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Exploring the Parallels Between a Hospital Pharmacy and a Distribution Center

Jennifer A. Pazour and Russell D. Meller

1 Introduction

The pharmaceutical supply chain is the means through which prescription medications are manufactured, transported, stored, and delivered to patients. Pharmaceutical distributors provide the link between manufacturers, which produce medications, and pharmacies, which administer medications to patients. By storing and managing inventory, distributors are responsible for ensuring that pharmacies are equipped with the needed medications to care for patients.

Because pharmaceutical distributors handle 85% of all prescription drug sales in the USA [7], pharmaceutical distributors play a vital role in our economy and impact the cost and quality of our healthcare system. One example of a pharmaceutical distributor is a wholesale distributor, such as Morris & Dickson or Cardinal Health. Another example is a company-owned distribution center, like a Walgreens or Walmart pharmacy distribution center. Typically, company-owned distributors handle only a small percentage of a company’s total stock keeping units (SKUs), relying on wholesale distributors for the remaining products [5].

Two types of pharmacies are hospital and retail pharmacies. A hospital pharmacy resides within an acute care facility and administers medications to patients during their stay at the hospital. Medications are delivered and stored in a pharmacy, and then when demand warrants it, are transported from the pharmacy to a clinical floor for a nurse to administer, typically in unit-dose packages. A retail pharmacy fills outpatient prescription requests and is responsible for the safe storage and dispensing of medications to patients.

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In our research we focus on the pharmaceutical supply chain from a distributor to a patient as represented in Fig. 1. We discuss two types of distribution centers within the pharmaceutical supply chain: a traditional distribution center and an onsite distribution center, the hospital pharmacy.

1.1 A Traditional Distribution Center

A traditional distribution center stores a set of SKUs to be distributed to an entity downstream in the supply chain. The basic operations in a distribution center are (a) to receive products from suppliers, (b) to store the products until requested from customers, (c) to fulfill the orders by retrieving the needed products and assembling the orders, and (d) to transport the orders.

Distribution centers provide many benefits. Distribution centers store inventory to balance supply with demand, allowing for quicker response to customer demand. The presence of a distribution center can reduce transportation costs by consolidating shipments. Distributor centers allow manufacturers to efficiently produce large quantities of products and through break-bulk activities, ship customers small quantities of a variety of products. Also, value-added processes are often conducted at a distribution center.

Gu et al. [8] provide a recent review of academic literature associated with distribution center operations and classify the literature within a unifying framework.
based on distribution center functions. A companion paper [9], reviews the academic literature in the area of distribution center design, performance evaluation, practical case studies, and computational support tools.

In the next section we provide further details on distribution centers used in the pharmaceutical sector.

### 1.1.1 A Pharmaceutical Distribution Center

Manufacturers outsource the distribution of much of their products to distributors, rather than engage in director customer delivery [5]. Consequently, pharmaceutical distributors are responsible for ensuring that hospital and retail pharmacies are supplied with the needed medication to care for patients. The pharmaceutical distribution business is characterized by several dynamics.

First, pharmaceutical distribution is characterized by high-valued products that have an expiration date. These characteristics motivate pharmacies to minimize their on-hand inventories by requesting frequent orders, leading to medication shipments being received daily or even multiple times a day. In 1998, 67% of distributors made deliveries five times a week; another 31% made deliveries six times a week [5].

Second, the number of delivery sites from which pharmaceutical products are dispensed is large. In 1998, pharmaceuticals were dispensed from 135,000 sites in the USA including 20,000 independent pharmacies, 19,000 chain pharmacy outlets, 60,000 clinics, 7,000 hospitals, and 12,000 mass merchandisers and food stores [5]. The median number of shipping points served per distributor in 1998 was 525 [5]. Therefore, pharmaceutical distributors mediate pharmacy’s desire for small quantities of a diverse number of products with manufacturers that produce large quantities of a few products.

Third, pharmacies place stringent requirements on order lead-time, order accuracy, and availability of a diverse product line. Extremely short lead time requirements of an hour or less can be placed on the order-fulfillment process [11]. Furthermore, it is common for pharmaceutical distribution facilities to consider more than 20,000 active SKUs [3].

