FORWARD PICK AREA

Design and Operation

BY

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Forward Pick Area - Design and Operations

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1 Introduction

In a typical warehouse operation, the order-picking process consists of retrieving products from storage locations to fulfill customer orders. The process has received a great deal of attention from warehousing practitioners and researchers because it is generally the most labor-consuming operation in a warehouse, accounting for approximately 35% of a warehouse operating cost [19]. From a general point of view, there are two basic order picking systems, namely *parts-to-picker*, and *picker-to-parts*. In the former, some sort of automated system is used to bring the products to the picker (i.e., the picking operator), whereas in the latter, the picker travels along the aisles of the warehouse retrieving the required products from the storage locations. Among these two types of systems, it has been well documented that the largest proportion of order picking systems found worldwide belong to the *picker-to-parts* type [8, 17], probably because of the lower capital investment required and the flexibility and adaptability of human workers.

Consequently, as most of the picking work relies on humans, the process is time-intensive and thus the cost of labor contributes the most to the operational cost. As pointed out in [25], the main activities required by a picker to complete a customer order in a *picker-to-parts* system are travel, search, and pick. The estimated proportion of time required by each of these activities is 50%, 20%, and 15%, respectively. From these proportions it is easy to understand why most of the academic work addressing the order picking process aims at minimizing the travel time of the picking operator, and this is used as a proxy for minimizing the operational cost. Only recently have researchers looked into the relationship between the well-being of the picking operators and the efficiency of the picking process. It has been shown that there is a potential trade-off between the time required by a picker to process a customer order and the human energy expenditure involved [5], motivating an integrated approach that considers both the ergonomic and economic aspects when designing such systems [10, 15, 16]. These recent efforts aim at reducing the worrisome high incidence rate of nonfatal occupational injuries and illnesses found in the transportation and warehousing sector, the second highest in the U.S., and only surpassed by the sector of agriculture, forestry, fishing and hunting [14].

A strategy for minimizing the distance traveled by the pickers that has recently drawn the attention of researchers and practitioners is that of concentrating the picking activities in a relatively compact area. This serves to both reduce picking time (and therefore cost) and to lower the walking distance of the pickers. As depicted in Figure 1, the approach consists of dividing the warehouse into two areas: the fast-pick or forward area, where most of the picking activities take place, and the reserve or storage area, from which the fast-pick area is replenished. The main advantage of a forward-reserve configuration is that both the time required to complete a customer order and the human energy expenditures decrease because of the pickers traveling less compared to picking the SKUs directly from the reserve area. However, the drawback is that this configuration requires the forward area to be replenished from the reserve area periodically. Forward areas are most suitable for small parts warehouses such as pharmaceuticals [4], healthcare and cosmetics [21, 20], shoes and footwear [3], or office supplies [8], as these warehouses generally store items that are small enough to be stored in sufficient quantities in a limited area.

Technology is another driver of operational efficiency, and combined with an appropriate layout can result in further labor cost reductions. Proba-

