the receiving and shipping docks are adjacent to one another.
- It yields high lift-truck utilization because put-away and retrieval trips are easily combined and because the storage locations closest to the receiving and shipping docks are natural locations to house fast-moving items.
- It allows expansion opportunities in three directions.
- It provides excellent security because a single side of the building is used for entry and exit.

With these inherent advantages, U-shaped flow design is the benchmark against which all other flow designs should be compared.

Straight-Through Flow

Examples of straight-through flow design are illustrated in [Figures 9.10](#) and [9.11](#). The straight-through configuration lends itself to warehouse operations that are attached to factories (with receipts arriving directly from production lines) to pure cross-docking facilities (sometimes referred to as *flow-through facilities*), or to operations in which the peak receiving and shipping times

coincide. The major disadvantage is that the design does not lend itself to ABC storage and dual-command trips.

Figure 9.10 Straight-through flow design.

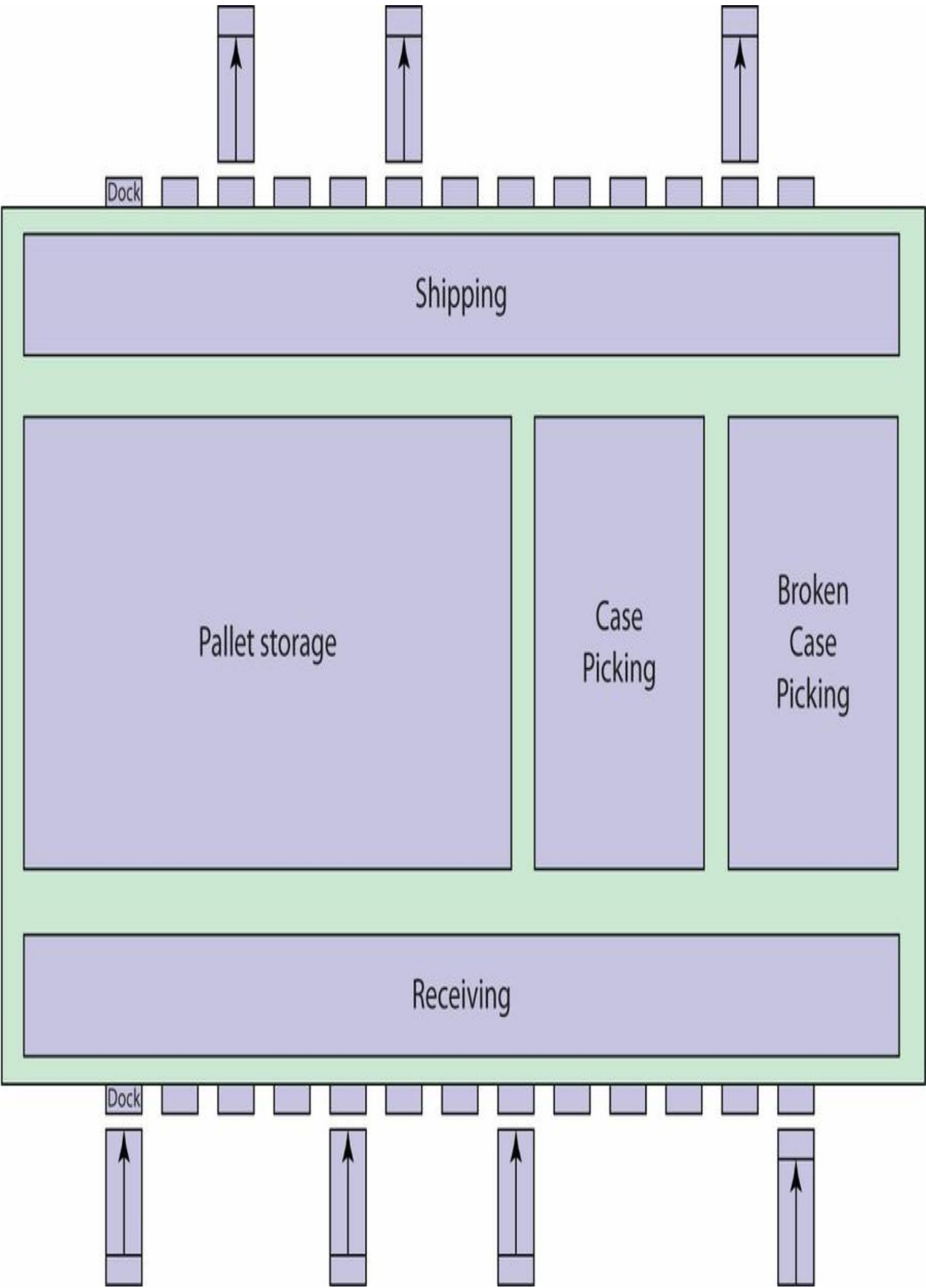
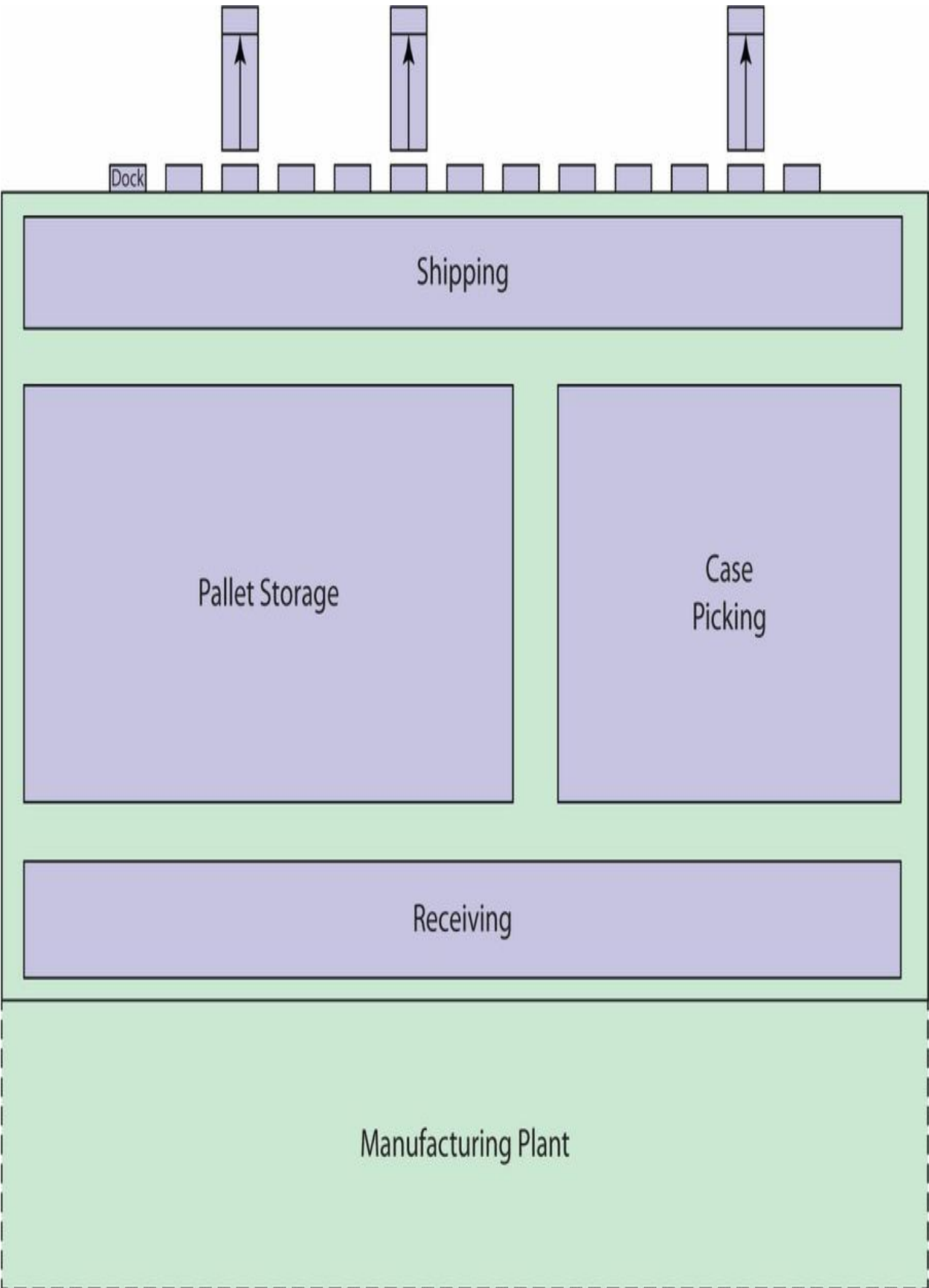