Pharmaceutical distributors have utilized automation to respond to customer needs by driving greater volumes through distribution centers at faster speeds. In particular, order-fulfillment technology allows pharmaceutical distributors better response to their customers’ needs by processing orders more quickly and accurately. One type of customer for a pharmaceutical distribution is a hospital pharmacy.

### 1.2 A Hospital Pharmacy

Hospital pharmacies oversee the procurement of medications used within the hospital. Because hospital pharmacies store a supply of medications and then are tasked with delivering medications in unit-dose packages to the clinical floor for the nurse
to administer, we consider them as on-site distribution centers. The flow of medications through the hospital can be categorized into the following functional processes: ordering, receiving, storage, order-fulfillment, and transportation.

Some pharmacies have automated the ordering process by investing in inventory technology that tracks inventory and par levels. In these systems, a pharmacy technician reviews the order, making necessary changes where applicable. The order is then transmitted to a supplier or a pharmaceutical distributor, where it is fulfilled. The order is transported from the distribution facility to the hospital pharmacy, typically through less-than-truckload or parcel carriers.

Upon arrival of the physical order to the pharmacy, a pharmacist or pharmacy technician receives the product and validates that the correct number of packages have been received. The medications are stored in various storage locations within the pharmacy. These can include carousel systems, refrigerated storage, narcotic vaults, open shelving, bins, and repackaging technologies. If medications are not received in unit-dose packages, repackaging processes occur.

Once medications are in unit-dose form, there are two main strategies for unit-dose medication distribution: cart-less and cart-fill. In both systems, unit-dose medications are stored on the hospital floor in a medication cart. In a cart-less system, available medications are sorted by medication types, whereas in a cart-fill system the medications are sorted by patients. In both systems, order-fulfillment is conducted by the central pharmacy; the only difference is in a cart-less system medications are picked and stored by medication-type, while in a cart-fill system medications are picked and stored by patient.

Medications on clinical units are typically stored in a controlled environment, often times in automated dispensing cabinets. Typically, a database manages information about the inventory in each automated dispensing cabinet, such that when a storage location reaches its par level, an order is generated and sent to the pharmacy. The orders generated are aggregated into a pick list that pharmacy technicians fill and pharmacists verify. The medication order is transported to the clinical unit and stored in the proper location until retrieved by a nurse for medication administration to a patient. Numerous safety and quality checks are implemented such that a nurse administers the correct medication for the correct patient at the correct time in the correct dose.

Controlled substances have additional regulations from the government, requiring additional monitoring and controls to be in place. From the time a controlled substance is delivered to the hospital until it is administered to the patient, the medication must be tracked by the hospital staff, which includes a number of tasks such as checking the ordered medication against the patient’s medical record, documenting for administrative records, and reconciling control substance records after each shift [13].

Hospital administrators and pharmacists have to manage a very complicated distribution network without the proper training or educational backgrounds to do so efficiently [13]. Consequently, one of the goals of our research is to compare hospital pharmacies to traditional distribution centers. From this comparison, best practices from distribution center design can be identified and transferred to hospital pharmacies, where applicable. In the next section we make an initial comparison.
2 Comparison Between a Traditional Distribution Center and a Hospital Pharmacy

We view a hospital pharmacy as an on-site distribution center as both perform similar functions: ordering, receiving, storage, order-fulfillment, and transportation. Viewing the hospital pharmacy as such, we make the following comparisons between a traditional distribution center and a hospital pharmacy.

- **Ordering and Receiving.** Distribution centers order and receive products so that transportation can be consolidated and inventory costs can be reduced at retail locations. Similarly, a hospital pharmacy orders and receives medications so that individual clinical units can experience reduced transportation and inventory costs.

- **Storage Process.** Distribution centers store inventory to be able to respond to customer requests. Likewise, hospital pharmacies hold stocks of medications in order to be able to respond to patient prescriptions and emergency situations. Due to the difficult-to-predict demand for medications and the emergency environment, higher levels of safety stock are typical in hospital pharmacies.