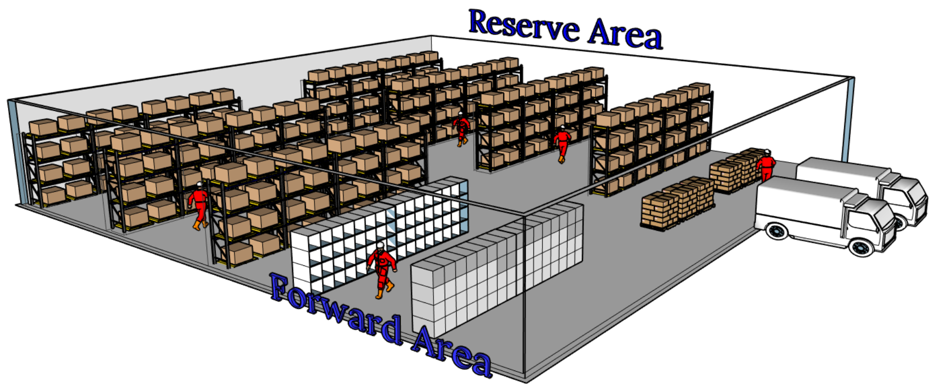


Figure 1: A typical forward-reserve configuration

bly the piece of technology that a forward-reserve configuration benefits the most from is a warehouse management system (WMS), as it allows the picking operators to focus on the picking activities rather than the paperwork. Also, having a WMS in place is a requirement for implementing other technologies that facilitate the picking process such as handhelds for barcode scanning, RFID tags, and enhanced picking aids such as pick-to-light and voice picking systems. The evolution from a fully manual operation to a partially automated warehouse has been an evolving journey. As pointed out by O'Byrne [18], this journey started with technologies such as gravity-fed racking, moved to pick-to-light systems, and now involve advanced robotic systems where autonomous equipment work alongside human operators. The use of the latter technologies has increased over the recent decade driven by the lower capital investment required, and the labor shortage experienced by some logistics industries.

2 Background

Most previous works in the literature addressing the forward-reserve problem use as a base the so-called fluid model proposed by Hackman and Rosenblatt [12] in 1990 to solve the product assignment and space allocation problem. In their now seminal work, the volume of each SKU is treated as a continuously divisible fluid between the forward area and the replenishment area. Some of the assumptions included in the fluid model are that the products are of small size, the demand and cost are stationary in continuous time, the larger area (i.e., the reserve) has infinite capacity, and the material handling cost is independent of the size of the parts. In this approach the objective is to minimize the replenishment cost only, as the distance traveled by the pickers within the forward area is considered negligible by the authors.

Some extensions to the work of Hackman and Rosenblatt include the problem of sizing the forward area, proposed by Frazelle et al. [9], and the problem of defining a picking period, addressed by Van den Berg et al. [6]. Heragu et al. [13] proposed a mathematical model and a heuristic algorithm to determine product assignment to the functional areas in a warehouse as well as the size of each area, whereas Gu et al. [11] solved the forward-reserve product assignment and space allocation problem with the objective of maximizing profit.

In 2008, Bartholdi and Hackman [4] presented a solution to the general forward-reserve problem. They used the fluid model and a greedy heuristic to define the size of the forward area and the fraction of that area that should be allocated to each SKU. They compared their results with two strategies commonly used by practitioners: equal space, in which the same amount of space is allocated to each SKU; and equal time, in which the space allocated to an SKU is equivalent to the inventory required to meet the demand of the SKU for a fixed period of time.

Accorsi et al. [1] proposed a four-phase hierarchical procedure to solve the forward-reserve problem (FRP) based on the work of Bindi et al. [7]. Phase one aims at finding the layout of the forward and reserve areas whereas phase two allocates space to the SKUs in both areas based on the work of Bartholdi and Hackman [4]. In phase three the SKUs are placed in the forward area, while phase four comprises running a simulation to compare alternative system configurations. In 2013, Walter et al. [27] addressed the discrete forward-reserve problem to solve the following three problems: (1) the discrete forward-reserve allocation problem (DFRAP), (2) the discrete forward-reserve assignment and allocation problem (DFRAAP), and (3) the discrete forward-reserve allocation and sizing problem (DFRASP). The authors proposed a repair heuristic for transforming a non-integer solution obtained from the fluid model to an integer solution. In the same year, Subramanian [23] published his dissertation addressing the problem of assigning a set of SKUs to one or multiple forward-pick areas. His work, based on the models of Hackman and Rosenblatt, solves a space allocation problem where the allocation is defined as a finite set of multiples of a common base.

Thomas and Meller [24] published in 2015 a set of guidelines for designing a case-picking warehouse that include, as decision variables, the size and layout of the forward area, the dock door configuration, the shape of the pallet area, and the pallet rack height. In their approach, the input data collected from a warehouse allows practitioners to find the values of the decision variables that minimize the labor hours. One year later, Bahrami et al. [3] studied the FRP where the reserve area stores goods in pallets or in bulk. The authors presented an approach to minimize the number of stock-outs in the forward area.