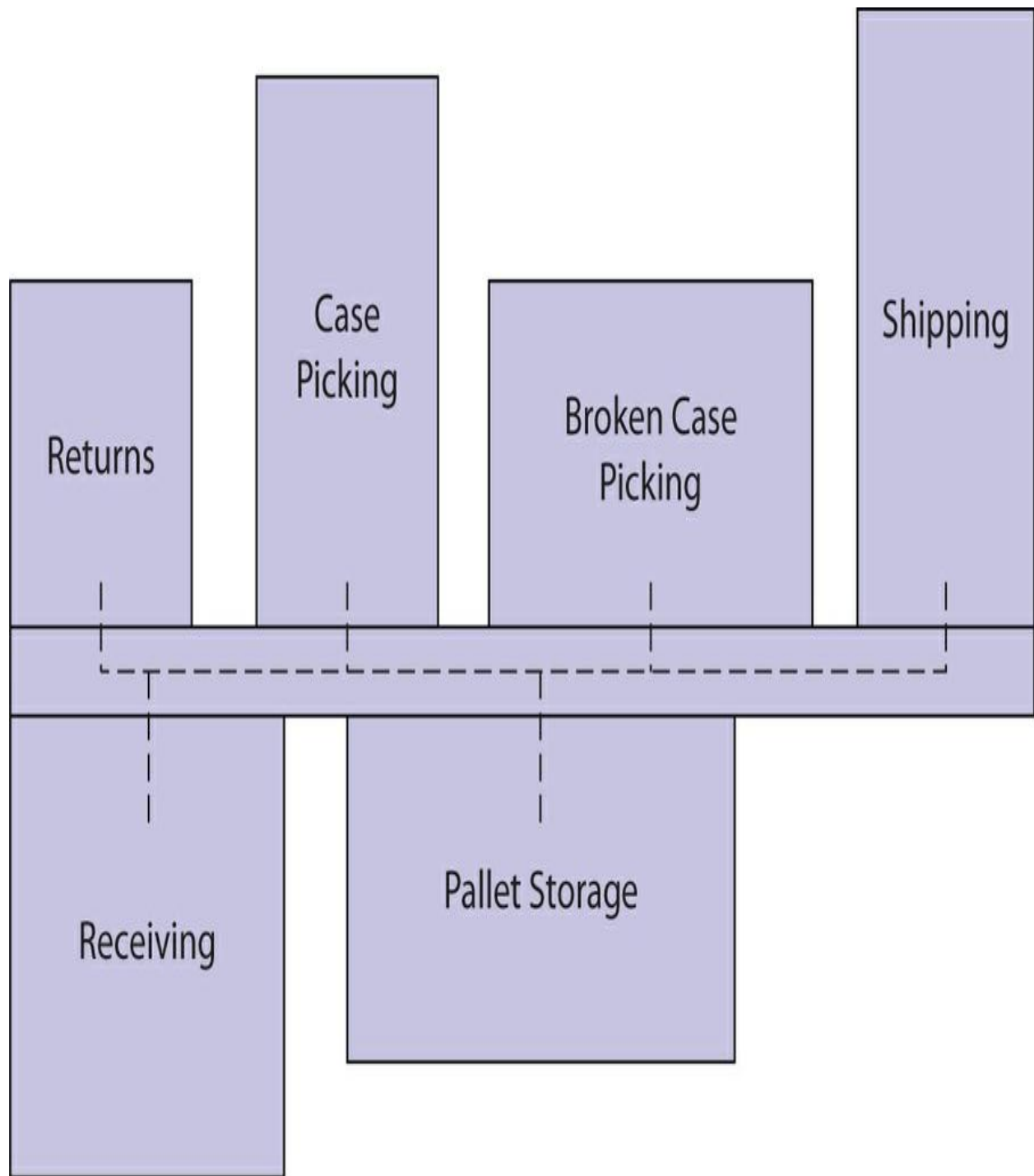
Figure 9.11 Straight-through flow design with an attached manufacturing plant.



Modular-Spine Design

A modular-spine design ([Figure 9.12](#)) uses a large material-handling spine to connect independent buildings dedicated to specific warehouse activities in large-scale warehousing and distribution environments. Examples of stand-alone warehouse buildings include rack-supported buildings for a unit-load automated storage and retrieval system (ASRS); an air-conditioned building for customizing operations such as monogramming, pricing, and marking; a building dedicated to returns processing; and a shipping building equipped with high-speed sorting equipment.

Figure 9.12 A modular-spine flow design.



Multistory Layouts

Multistory distribution buildings ([Figure 9.13](#)) are necessary when land is extremely scarce. Multistory distribution centers are common in Japan and some parts of Europe. They are the least desirable of the flow-path

alternatives because of the material-handling difficulties and bottlenecks encountered in moving merchandise between floors.

Figure 9.13 Recently completed multistory distribution center design for one of Japan's top consumer-direct apparel companies, Scroll, located just outside of Nagoya.



9.4 Bay Matching

One of the major reasons for low building cube utilization in warehouse facilities is that processes that can be executed in low-bay space—receiving, broken-case picking, customization, returns processing, and so on—are often executed in high-bay space. High-bay space can be mezzanined to accommodate multiple low-bay processes in the same floor space. The key design principle is to assign processes with high storage requirements to high-bay space and labor-intensive processes to low-bay space.

9.5 Material Handling Equipment

In addition to the material handling moves within activities, there are major moves between warehouse activities. The two basic categories of interactivity material handling equipment are industrial vehicles and conveyors.

Industrial Vehicles

Lift trucks, automated guided vehicles, sorting transfer cars, and automated storage/retrieval vehicles are industrial vehicles used to move goods between the major activities in a distribution center ([Figure 9.14](#) and [Figure 9.15](#)).

Figure 9.14 Automated guided vehicle systems are an increasingly popular means of transporting goods between warehouse activities.



Figure 9.15 Small-load autonomous mobile transporter (Adept).



Conveyor Systems

Overhead power and free conveyors, car-on-track conveyors, pallet conveyors, and tow-line conveyors are all used to move material between the major functional areas of a warehouse ([Figures 9.16 through 9.19](#)).

Figure 9.16 Powered pallet roller conveyor is the benchmark for interactivity distribution center conveyor movements.



Figure 9.17 Overhead monorails provide quiet, high-speed transport between warehouse activities.



Figure 9.18 Suntory uses cart-on-track conveyors to rapidly move full pallets throughout its distribution center.



Figure 9.19 Pallet conveyors feeding vertical transport systems are a common means of interactivity movement in multistory warehouses.



9.6 Maximize Space Efficiencies

Floor-space requirements in a given area and in the overall layout can and should be reduced by

- Running storage lanes and racking parallel to the long axis ([Figure 9.20](#)) vs the short axis ([Figure 9.21](#)) of the building

Figure 9.20 Running storage lanes along the long axis of the building yields high floor-space utilization.