- **Order-Fulfillment Process.** Distribution centers experience demand for products that must be picked and transported. Typically, distribution centers receive products in large quantities from manufacturers and provide retail locations with small quantities of a variety of products through the order-fulfillment process. Orders can be fulfilled at different levels, ranging from piece-level, carton-based, or unit-load fulfillment. A hospital pharmacy also experiences demand for medications from clinical units that must be picked and transported. Medications typically arrive to the hospital pharmacy at the piece or case levels and are supplied to the clinical units in unit-dose form. Therefore, delivering unit-dose medications to the hospital floor can be viewed as piece-level order-fulfillment.

- **Multichannel Fulfillment System.** Distribution centers typically have a multichannel fulfillment system, especially when the storage and picking activities are separated. A separate picking area, called a fast-pick area, is a subregion of the warehouse that concentrates picking within a small physical space to reduce pick costs and increase responsiveness to customer demand. The fast-pick area often utilizes order-fulfillment technology such as pick-to-light, A-Frame systems, carousel systems, or picking machines. In a pharmacy, medications can be picked from traditional bins, carousel systems, or fully-automated repackaging systems. An additional channel devoted to controlled substances and medications formulated for patient-specific needs also exists.

- **Labor and Infrastructure Trade-off.** In a distribution center, labor is the dominant expense. A trade-off lies in balancing the capital expenditures in infrastructure with the labor savings and increased quality gained by the technology. Hospital pharmacies are also labor intensive and investments in infrastructure can also aid in reducing labor and increasing quality. Even though some of the specific technology varies between a distribution center and hospital pharmacy, there are also similarities; for example, carousel systems are common in both.
• Value-Added Processes. Distribution centers can provide value-added processes, such as delayed product differentiation and packaging improvements. In a pharmacy, repackaging medications from bulk quantities to unit-dose packages is a value-added process used to increase patient safety through barcode-enabled point-of-care (BPOC). Other value-added processes in a hospital pharmacy include validating that a patient is not allergic to the prescribed medication and creating dilutions.

• Facility Variety. Distribution centers have varying demand, infrastructure, product, and customer profiles. Likewise, each pharmacy has unique characteristics. Some examples include the lead time allowed from when the doctor prescribes the order to when the medications must be on the hospital floor, the volume of medications, the diversity of medications, and the type of software and infrastructure used for distribution.

In the next section we provide an overview of the technologies used in a traditional distribution center and a hospital pharmacy, with special emphasis on the order-fulfillment process.

3 Order-Fulfillment Technologies in Pharmaceutical Distribution

In both a traditional distribution center and a hospital pharmacy, order-fulfillment, the process of retrieving products from storage in response to a specific customer request, is one of the most critical and expensive tasks in the distribution process because of its simultaneous impact on the cost, quality, and accuracy of the process. Therefore, specifying an effective order-fulfillment process is an important aspect in distribution center and hospital pharmacy design. Our research will focus on the piece-level fulfillment process as it is the most common fulfillment level used in pharmaceutical distribution.

When item-level demand is high, the piece-level order-fulfillment process can be very labor-intensive. Furthermore, when labor wages are also high, this type of order-fulfillment becomes a good candidate for automation. And in the pharmaceutical industry, an added motivation for automation is the requirement of extremely high-order accuracy and short lead time requirements.

3.1 Distribution Center Order-Fulfillment Technologies

There are three typical piece-level order-fulfillment strategies in a distribution center—picker-to-stock, stock-to-picker, and an automated dispensing system—with various technologies used to automate the order-fulfillment process associated with each strategy (see Table 1).
Table 1. Piece-level order-fulfillment technology

<table>
<thead>
<tr>
<th>Picker-to-stock</th>
<th>Stock-to-picker</th>
<th>Automated dispensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick-to-light</td>
<td>Carousels</td>
<td>A-Frame systems</td>
</tr>
<tr>
<td>Sortation systems</td>
<td>Vertical lift modules</td>
<td>Dispenser systems</td>
</tr>
<tr>
<td>Conveyor systems</td>
<td>Mini-load AS/RS</td>
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<tr>
<td>Pick-and-pass systems</td>
<td>Picking machines</td>
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<td></td>
<td>Put-to-light systems</td>
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</table>

With a picker-to-stock strategy, an operator visits fixed locations to make a pick. Picking is often performed in a consolidated area, known as a fast-pick area. When warranted due to high labor wages or the need for high picking accuracy, a pick-to-light system is employed in order to reduce the amount of time an operator spends searching for the next pick and/or for increasing accuracy. To decrease walking, orders may be batched picked such that cases are picked but less-than-case quantities are shipped. To facilitate this strategy, a split-case sortation function is performed to sort the correct items into the correct order. Additionally, conveyor systems may be used to transport items, further reducing the amount of walking performed. In a pick-and-pass system, each pick station has buffer spaces such that the main flow of totes does not become blocked by totes waiting for picking.