Shah and Kanzode [21] addressed the design of a forward-reserve configuration from a lean thinking point of view, identifying that previously published approaches produce waste in the form of excess inventory and customer waiting time. They proposed a heuristic to solve the problem with the objective of minimizing the waste. In 2020, Wu, de Koster, and Yu [28] compared response travel time models for FR storage in an automated storage/retrieval system using an ABC class-based storage strategy and a *parts-to-picker* system. To measure the response time, the authors focused on crane travel time, as cranes are expensive and require large spaces. The study aimed at identifying the circumstances for which it is better to implement an FR storage strategy. They concluded that the FR storage is usually more beneficial when the average number of picks per replenishment is larger than 1; with response time savings up to 50% when the average is greater than 10.

Recently, Velez-Gallego and Smith [26] considered the discrete forward-reserve allocation problem in a *picker-to-parts* warehouse of small parts. In their work the distance traveled by the pickers within the forward area was included in the picking cost, a consideration heretofore not included in the literature. The work was inspired by the warehousing operation of the cosmetics company depicted in Figure 5. Here, the layout of the forward area consists of a single aisle with racks on both sides (see Figure 5a); and several storage locations at each side (see Figure 5b). As the company decided to store all SKUs in the forward area, no picking is performed from the reserve area. After jointly formulating the space allocation and product allocation problems as a mixed-integer linear program, the computational experience showed that although several feasible solutions were found, finding the optimal solution for realistically sized instances is still challenging.

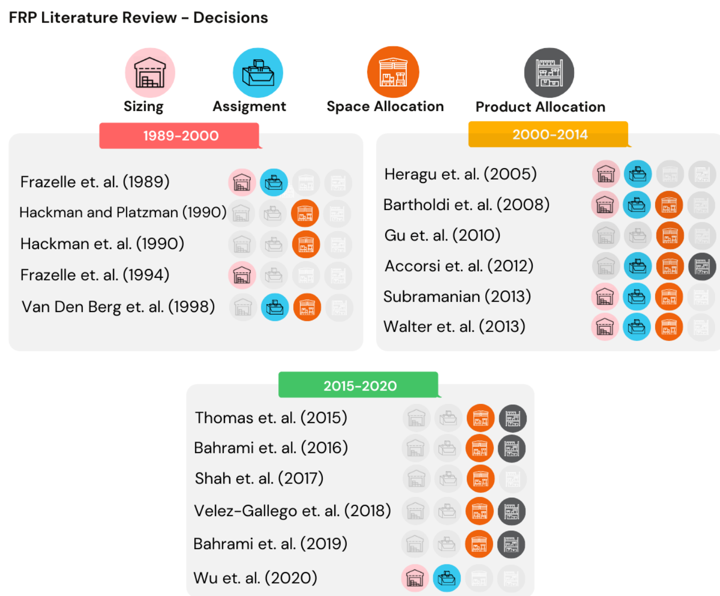


Figure 2: Literature Review Summary - FRP Decisions

The authors of this paper are currently working on extending the work of Velez-Gallego and Smith [26] by devising a heuristic approach that allows for solving realistic sized instances, along with other extensions. There are four main forward-reserve subproblems that have been studied in the literature: (1) the sizing problem, (2) the SKU assignment problem, (3) the space allocation problem, and (4) the slotting or product allocation problem. Figure 2, presents a summary of the most relevant papers found in the literature, with the corresponding subproblem studied in each work identified.

3 Design of a Forward Area

How beneficial a forward area will be depends on its design. Compared with warehouse design in general, the forward pick area has not gotten much attention in the literature. In this section we discuss the most common elements of forward area design and divide the elements into the categories shown on Figure 6; the sizing problem, the assignment problem, the space allocation problem, and the product allocation problem. We then discuss the approaches to achieving the design task by considering the physical as-