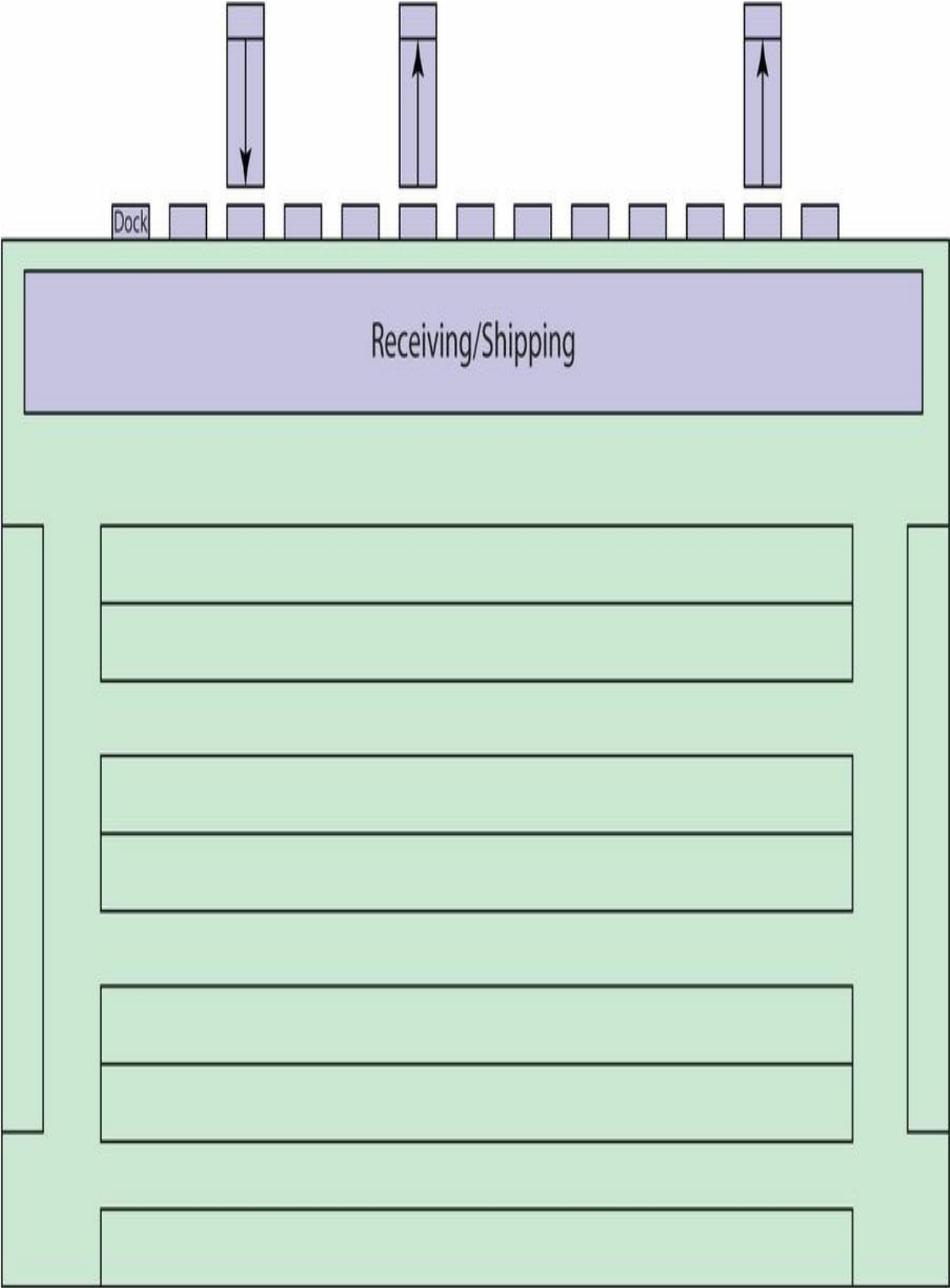
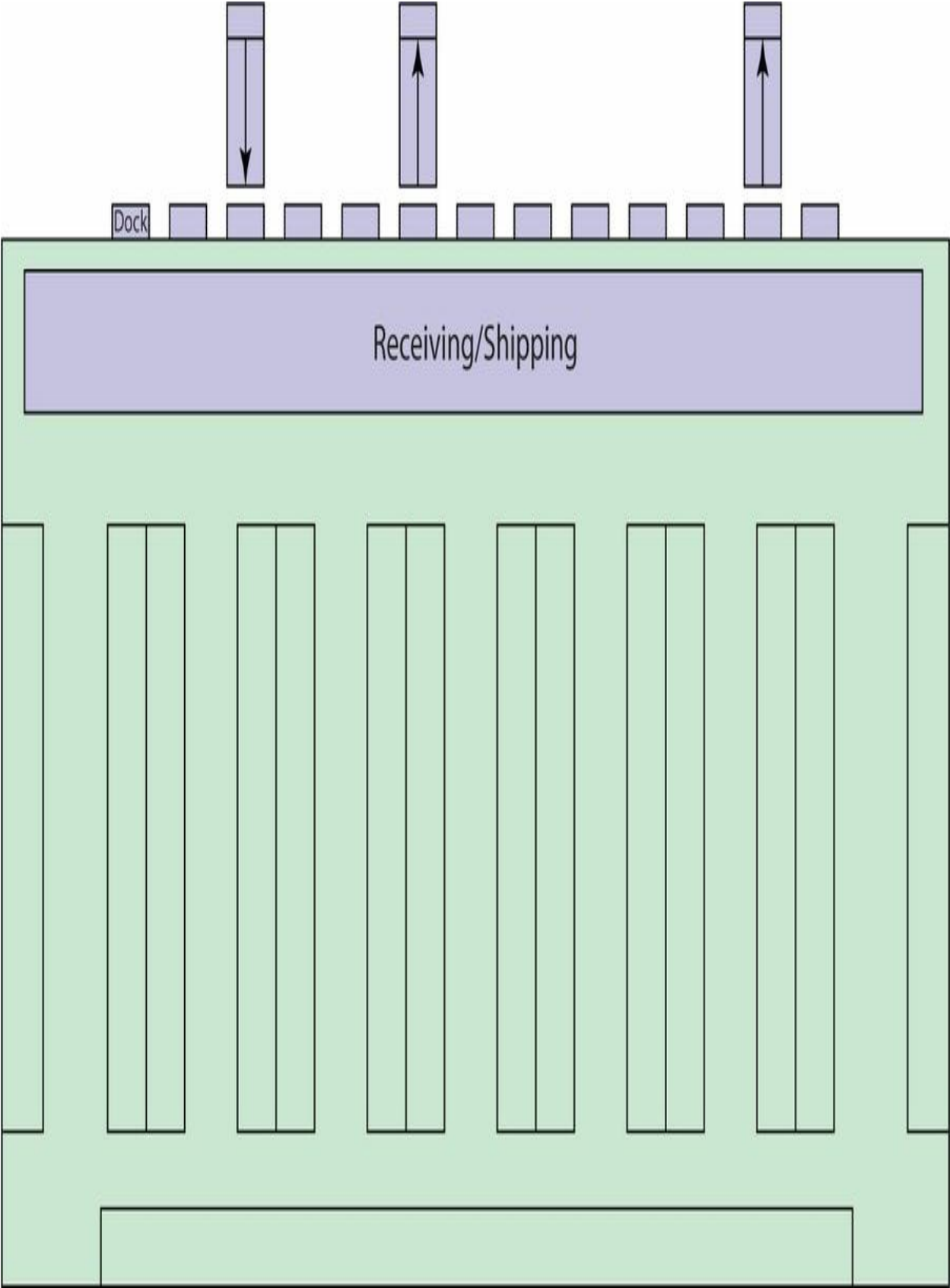
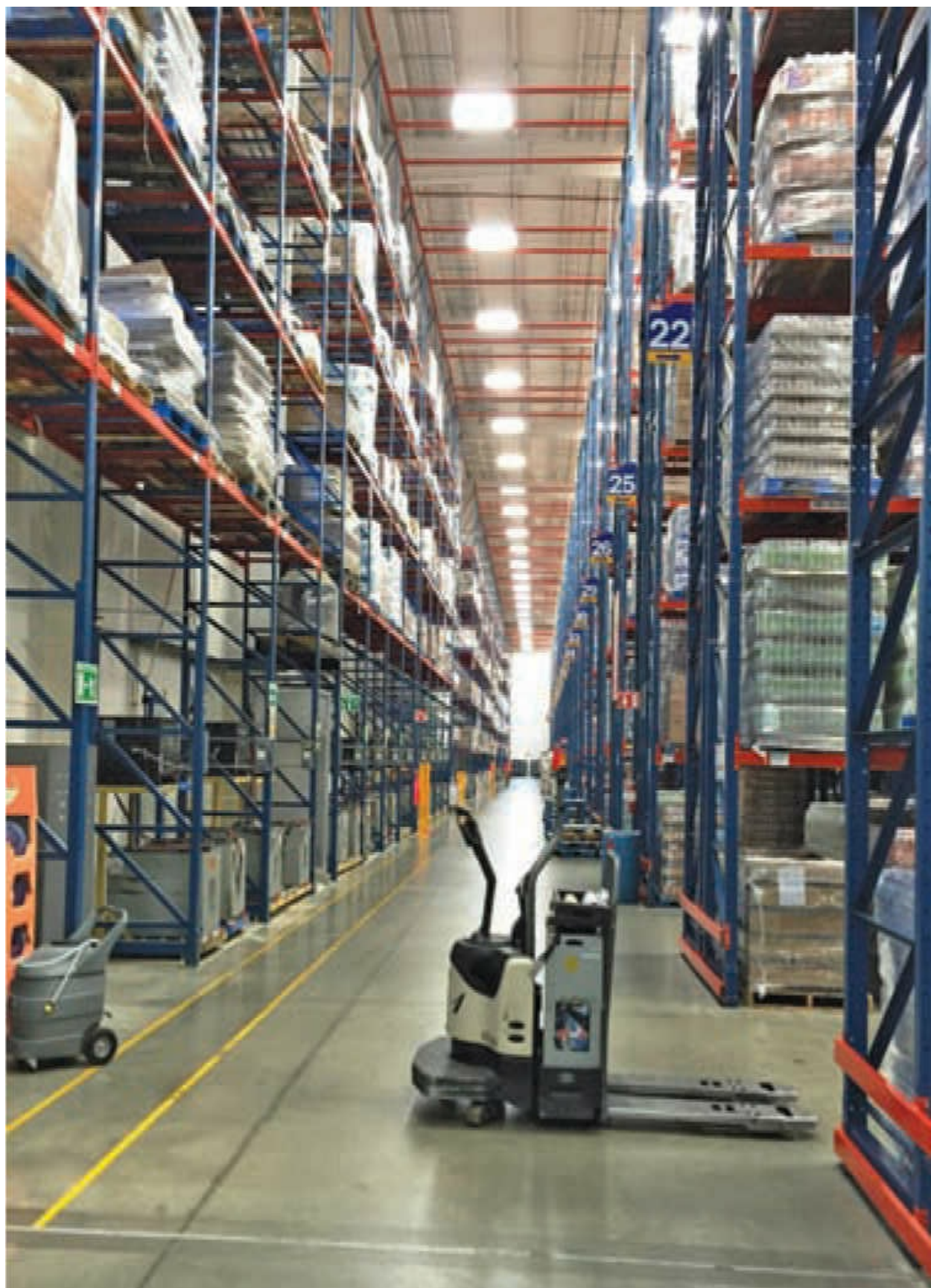


Figure 9.21 Running storage lanes along the short axis of the building yields good location access.