With a stock-to-picker strategy, materials to be picked are transported to the operator. Technologies to facilitate this strategy include carousels, vertical lift modules (VLMs), mini-load automated storage and retrieval systems (AS/RSs), picking machines, and put-to-light systems.

Finally, with an automated dispensing strategy, automated order picking machines can be used to completely eliminate manual picking; common automated dispensing technologies are the A-Frame and dispenser systems. However, even in automated dispensing systems, operators typically perform manual replenishment.

### 3.2 Hospital Pharmacy Order-Fulfillment Technologies

Order-fulfillment technology is used in a hospital pharmacy to increase patient safety by reducing picking errors, as well as to reduce costs through labor, inventory, and space savings. Some example technologies include vertical carousel systems, repackaging technologies, and automated dispensing cabinets. Vertical carousel systems store medications and can reduce the labor associated with the order-fulfillment process by bringing the medication closer to the technician. Repackaging technologies package bulk medications in unit-dose form. Automated dispensing cabinets are medication storage devices on the clinical units and are commonly what the pharmacy technicians are fulfilling orders to.

These technologies, as well as order-fulfillment technologies used at distribution centers will be the focus of the next section. We provide a description of the order-fulfillment technologies and review the analytical models associated with these technologies.
4 Modeling of Order-Fulfillment Technologies in Pharmaceutical Distribution

We focus on models that analyze order-fulfillment technology in pharmaceutical distribution. Unlike the consumer-product supply chain, the healthcare supply chain has not received much attention from the academic-research community and thus an opportunity for impact in this line of study exists.

We have identified five technologies used in the order-fulfillment process as the main focus of our discussion: A-Frame systems, carousel systems, picking machines, automated dispensing cabinets, and unit-dose repackers. The former three technologies focus on pharmaceutical distribution from a traditional distribution center to a hospital pharmacy, while the latter two technologies focus on order-fulfillment within a hospital. Figure 2 illustrates where each identified technology is applied in the pharmaceutical supply chain.

In addition to discussing each of the identified technologies, we review the models available in the academic literature to analyze piece-level order-fulfillment technologies prevalent in pharmaceutical distribution.
4.1 A-Frame Systems

A common automated dispensing system used in pharmaceutical distribution is the A-Frame system. As illustrated in Fig. 3, the products are placed in side-by-side channels of varying magazine length on two sides of a collection belt, forming an “A” and the items are automatically dispensed onto the belt that passes inside the tunnel created by the frame. Orders are filled one at a time, with products then directly fed into customer order totes and transported via a conveyor to another picking station or a packing station. While the machine is operating, manual replenishment activities of the product channels can be performed with no impact on the dispensing operations.

A-Frame systems are capable of filling orders quickly (up to 750,000 picks/day, 1,200–2,400 orders per hour) with incredible order accuracy (>99.95%) [6]. They are common in pharmaceutical, electronic, and cosmetic distribution facilities, where large volumes of highly valued items are fulfilled in small order sizes with stringent constraints on lead-time and order accuracy.
The main decisions to be addressed when designing an A-Frame system are determining which medications (and in what quantities) should be stored in the A-Frame, as there tends to be capacity constraints due to the infrastructure costs related to the A-Frame system. In addition, A-Frame systems are complex machines with interacting components that affect throughput. There are three primary criteria used to determine which SKUs to assign to the A-Frame, and in what quantities.