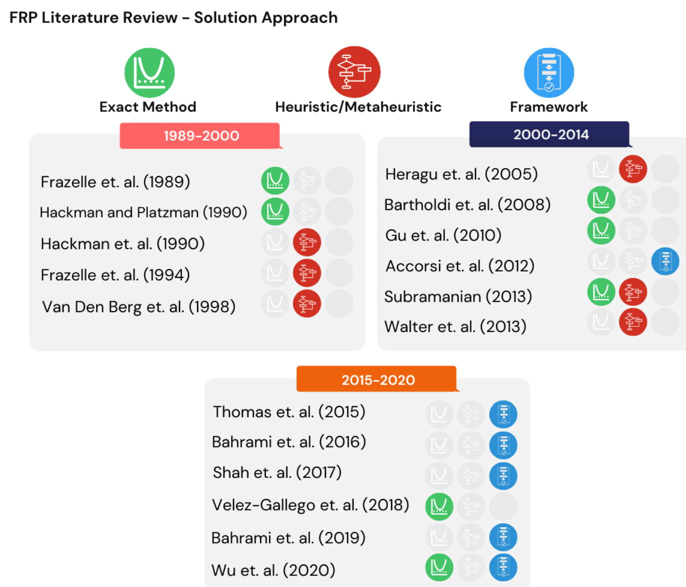


Figure 3: Literature Review Summary - FRP Solution Approaches

pects of the forward area followed by the operational aspects.

The sizing problem is not just about size. It is also about the shape and layout. These include specifying the dimensions of the forward pick area, the location of input/output location(s), and whether to use a single aisle or a U shape (see Figure 7). Then, the storage equipment such as racking and storage must be chosen. This is a decision to be made in conjunction with the decision on how the picking will be accomplished, human or robotic. If human, will picking aids be used such as pick to light? How will orders be collected - a rolling cart, for example? Remember that forward pick areas typically contain small, low weight items. Similarly the equipment for the replenishment task must be specified. The design specifications mentioned in this paragraph tend to be one time decisions, or at least done very infrequently. They require substantial investment in capital and will not change frequently. Therefore, much care must be taken to choose these aspects.

After the physical specifications of the area and how the picking and replenishment will be accomplished are defined, then product assignment, space allocation, and product allocation must be addressed. These decisions