- Running storage lanes and racking along interior walls ([Figure 9.22](#))

Figure 9.22 Storage along interior walls helps maximize space utilization.



- Implementing a random storage location policy in large storage areas
- Using over-aisle ([Figure 9.23](#)), over-dock ([Figure 9.24](#)), and over-line storage ([Figure 9.25](#))

Figure 9.23 Over-aisle storage.

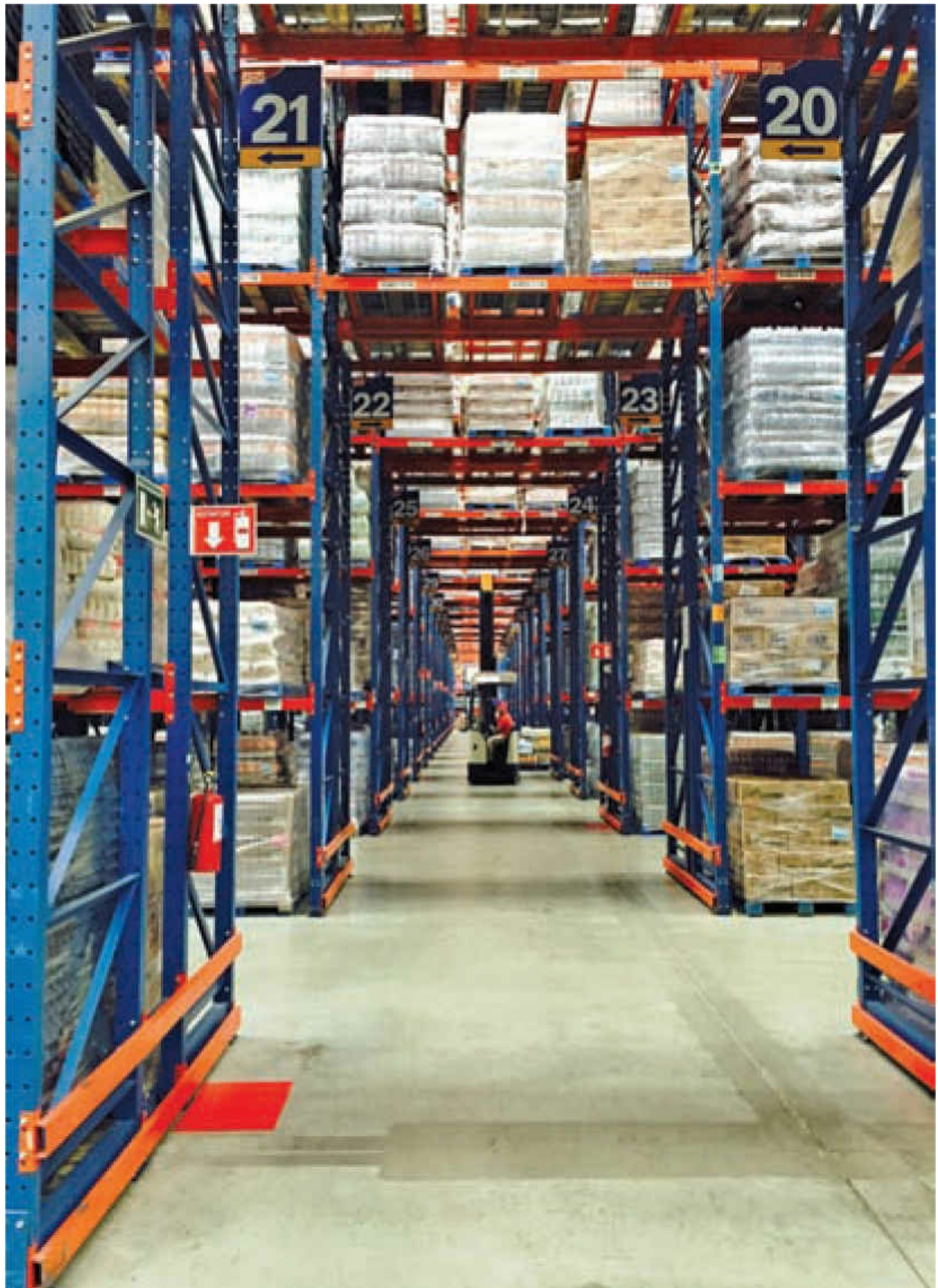


Figure 9.24 Over-dock storage in a telecommunications warehouse.



Figure 9.25 Storage capacity created over conveyor lines in a Japanese wholesale distribution center.



- Burying building columns in storage racks ([Figure 9.26](#))

Figure 9.26 Column placement is one of the critical design features in warehouse layout. In this design for Payless Shoes, we made sure to bury columns within the confines of required material handling structures to maximize floor space utilization.



9.7 Expansion/Contraction Planning

The only thing we know about tomorrow is that it will be different from today. In a warehouse, *different* may mean larger or smaller, faster or slower, more or less variety, taller or shorter, more or fewer people, more or less technology, and so on. To accommodate the rapid pace of change, a carefully configured warehouse layout includes expansion and contraction plans for each activity in the warehouse and for the warehouse as a whole.

CHAPTER TEN

WAREHOUSE COMMUNICATION SYSTEMS

10.1 Automatic Identification Systems

10.2 Automatic Communication Systems

10.3 System Selection and Justification

Each year we conduct a survey to determine industry priorities for warehouse management systems functionality. Nearly every year the top three priorities are (1) paperless communication, (2) live inventory, and (3) productivity tracking.

Why is paperless the top priority? Many of the hurdles on the race to world-class warehousing are related to paper and paper handling. First, it is easy to lose paper. I do it every day. Second, you have to read paper. Reading warehouse documents usually requires searching through a maze of information for just a single line that matters for the transaction at hand. Transpositions creep in. Third, you have to write on paper. Again, it is easy to transpose something. Fourth, things on paper cannot be communicated in real time. As a result, errors in inventory levels, product locations, task status,

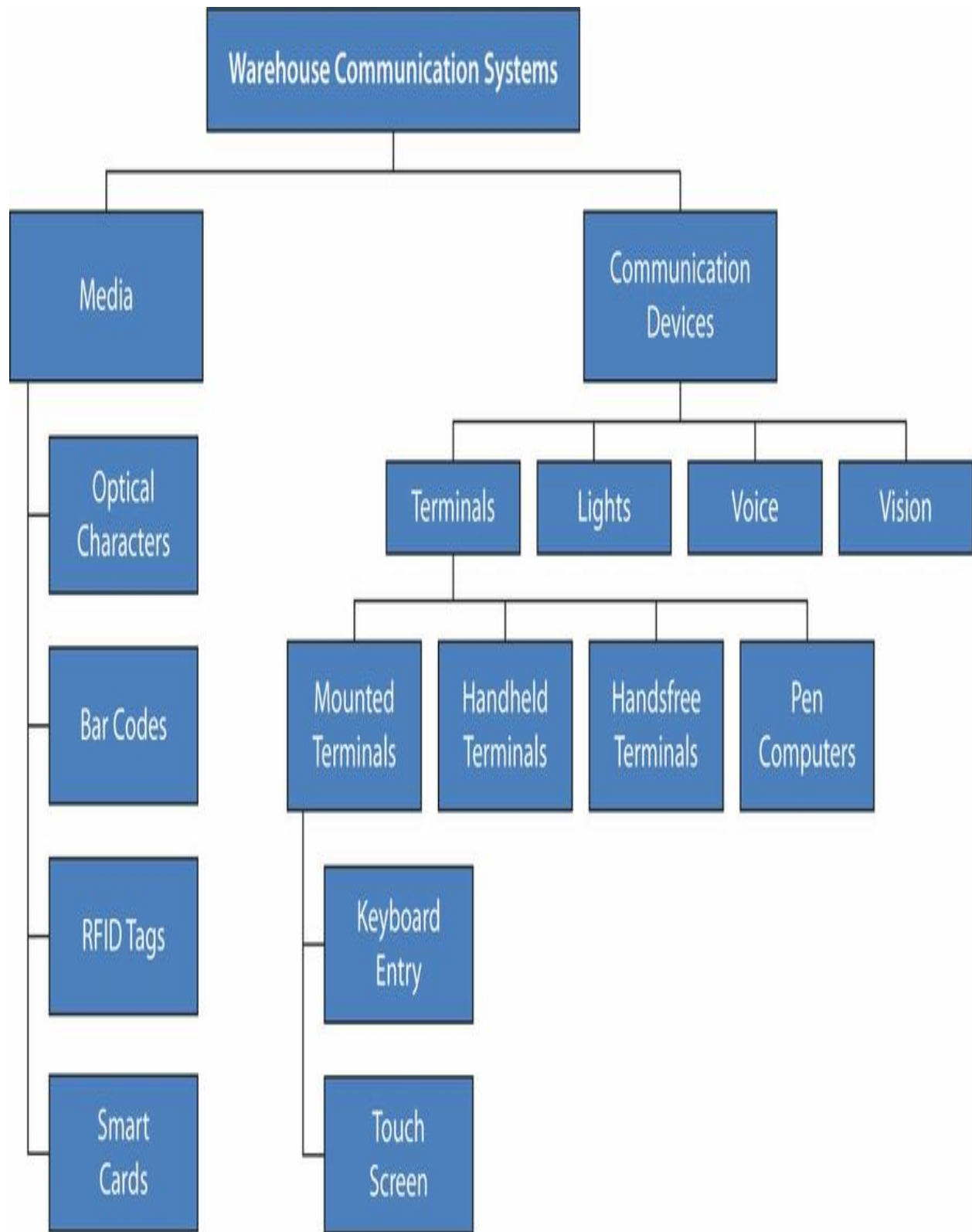
and/or order status are not known with real-time reliability, making it difficult or impossible to implement cross-docking and transaction interleaving. Fifth, paper is expensive to print, handle and file. Sixth, it is easy to damage and smudge paper. Paperless warehousing and world-class warehousing go hand in hand!