- Replenishment
- Economical Trade-offs of Infrastructure and Picking Costs
- Throughput

The first criterion, replenishment, has been researched by Bartholdi et al. [2], Caputo and Pelagagge [6], and Jernigan [12]. Caputo and Pelagagge [6] design a decision-support tool for modifying the system setup once demand is observed for a period of time. Through a rule-based heuristic, the system setup can be tuned for the next period, evaluating product substitutions, modifying the number of channels, and determining the reorder level and the maximum quantity to be dispensed. A significant component of their decision-support tool is the consideration of channel fill levels. The authors' decision support tool suggests through empirical testing that these levels tend to be much higher in practice than appropriate.

A method for the assignment and allocation of SKUs to an A-Frame based on the number of replenishments and pick costs is presented by Bartholdi et al. [2] and Jernigan [12]. They do not consider infrastructure costs in their model, but instead assume that each order-fulfillment area has a known storage capacity. Moreover, they consider minimizing the number of restocks to the A-Frame and assume that each replenishment, regardless of the number of items, has a fixed replenishment time and can occur instantaneously (i.e., no allowance for safety stock or stochastic demand). Their replenishment schedule allocates space in terms of a fraction of the available storage capacity, which does not address the discreteness of channels, the different lengths of channels, or if an SKU can fit or fill the space allotted to it. They extend their models to consider several time periods and reassignment costs.

Liu et al. [14] extend Jernigan's work by analyzing a system with both an A-Frame and an alternate horizontal-dispenser (HD) system. In an HD system, the channels are arranged horizontally versus vertically and are capable of ejecting more than one item at a time. They incorporate the discreteness of channels, but assume that all SKUs have the same physical dimensions and ignore pick costs, infrastructure costs, and throughput. They determine the number of channels to provide to each SKU based on minimizing the number of restocks required, assuming restock costs are not a function of the number of items replenished. They assign SKUs to either the A-Frame or HD system using a greedy heuristic based on a labor-efficiency ranking.

Yaohua and Yigong [30] analyze a parallel-dispenser system, which is also an alternative automated dispensing technology. A parallel-dispenser consists of three kinds of channels (i.e., launching, pushing, and replenishing channels) and can eject more than one item at a time. Unlike an A-Frame system, the sequence of orders does impact throughput in a parallel-dispenser system. Therefore, they develop a
heuristic for sequencing orders to minimize the total picking time. They assume the allocation and assignment of SKUs to the parallel-dispenser system is given and do not consider infrastructure costs of the system.

Reference [22] analyze the design of an A-Frame system in a distribution center, which includes evaluating the technology to arrive at the best-cost solution that meets throughput considerations. Their research addresses the question of which SKUs to assign to an A-Frame system, and in what quantity, considering labor, infrastructure, and throughput. This is a critical decision as it has a direct impact on the efficiency of an A-Frame system through balancing replenishment costs, picking costs, and infrastructure costs, as well as the throughput of the process.

A math programming-based approach to determine the amount of A-Frame infrastructure investment, as well as the assignment and allocation of SKUs to the A-Frame, is provided in [22]. They allocate channels in an A-Frame system based on an inventory modeling approach. Next, they address throughput considerations explicitly by developing analytical models for the throughput of an A-Frame and heuristics to adjust the allocation and assignment of SKUs in order for the A-Frame to meet a throughput constraint. They prove that the best-case allocation for labor savings is the worst-case allocation for A-Frame throughput. They test their methodology on a pharmaceutical industry example and determine the impact of parameters on their model.

Their methodology indicates that A-Frame systems provide the greatest impact on labor savings when a distribution center has high item commonality, small order sizes, and high skewness levels and on throughput when a distribution center has low item commonality, small order sizes, and low skewness levels.

4.2 Carousel Systems

A carousel system is a stock-to-picker piece-level technology that consists of storage locations that rotate around a closed loop. The carousel system is served by an operator (either human or robotic) that is at a fixed-picking position and the storage locations rotate in either direction to bring items to an operator.

Carousel systems are used in both a traditional distribution center and a hospital pharmacy and have average picking rates of 200–400 lines per person hour [27].