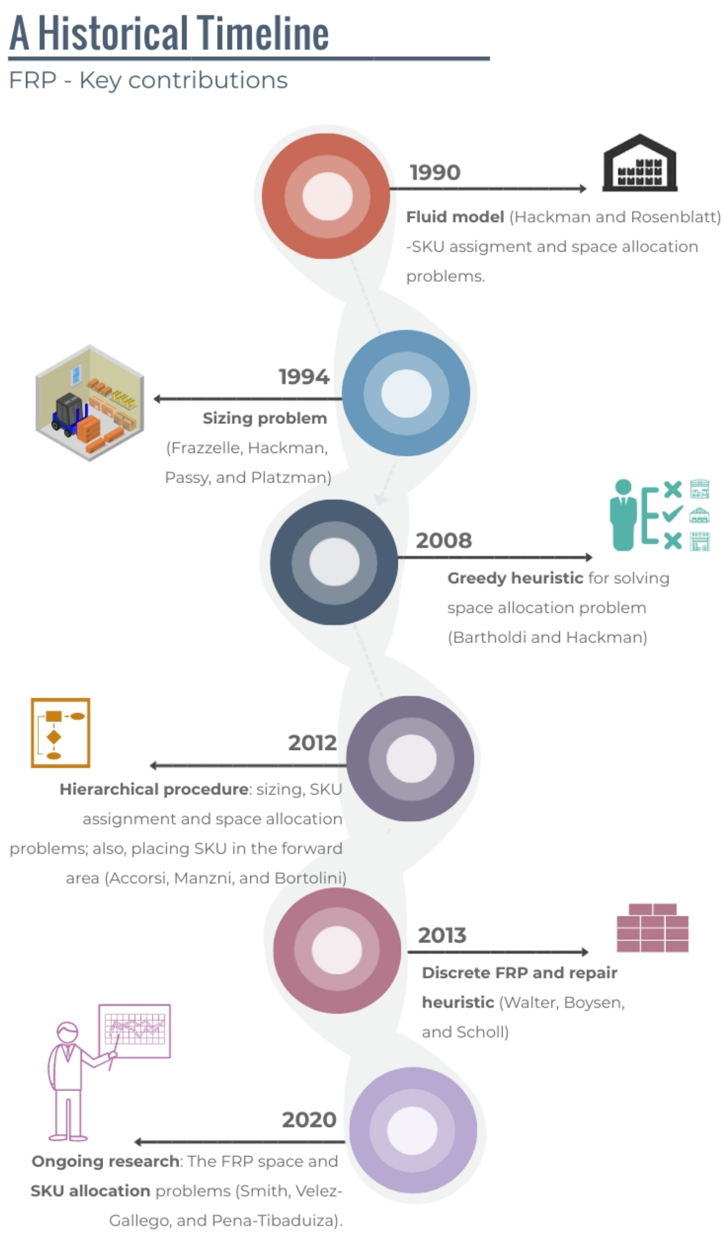
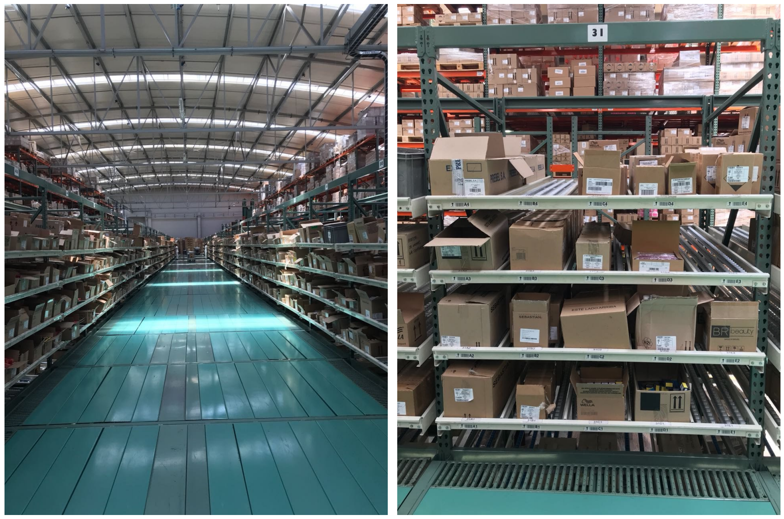


Figure 4: Key contributions to the FRP



(a) Forward area aisle (b) Single storage location

Figure 5: The forward area - a typical cosmetics company

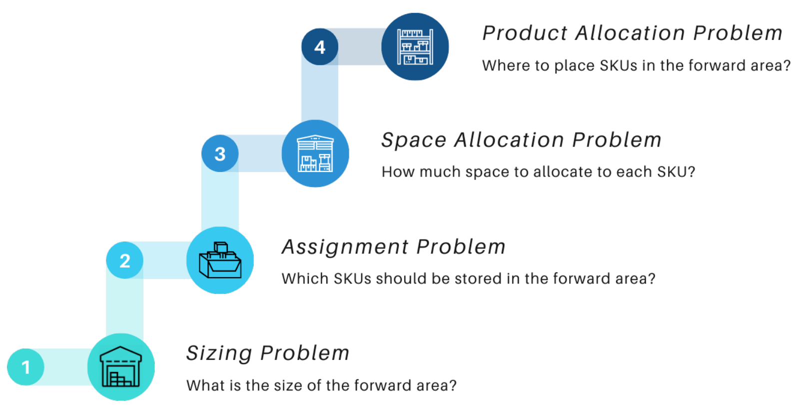


Figure 6: Forward-reserve sub-problems

are done more often than the sizing / physical specifications and equipment selection from above but are not done that frequently, that is, not done daily or weekly. They need to be responsive to changes in demand caused by new products, promotions, seasonality, and general tastes and needs.

3.1 Physical Decisions

Universal decisions are those that are fundamental and must be made for all situations considering a forward pick area. Among the universal decisions, the first one is whether to even have a forward area. We discussed this aspect early in the white paper as to which industries and operations are most likely to benefit from a forward pick area. The organization needs to weigh the trade offs in benefits (e.g., quicker picking time, less worker travel) with the costs (e.g., dedicating part of the warehouse for this purpose, purchase of racking and automation, replenishment costs).