Digital and real-time warehousing requires an enabling set of devices and technologies. These devices are the data-collection and communication devices forming the backbone of integrated logistics information systems. Because the list of devices grows daily, it is impossible to present a perfectly current picture of the state of paperless warehouse technologies in book form. Logistics industry trade shows and related websites are the best and perhaps only continually updated presentation of the current state of paperless warehousing technology.

Although the menagerie of devices is changing and being upgraded rapidly, the general categories of technologies have remained fairly stable. First, to support paperless warehousing, we need a way to automatically identify warehousing objects (i.e., containers, documents, vehicles, and locations). We call those means *automatic identification technologies*. They include optical characters and readers, bar codes and bar code readers, radio frequency (RF) tags and readers, smart cards and smart card readers, and vision systems. Second, we need a means to communicate information to warehouse operators. Those means we call *automatic communication technologies*. They include RF data communications, digitized voice, virtual displays, and task-by-light systems.

Paperless warehousing communication devices are the interface between warehouse operators and warehouse management systems. The decisions made in those brief and myriad interactions govern the productivity, accuracy, and speed of the entire warehouse. Hence the design and selection of these devices and systems are critical to the success of the overall operation ([Figure 10.1](#)).

Figure 10.1 RightComms™ taxonomy of warehouse communication systems.



10.1 Automatic Identification Systems

Four primary automatic identification systems are used in warehousing—optical characters and readers, bar codes and bar code readers, RF identification (RFID) tags and readers, and smart cards and smart card readers.

Optical Characters

Although rare, optical characters ([Figure 10.2](#)) are still employed in some warehouse operations. Optical characters are readable by both humans and machines. The digits at the bottom of a bank check are the most common use of optical characters ([Figure 10.2](#)). Much like a bar code, an OCR label is read with a hand-held ([Figure 10.3](#)) or automated scanner ([Figure 10.4](#)). OCR systems operate at slower read rates than bar-code systems and are priced about the same. OCR systems are attractive when both human- and machine-readable capabilities are required.

Figure 10.2 Optical characters

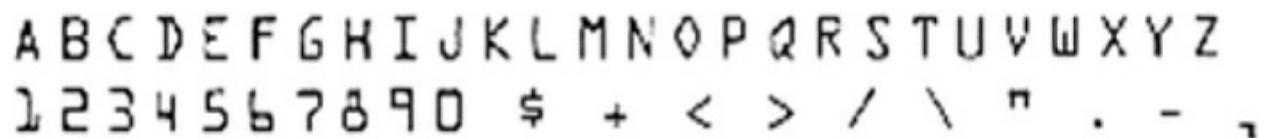


Figure 10.3 Sorter induction operator scanning optical characters in a large Japanese book distributor.



Figure 10.4 OCR reader scanning optical characters in a large Japanese

book distributor.



Bar Codes and Bar-Code Scanners

A bar-code system includes a bar-code *symbology* to encode and decode alphanumeric characters to/from dark and light spaces, bar-code *readers* to interpret the bar-code symbology, and bar-code *printers* to reliably and accurately print bar codes on labels, cartons, and/or documents.

Bar-Code Symbologies A *bar code* is a series rectangles and intervening spaces. The structure of unique rectangle/space patterns represents various alphanumeric characters. The same pattern may represent different alphanumeric characters in different symbologies.

The codes themselves fall into one of five major groupings—one-dimensional (1D) linear bar codes, stacked linear bar codes, two-dimensional (2D) matrix codes, postal codes, and Quick Response (QR) codes. Linear 1D bar codes are the most common type of bar code. All the information contained within the code is organized horizontally and read from left to right by the scanner ([Figure 10.5](#)).

Figure 10.5 Linear 1D bar code.



As the name implies, stacked linear bar codes are simply 1D linear bar codes stacked on top of one another. An example is shown in [Figure 10.7](#). The main advantage over simple 1D codes is the ability to encapsulate a large amount of alphanumeric data in a small footprint.

Two-dimensional bar codes, sometimes referred to as *high-density codes*, are overlapping linear bar codes, one horizontal and the other vertical, in the same field. These codes permit the automatic encoding of nearly a printed page's worth of text in a square inch of page space. Examples include Code 49, Code 16k, PDF 417, Code One, Datamatrix, UPS's Maxicode, and the

currently popular QR code ([Figure 10.10](#)). It is a type of 2D or matrix code developed in Japan and now in popular use because of its information density and ability to encode URLs.

Figure 10.6 Linear bar codes in use at Boots Pharmacy (London, England).

THE BOOTS CO NOTTM

Address Information

D80



02619722003

03 / 06 / 2005

TEL 0115 9506111

005065



00906085139055

BRADA

DISP

DISP

Figure 10.7 Stacked linear bar code

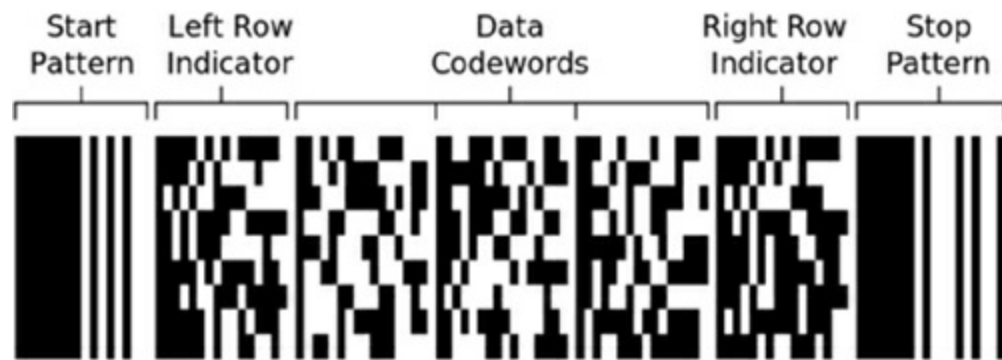


Figure 10.8 Linear bar codes in use for product identification and sorter induction at L.L. Bean.



Figure 10.9 Product with identifying code and tag unitized in a case with identifying code and tag, palletized onto pallets with identifying code and tag, and containerized in container with code and tag.



Figure 10.10 QR code



Bar codes can be used effectively to identify products, containers, locations, operators, equipment, and documents. However, one bar-code “gotcha” is the tendency to get caught up in bar coding for the sake of bar

coding. If there is too much bar coding and too much bar-code scanning, the costs and time to print and scan all the codes can quickly negate potential productivity and accuracy benefits ([Figure 10.11](#)).

Figure 10.11 An over labeled and over coded carton.



Bar-Code Readers Bar codes are read by contact and noncontact scanners. Contact scanners ([Figure 10.12](#)) must touch the bar code. They can be portable or stationary and typically come in the form of a wand or a light pen. The wand/pen is manually passed across the bar code. The scanner emits either white or infrared light from the wand/pen tip and reads the light pattern that is reflected from the bar code. This information is stored in solid-state memory for subsequent transmission to a computer. Contact scanners are excellent substitutes for keyboard or manual data entry. Alphanumeric information is processed at a rate of up to 4 to 24 inches per second, and the error rate for a basic scanner connected to its decoder is 1 in 1 million reads.