In a distribution center, carousels are commonly utilized in pods with more than one carousel unit per pod, as shown in Fig. 4. This configuration allows one unit in the pod to retrieve the next pick, while the operator is retrieving an item from another unit in the pod. A carousel system rotates such that the requested items are in front of the operator. Pick lights inform the operator of the position and quantity of the product to be picked. After picking the items and putting them in the correct tote, the operator walks to another carousel in the pod and picks again. The rotation time of a carousel is a function of the length of a carousel; consequently, the number of carousels in a pod can be varied to ensure that the carousels are not the bottleneck in the system, constraining the human order picker. As carousel systems
are typically throughput constrained (rather than space constrained) [17], multiple carousel pods may be implemented to meet throughput requirements. One operator is assigned to each pod of carousels and batch picking is usually performed.

The literature on carousel systems used in a distribution center is abundant and can be classified into the following problem areas: rotation strategies, performance models, and assignment of storage locations. For a recent review, see Hassini [10] and the references within. The majority of the literature focuses on models for single carousel systems picking a single item.

Hospital pharmacies that use carousel systems typically pick a batch of medications and often have multiple carousels. Multiple medications are stored in a single bin to increase storage densities. Whereas specific models for carousels used in a
hospital pharmacy have not received attention from the academic community, Meller and Klote [17] could be applied to determine the throughput of a carousel with human order-pickers picking batches of orders.

In the next section models for an additional stock-to-picker system, a picking machine, are presented.

4.3 Picking Machines

Picking machines, also known as automated-storage-and-order-fulfillment systems, are an example of an alternate stock-to-picker piece-level fulfillment technology. Picking machines incorporate pick-to-light technology, put-to-light technology, conveyor systems, and carousels or mini-load AS/RSs in order to increase throughput and provide high product density. Depending on the system configuration, a picking rate of up to 1,000 order lines per person-hour is possible [28], which indicates why this technology is seen in industries that have a large number of active SKUs and small order sizes. These characteristics, as well as the security of the items and the ability to conduct lot-tracking, make picking machines common in the pharmaceutical industry.

A picking machine consists of numerous pick stations and a system of carousel units or a mini-load AS/RS to provide storage. An integrated conveyor system transports the requested totes to and from the storage area and the picking stations, as depicted in Fig. 5.
Therefore, even though there are numerous pick stations, each pick station utilizes the same carousel system or mini-load AS/RS for storage. The required orders' shipping containers are transported via a conveyor to a pick station. At the same time, the requested SKUs are retrieved automatically from the storage system and are sent to the pick station. Displays indicate to the operator both the position and the quantity of the product to be picked, as well as the position of the container to which the SKU should be transferred (the put operation). The replenishment of the storage area can be conducted concurrently with the order-picking process or handled off-shift.

Two conference papers with preliminary simulation results address picking machines. Perry et al. [25] use a discrete-event simulation model to assist in the physical system design of a picking machine. A simple, expected-value model is used for initial design variable values, which are then modified based on throughput requirements. Their testing indicates that the conveyor system is the bottleneck on system throughput. Raghunath et al. [26] describe an interactive and flexible simulation structure for a picking machine.

Picking machines have been mentioned in the literature as future research by Bozer and White [4]: “A possibility is to investigate the use of remote picking stations where each station is interfaced to the storage/retrieval system via a closed conveyor loop. Such a system allows each picking station access to the aisles.” Also, Park et al. [19] classify mini-load AS/RSs into three categories, one mentioned as future research is a closed-loop conveyor: “mini-load systems containing a closed-loop conveyor, often called the remote order picking system, have a closed-loop conveyor system to deliver the containers that interconnects each aisle of the mini-load system with the remote order picking stations.”

Because picking machines are touted as a lower-inventory alternative to carousel systems, Pazour et al. [21] develop a probabilistic model capable of quantifying the inventory differences between these two technologies. They also determine the throughput of a picking machine by analyzing its subsystems, the carousel storage system, the closed-loop conveyor, and the pick stations, independently. An expected cycle-time model is developed to determine the throughput of a carousel system with a storage and retrieval machine performing batch retrievals. A stability-condition model is applied to determine if the conveyor system will be stable for an expected throughput requirement. A case study comparing a picking machine to a carousel-pod system is presented to illustrate how a manager could use their analytical models to answer system design questions.

In the next section we focus on order-fulfillment technology used within a hospital.