Once the decision has been made to establish a forward area, the next question is how large it should be and of what shape. (Note, we are assuming a single forward area but there could be multiple forward areas within the same warehouse or distribution center.) A related question is where to put this area in the warehouse and the obvious answer is near to one or more input/output locations (that is, close to the onward transit staging area) to minimize travel times and distance walked. The sizing of the forward pick area should be chosen based on how much space can be given over to this function, the number of products (SKUs) envisioned being stored there, and how much of each product might be stored in the forward area. More storage means less replenishment but also takes up more of the available area in the warehouse. Next, a layout type needs to be selected. The two most popular ones for forward pick areas are the U shape and the one aisle shape. The shape and size of the forward area may dictate which layout type is more appropriate.

The next set of decisions concern the storage, handling, and picking equipment. This includes racking, storage, handling equipment (such as carts), and picking aids (such as pick to light). Among the equipment decisions, how to replenish the forward area from the main part of the warehouse needs to be defined. Aspects to be considered include the size and weight of the products, the nature of the pick lists (length and diversity), and the investment level allowed. The replenishment method may also depend on

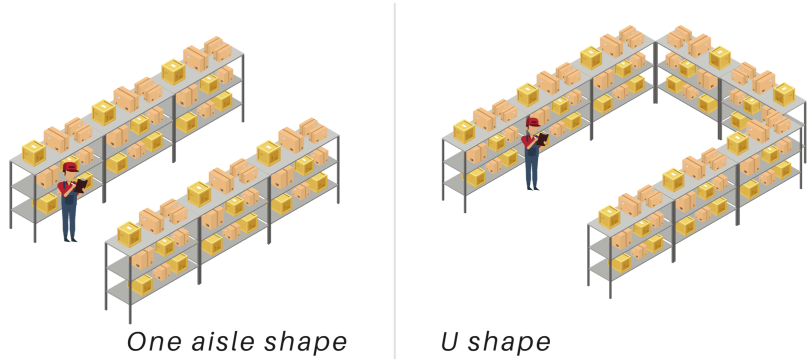


Figure 7: Common configurations of a forward area

the characteristics of the transit paths such as width, turns, and traffic from the forward area to the reserve area and on the path =characteristics within the forward area itself.

3.2 Operational Decisions

The first operational decision has to do with the actual products, or SKUs, stored in the forward area. Which ones will be stored there? All products or a subset? If a subset, how will the products be chosen? This is the assignment problem. If a subset of items is selected, the popularity of the products is the primary consideration. Products ordered more frequently should have a greater priority to be located in the forward area. With product assignment there may be other considerations that would cause a product not be located in the forward area including size, security aspects, and special handling aspects (such as refrigeration).

Then, the amount of space allocated to each SKU stored in the forward area needs to be chosen. This is the space allocation problem. The space allocated to each product should be based on its size (obviously) but also its popularity. The goal is to minimize replenishment trips. A popular item will need to be replenished more often if it is not assigned enough space in the forward area.

Next is locating the space assigned to each SKU to the appropriate place(s) in the forward area. This is the product allocation or product slotting problem. A natural way to do this is to consider product popularity and put the most ordered products close to the input/output location. Integral to this is whether to consider product correlations when choosing where to locate the SKUs within the forward pick area. Products that tend to be ordered together can benefit from being located close to one another to enhance picking efficiency. Another part of the product allocation problem is whether to put each SKU in a single contiguous location or in multiple locations within the forward area. Most installations will choose the former but if there are strong correlations among diverse products, picking time can be reduced by storing multiple disjoint quantities of a given SKU within the forward area. Nuances then can include placing the most frequently picked items in the locations of greatest ease for the picker, such as at arm or eye height.