Figure 10.12 Pen (or wand) bar-code scanner.



Non-contact scanners ([Figures 10.13](#) through [10.18](#)) may be hand held or mounted and include fixed-beam scanners, moving-beam scanners, and

charge-coupled-device (CCD) scanners. Non contact scanners employ fixed-beam, moving beam, video camera, or raster scanning technology to take from one to several hundred looks at the code as it passes. Most bar code scanners read codes bidirectionally by virtue of sophisticated decoding electronics that distinguish the unique start/stop codes peculiar to each symbology. Further, most scanner suppliers provide equipment with an auto-discrimination feature that permits recognition, reading, and verification of multiple symbol formats with no internal or external adjustments. Finally, suppliers have introduced omnidirectional scanners for industrial applications that are capable of reading bar codes passing through a large view field at high speeds regardless of the orientation of the bar code. Omni-directional scanners are commonly used in high-speed sorting systems.

Figure 10.13 Hand-held bar-code scanner.



Figure 10.14 Long-distance hand-held bar-code scanner.



Figure 10.15 Hands-free ring scanner.



Figure 10.16 In-line bar-code scanner.



Figure 10.17 Omnidirectional bar-code scanning.

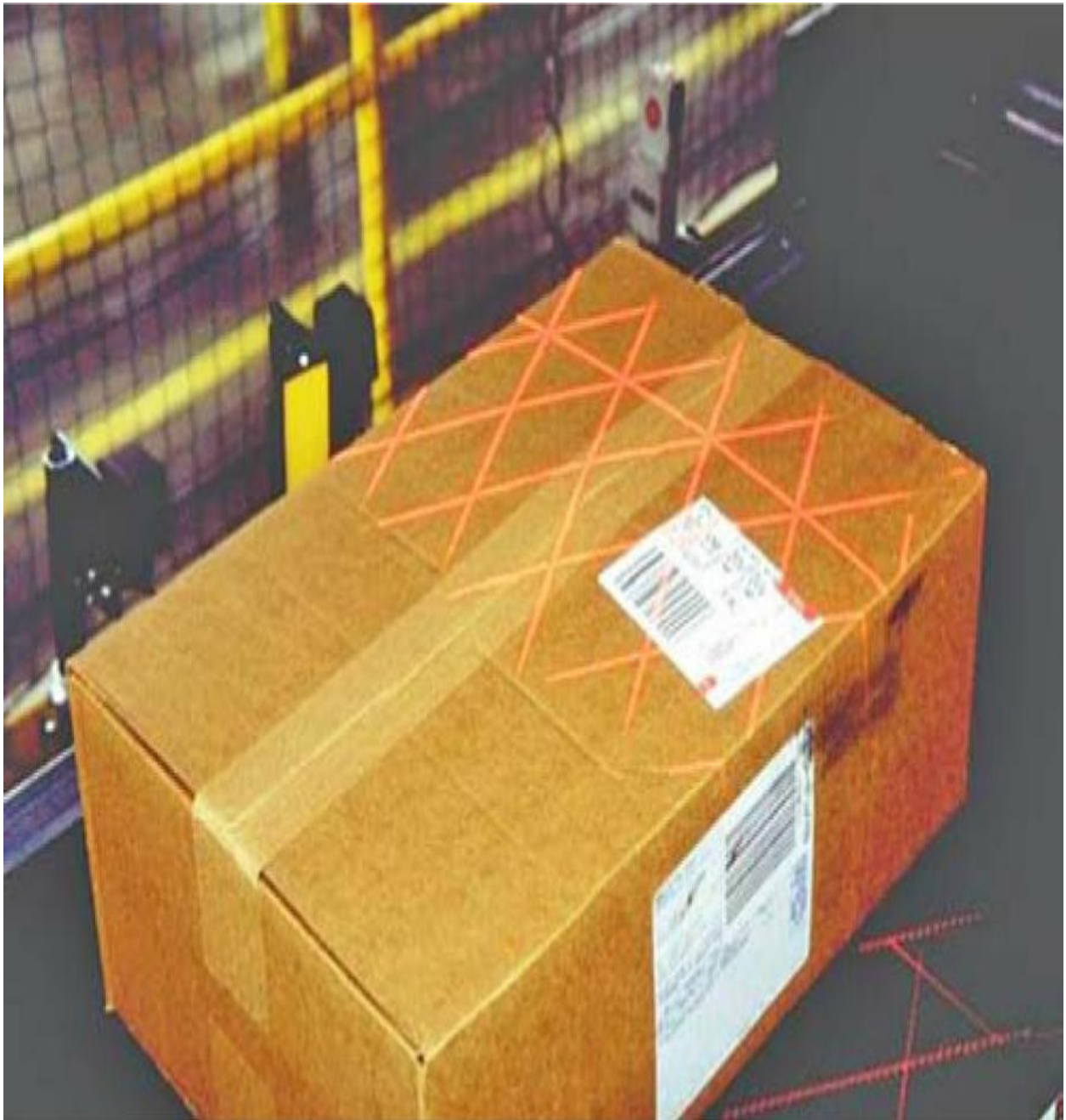


Figure 10.18 Omnidirectional bar-code scanner for tilt-tray sorting.



Radio Frequency Tags

Radio frequency identification (RFID) tags ([Figures 10.19 through 10.24](#)) encode data on a chip that is encased in a tag. When a tag is within range of a special antenna, the chip is decoded and read by a tag reader. RFID tags can be programmable or permanently coded. Some tags are permanently coded and can be read only within a small range.

Figure 10.19 RFID tag.



Figure 10.20 Tagged pieces in tagged cartons on a tagged pallet (Lindsay and Reade).

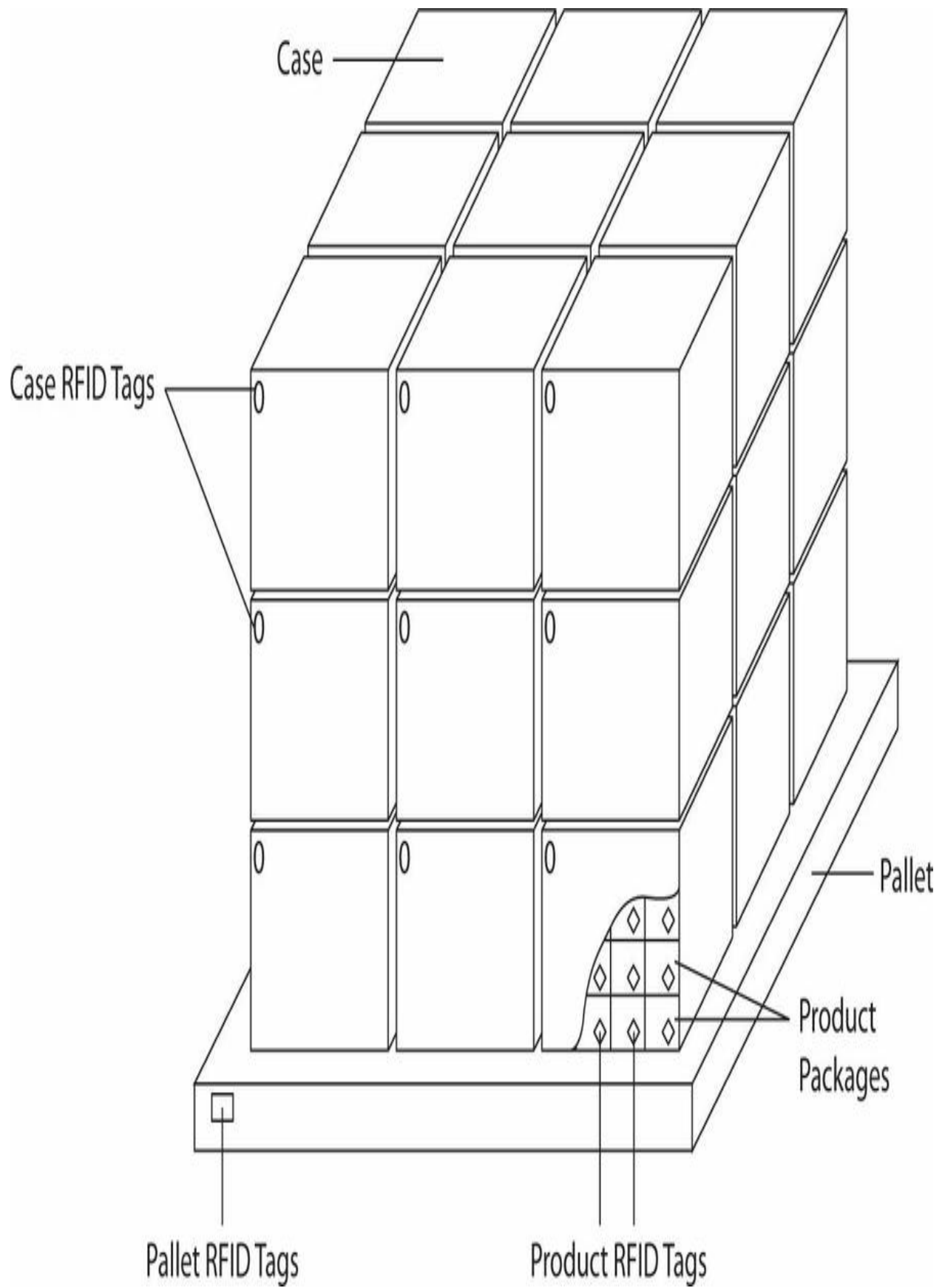


Figure 10.21 Inbound pallet RFID tag reader at a Marks & Spencer distribution center (London, England).