### 4.4 Unit-Dose Repackaging Technologies

In hospitals, medication errors can occur during every step of the process, but occur most frequently during the prescribing and administering stages. In fact, the following startling statistic is given in a report entitled Preventing Medication Errors [1], “when
all types of errors are taken into account, a hospital patient can expect, on average, to be subjected to more than one medication error each day. One way to prevent such medication errors and increase patient safety is to administer medications in unit-dose packages [15]. To further increase patient safety, many hospitals today are implementing barcode-enabled point-of-care (BPOC) systems. These systems require that medications are in barcoded unit-dose packages and also that patients wear a barcoded bracelet. When a nurse administers the patient’s medications, he or she must first scan the barcodes on the medication and the patient. These systems help ensure that the right medications reach the right patient at the right time by allowing barcodes on a patient’s ID wristband and medication packaging to be checked against a database containing medication identification and physicians’ orders.

Unfortunately, not all medications are available in unit-dose form. A 2008 survey of hospital pharmacists found that on average, hospitals could obtain only 56% of their total formulary in unit-dose form directly from the manufacturer [16]. Currently, if a hospital wants to use unit-dose dispensing, the choice is to either purchase pre-packaged unit-dose medications directly from the supplier, utilize a third-party repackager, or purchase bulk supplies of medications from manufacturers and repackage them on-site into unit-dose packages [18].

Various levels of automation are currently being utilized to handle unit-dose medication repackaging on-site. As illustrated in Fig. 6, a typical process is to buy bulk medications from the supplier, package medications in unit-doses, and then store the unit-dose medications on the hospital floor, typically in automated dispensing cabinets.

Technology for repackaging medications in unit-dose form is classified into three levels: manual, semi-automated, and fully-automated. In a manual system, a technician retrieves the appropriate bulk medication and then has the laborious task
of physically repackaging the bulk medication into unit-dose packages. A manual process typically uses little more than a device to seal the packaging with manual labor used for the repackaging and relabeling process.

The semiautomated option is typified by what is referred to as a **table-top unit**, consisting of a rotary table, an automated sealer and labeler, and a manual induction process, which involves placing individual medications into openings on the top of the rotary table. In a semiautomated system, the actual repackaging process is automated, but the retrieval of medications and monitoring processes are not. A technician is required to retrieve the appropriate bulk medication, fill the machine, and monitor the process. In addition, the system requires manual cleaning in order to prevent the cross contamination of medications.

Finally, a fully-automated system, also known as an automated repackager, removes a large portion of the labor associated with repackaging. A fully-automated system consists of a set of canisters, where each canister holds one medication. The medications travel down a common chute to the packaging and labeling units. Manual bulk replenishment of the machine is required. Because of the common chute, medications that would contaminate other medications cannot utilize an automated repackager. Therefore, these machines are not always able to hold all of the unit-dose medications on the formulary and some other system (i.e., a manual or semi-manual system) is still required.

Reference [23] develop a mathematical model that simultaneously determines which level of technology is warranted and how each medication that is not delivered to the pharmacy in unit-dose form should be repackaged subject to multiple constraints. This model has been integrated into a free Excel-based tool available to pharmacy directors. They test their model with data based on small, medium, and large hospitals and conduct sensitivity analyses to gain further insight. They illustrate how the results from their model can aid in incorporating qualitative aspects into technology selection. Their results show that a semiautomated repackaging system is the most economical technology alternative for most hospital pharmacy in-house repackaging operations. This result, however, is sensitive to quantitative factors like the number of unit-dose medications to repackage and the available labor, and to qualitative factors like, repackaging quality, pharmacist retention, and storage space constraints.

Once medications are in unit-dose form, the medications are stored on clinical units in automated dispensing cabinets, which are the focus of the next section.

### 4.5 Automated Dispensing Cabinets

Automated dispensing cabinets (ADCs) are medication storage devices that allow medications to be stored and dispensed near the point of care, creating a more decentralized medication distribution system with shorter nurse response times. An example of an ADC is a Pyxis machine shown in Fig. 7. Currently, 83% of USA hospitals use ADCs [24] and it is common to have one or more ADCs in each clinical unit.
Medications are stored within ADCs such that each medication has its own separate and segregated location. In the case of a matrix drawer, all medications within a drawer are accessible to a nurse and 48.5% of hospitals surveyed use matrix drawer configurations as the predominant configuration in their ADCs [24]. Typically, no scanning of medications is performed when a nurse removes the prescribed medications for a patient.