Figure 10.22 RFID tags for tote tracking at Marks & Spencer.



Figure 10.23 Pallet RFID tag reader at Metro (Munich, Germany).



Figure 10.24 RFID tag reader reading the contents of outbound totes.



RFID tags are often used for permanent identification of a container, where printed codes may deteriorate and become illegible.

Magnetic Stripes and Optical Cards

Magnetic stripes commonly appear on the back of credit or bank cards. The magnetic stripe is readable through dirt or grease. Data contained on the stripe can be changed. The stripe must be read by contact, thus eliminating high-speed sorting applications.

Smart cards are now used in logistics to capture information ranging from employee identification, to the contents of a trailer load of material ([Figure 10.25](#)), to the composition of an order-picking tour ([Figure 10.26](#)). For example, at a large cosmetics distribution center, order-picking tours are downloaded onto smart cards. The smart cards, are inserted into a smart card reader built into each order picking cart. The picking tour is illuminated on an electronic map of the warehouse appearing on the front of the cart.

Figure 10.25 Optical memory card used in automated truck manifesting and RFID tag used in container identification.



Figure 10.26 Smart cards used in an order-picking application at Shiseido's Tokyo distribution center. Each card's magnetic stripe holds a picking tour. The smart cards are read by a smart card reader attached

to each intelligent picking cart.



10.2 Automatic Communication Systems

The basic information required by operators to complete a warehousing task includes the identification and quantity of the material to move, the origin, and the destination. There are a variety of means of communicating this basic information, including RF data communications, lights, digitized voice, and virtual displays.

RF Data Communications

Hand-held, lift-truck-mounted, and hands-free RF data terminals (RDTs) are reliable tools for inventory management. RDTs ([Figures 10.27 through 10.30](#)) incorporate a multicharacter display, full keyboard, and special function keys. They communicate and receive messages on a prescribed frequency via strategically located antennas and a host computer-interface unit. Improved inventory accuracy and warehouse resource utilization are most often cited in financial justifications for RDTs. The increasing availability of software packages that permit RDT linkage to existing plant or warehouse control systems greatly simplifies their implementation.

Figure 10.27 Vehicle-mounted RDT with touch-screen capability at Happinet's Tokyo distribution center.



Figure 10.28 Vehicle-mounted RDT.



Figure 10.29 Hand-held RDT.



Figure 10.30 Cycle counting via RDT with pen computing.



Lights and Displays

Task lit operations ([Figures 10.31](#) through [10.38](#)) use indicator lights and lighted alphanumeric displays to direct warehouse operators in order picking, put-away, and/or sorting. The most popular use is in broken-case picking from flow racks, shelving, and/or carousels. In flow racks or bin shelving, a light display is placed at the front of each pick location (in the place of a location label). The light is illuminated if a pick is required from that location. The number of units to pick appears on the same display or on a display at the top of the flow rack or shelving bay. Typical picking rates are in the range of 300 to 600 lines per person-hour, and accuracy is around 99.97 percent.

Figure 10.31 This pick-to-light system at Bertelsmann's Gutersloh distribution center directs the operator to picking locations from the three pallet locations, with weigh checking to prohibit mispicks.



Figure 10.32 Pick-to-light with next task director display at Bertlesmann (Gutersloh, Germany).



Figure 10.33 Pick-to-light in Lifeway's National Logistics Center.



Figure 10.34 Pick-by-light flow rack.



Figure 10.35 Pick-by-light carton flow rack in a Verizon warehouse.



Figure 10.36 Pick-by-light carton flow-rack facings.



Figure 10.37 Pick-by-light carton flow-rack picking line for e-fulfillment at Nutrisystem's Philadelphia distribution center. In addition to the pick-by-light system, notice the walking mats lining each side to reduce picking fatigue.



Figure 10.38 Pick-by-light and put-by-light to retail-store totes aided by next-pick and next-put director and motion detector to prevent mispicks and misputs (AT&C).



For carousels, a light tree is placed in front of each carousel. A light display appears on the tree to correspond to every picking level on the carousel. As a carrier is positioned in front of the order picker, the light display corresponding to the level to be picked from is illuminated. Lights also can be used to direct case picking and pallet storage and retrieval

operations.

Voice Headsets

The use of synthesized voice is increasingly popular in warehouse operations. In mobile voice-based systems ([Figures 10.39 through 10.41](#)), warehouse operators wear a headset with an attached microphone. Via synthesized voice, the warehouse management system talks the operator through a series of transactions. For example, for a pallet put-away, the lift-truck operator hears a command to put away a particular pallet into a particular warehouse location. When the transaction is complete, the operator says, “Put-away complete” into the microphone. Then the system speaks the next transaction to the operator. If the operator forgets the transaction, he or she simply says, “Repeat transaction” and the system repeats the instruction.

Figure 10.39 Lift-truck operator with voice headset at Oxxo’s Monterrey distribution center.



Figure 10.40 Voice picking from a flow rack inside a cold room.



Figure 10.41 Voice headsets in case picking at Edeka, a large grocery retailer in the United Kingdom.



Voice-based systems permit operators to work with their hands free of

documents or terminals and eyes free of reading the same. Another advantage is the ease with which the system is programmed. A simple Windows-based software package is used to construct conversations. To operate every area of the warehouse with a voice-based system would require conversations for receiving, put-away, restocking, order picking, and shipping. Once these conversations have been developed, the system is a warehouse management system unto itself. This approach can be an inexpensive way to achieve most of the functionality of a typical warehouse management system. A typical mobile voice-based system costs approximately the same as an RDT-based system.

Vision Systems

Vision system cameras take pictures of objects and codes and relay the images to a computer for interpretation. Vision systems “read” at moderate speeds with excellent accuracy. Obviously, vision systems do not require contact with the object or code. Vision systems are becoming less costly but are still relatively expensive.

A large mail-order operator recently installed a vision system ([Figure 10.42](#)) at receiving. The system is located above a telescoping conveyor used to convey inbound cartons from a trailer into the warehouse. The system recognizes the inbound cartons that do not have bar codes, reads the product and vendor number on the carton, and directs a bar-code printer to print and apply the appropriate bar-code label. One of our large health and beauty clients uses vision systems throughout their picking area to automatically detect picking errors ([Figure 10.43](#)).

Figure 10.42 Vision system used to automate receiving inspection at Quelle’s logistics center in Leipzig, Germany.



Figure 10.43 Automated picking and shipping inspection.



Virtual “Heads Up” Displays

Virtual displays ([Figure 10.44](#)) present an operator with virtual overlays on the warehouse floor, to direct the operator through travel paths and/or to perform specific transactions on specific products. The displays also can be used to take an operator on a virtual tour of a three-dimensional (3D) warehouse layout. Virtual displays can be used in training warehouse operators in the full range of warehouse transactions.

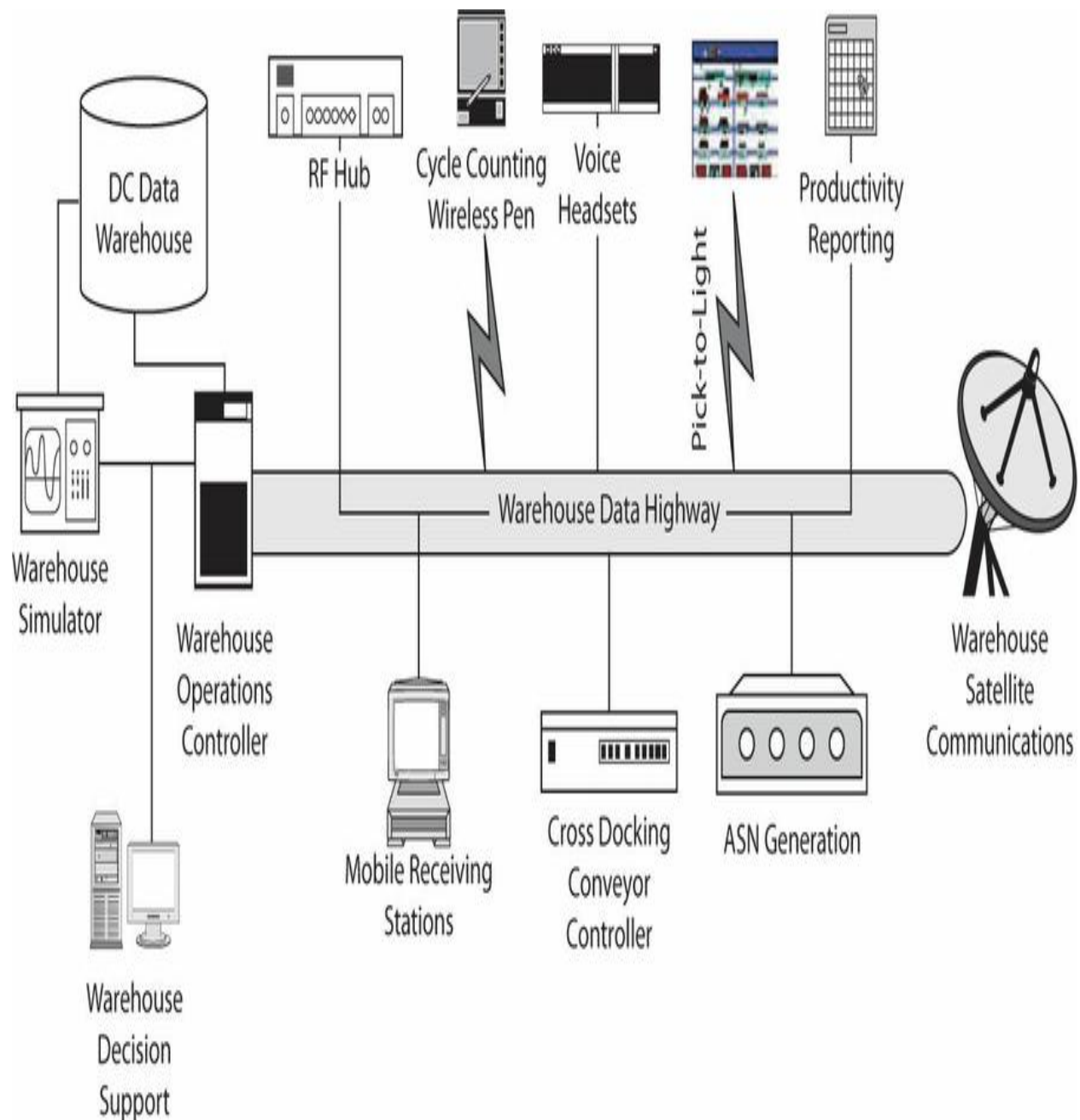
Figure 10.44 Warehouse Data goggles (Knapp Logistics).



10.3 System Selection and Justification

The choice of a warehouse communication technology should be made considering the unique ergonomics for each warehouse activity. For example, picking is handling intensive and hence is best automated with hands-free communication technology, such as voice headsets or pick-to-light. Cycle counting or any kind of inspection is forms based and, lends itself to pen computing. The type, conditions, and frequency of the communications in each warehouse activity should guide the technology selection. An example warehouse communications plan developed for a recent client is shown in [Figure 10.45](#).

Figure 10.45 RightComms warehouse communication systems design for a large retail distribution center.

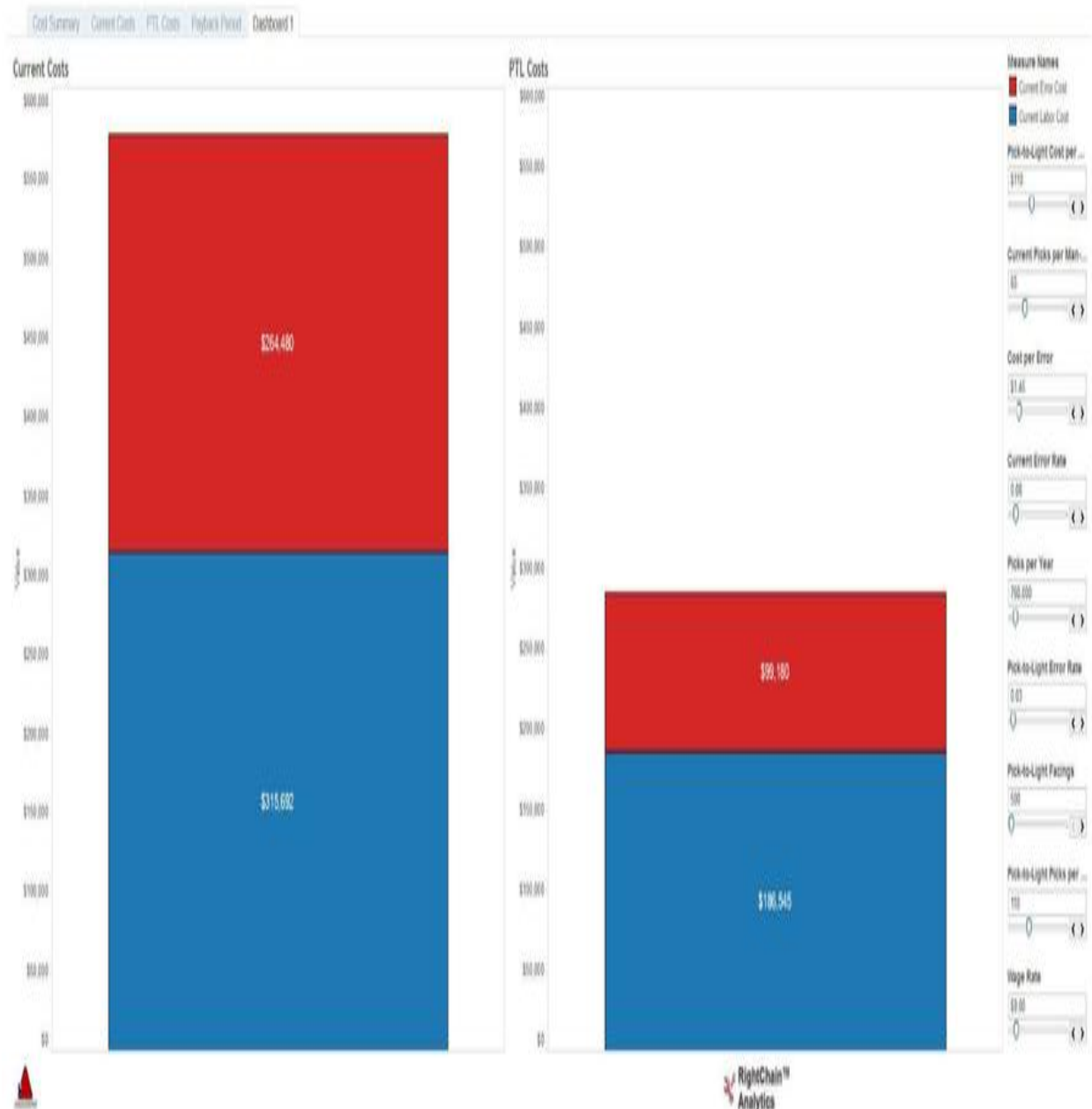


Another critical factor in the selection of warehouse communications technology is its return on investment (ROI). We take into consideration each technology's impact on productivity, accuracy, investment, and reliability in developing an ROI for each warehouse activity. An example pick-to-light ROI is illustrated in [Figure 10.46](#).

Figure 10.46 Warehouse communication system justification.

Justifications >

RightPick™ Justification



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ABOUT THE BOOK

Two proverbs from Solomon are the guiding forces for *World-Class Warehousing*.

“Do your planning and prepare your fields before building your house.”
—Solomon

The wisest man who ever lived advises us in his terms to plan our business first and then build a warehouse to support it. A wisely conceived warehouse provides value added services to the business and should be designed accordingly.

By wisdom a house is built, and through understanding it is established.”
—Solomon

The wisest man who ever lived also advises us to use wisdom and understanding in building and operating a warehouse. That wisdom and understanding are embedded in the analytics and practices of *World-Class Warehousing*.

I have been consulting, teaching, benchmarking, and researching in supply chain logistics my entire career. I have traveled to 72 countries and worked in nearly every major industry. Along the way I have visited over a thousand warehouses. With that as background, to the best of my ability, this book is an extraction, synthesis, description, and illustration of the fundamentals, operating principles, best practices, and designs that make world-class warehouses world-class.

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ABOUT RIGHTCHAIN™

RightChain™ is a proprietary methodology, analytics suite, and curriculum guiding the supply chains of large, medium and small companies in major industries around the world. RightChain™ currently accounts for more than \$5 billion in bottom line impact through increased sales, lower expenses, and improved capital utilization.

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