To reduce opportunities for wrong medication selection and dosing errors, medications should be located in the compartments such that similar medications are not in close proximity to one another. Medication similarity can be defined in terms of a medication's nomenclature, packaging, dosage form, risk level, and dosage concentration. A safe practice is to store different concentrations or dosages of a medication in a manner that will minimize the risk of accessing the wrong strength of the medication. The Institute of Safe Medication Practices (ISMP) has defined a list of medications that are look- and sound-alike medications and recommend that they should not be located near each other within the ADC. For example, it is best not to place metformin near metronidazole, as both are oral solid medications that sound-alike but have very different uses (metformin is used to improve glycemic control in adults, while metronidazole is used to treat bacterial infections).

Due to capacity constraints on the ADC and medication expiration dates, the assignment and removal of medications from compartment locations within an
ADC occurs daily. Medication selection and removal is primarily determined based on the collective needs of the patients on a clinical wing. Determining the locations of medications in the ADC is typically a manual process performed by a pharmacist technician.

Wise et al. [29] conduct a cost-benefit analysis on the decision of purchasing an automated medication distribution system in a hospital unit. They cite that medication and distribution compose a considerable amount of economic costs due to the current medical practice of prescribing an increasing number and diversity of medications to patients. Consequently, the cost of labor to store, distribute, and administer medications in a hospital has increased. A case study is performed that justifies the purchase of ADCs; primarily due to reduced nursing time in the travel and administration of medications.

Pazour and Meller [20] study the problem of locating medications in an ADC to minimize human errors and formulate this problem as a series of location problems. They develop heuristic methodologies that are computationally efficient and test their methodologies on a hospital example, testing situations with existing medications located in a drawer and when the drawer is empty.

5 Conclusions and Future Research

We analyzed the hospital pharmacy by drawing upon concepts from distribution center design. Our research focused on the similarities between a traditional distribution center and a hospital pharmacy, with special attention to order-fulfillment technologies. We reviewed the literature on analytical models for order-fulfillment technologies used throughout pharmaceutical distribution. A multitude of operations research techniques have been used to analyze the technologies including mixed-integer, linear programming, heuristic algorithms, probabilistic modeling, and simulation.

While order-fulfillment technology is used in both facilities, the driving force for implementation is different: in a distribution center, order-fulfillment technology is typically implemented to reduce lead times and labor costs. On the other hand, in a pharmacy, order-fulfillment technology is implemented to first enhance patient safety, and second to improve the pharmacy or nursing staff’s productivity. The objectives used in the order-fulfillment technology models reflect this difference. Minimizing cost or time are common objectives for a traditional distribution center, while minimizing errors or maximizing quality are common objectives in the pharmacy-application domain.

The area of pharmacy system design presents a host of challenging problems. Future research could expand the analysis of functional processes beyond order-fulfillment within a hospital pharmacy. Because retail pharmacies tend to handle larger volumes of medications, retail pharmacy operations differ considerably from hospital pharmacy operations and could be analyzed. Also, because it is common for both a distribution center and a hospital pharmacy to use carousel systems, an analysis that addressed the unique nature of operating within a pharmacy would be interesting.
New initiatives are taking place in pharmaceutical distribution, including track-and-trace or pedigree programs. These programs are designed to help protect patients from counterfeit or tampered medications. The state of California has issued a mandate that all prescription drugs must have an electronic pedigree by 2015 and other states have begun to institute similar mandates. The California legislation requires that each prescription medication be electronically tracked at the item level through the distribution system, from the manufacture through distributors and wholesalers to its final transaction to a pharmacy. The implementation of this program presents a number of challenges and requires numerous changes to the current practices in the pharmaceutical supply chain. Interesting research questions specific to automation and distribution center design will be associated with these changes. For example, how will pedigree programs impact the ordering, handling, and distributing quantity? What are the logistic implications of tracking a unique product instead of bulk products through the pharmaceutical supply chain? What level of granularity is appropriate to track medications through the supply chain? What technologies should be employed to track medications, store medication information, and process information?

References