However, product popularity usually changes over time and can exhibit seasonality and responses to promotional periods. Therefore, product assignment and allocation is far from a one time activity. Locating SKUs (and even choosing which SKUs are in the forward area) is dynamic that needs respond to market forces. The frequency of reallocating product should be determined based on the speed of demand dynamics and the cost and disruptions of rearrangements. Forecasting product sales considering such factors as seasonality, promotional periods, and product trends can be important to establish the best product allocation proactively, not just in response to actual sales. Changing the product assignment, the space allocated to each product and/or the location of the products has costs of course, including the physical costs of moving products around, the disruption to the picking and replenishment activities, and subsequent possible confusion to workers who must deal with a different arrangement of SKUs.

Importantly, the method of replenishment needs to be defined. Will it be visual, a set time, a set quantity, or top-off? The idea is to minimize replenishment costs while keeping the forward area fully functional, that is, with enough product to fulfill the orders when needed. Most approaches in the literature have considered each replenishment trip / activity to have a predefined, constant cost. However, this may not be accurate. Replenishing product from further within the reserve area will necessitate more travel and thus more time. Replenishing a larger quantity or larger items may require more time and effort that is not accounted for in the literature. Finally, a policy on what happens if a product being picked has zero supply in the forward area (that is, there are none in the area(s) allocated to this product) must be established. What should happen? A corollary of this is what happens if one of the areas when there are multiple areas for a given SKU is empty. Should the picker be rerouted to another storage slot where the product is available or should replenishment of that empty slot be triggered, or should both happen?

3.3 Design Approaches

Much design of the forward pick area is done in a rather ad hoc manner. This is not necessary bad. When done by people who have a good understanding of the forward pick operations and the product mix and churn, good designs and operational policies can result. But taking a more analytic approach can reap benefits in terms of efficient capital investments and ongoing operational savings. The papers cited throughout this white paper contain approaches to different aspects and versions of the forward pick area design problem. These papers are academic and abstract or ignore some of the pragmatic aspects or details. The designs using these approaches will not result in final, detailed designs for realistic situations but they are useful to guide the design process. They will identify superior layouts as well as product assignment and allocation strategies.

Regardless of the design solution approach selected, when it comes to modeling the operation of a warehouse, the recently published work of Ansari and Smith [2] may come handy as a guideline for planning the data collection phase. Their work consists of a comprehensive data structure for modeling warehouse operations that explicitly describes the data that needs to be collected in order to model the operations of a warehouse. The proposed data model is divided into four sections. Section one is devoted to capture the possible movements of the picking operators. These movements are described using a graph representation in which the nodes correspond to the locations where the picker might stop to access a certain number of picking locations or slots, and the arcs correspond to all of the possible picker movements. Section two in the data model corresponds to the physical characteristics of each SKU such as dimensions and weight. Section three corresponds to the description of the locations in the pick area where the SKUs are assigned for storage, which includes the type of storage equipment used and the quantity of a given SKU that each slot can hold. The fourth section in the data model contains the information about the picking orders and line items. The former holds information about the order itself such as customer, arrival date and so on, while the latter stores the data related to each line in the order, where a line corresponds to a single request for a specific quantity of a given SKU.

The data structure described above is particularly useful for developing a discrete-event simulation model to assess the performance of different designs. A simulation model allows practitioners to evaluate different layouts, storage assignment and replenishment policies, and do so under alternative scenarios of labor availability and demand patterns. A simulation model is also ideal for evaluating the expected productivity improvements if technologies such as pick-to-light or voice-picking were incorporated to the picking operation.

Typically a simulation model is developed following the process depicted in Figure 8. This modeling framework starts with defining a conceptual model of the system that comprises both its physical description and the policies and rules that describe the picking operation. This conceptual model is then translated into a computational model of the system using a commercial discrete-event simulation software. The input analysis step deals with identifying the elements in the data model that are subject to variability in order to find a suitable way of representing their stochastic behavior. Typical examples of these types of stochastic elements in the data model are the demand of a given SKU, the time required by a picker to travel a unit distance within the picking area, or the fact that a given material handling equipment fails and needs to be repaired, just to mention a few. All of these phenomena need to be represented in the computational model as random variables with their corresponding distribution functions in order to capture their intrinsic variability. The random elements are assumed to follow common probability distributions such as uniform, triangular, Normal (Gaussian), or exponential. Which probability distribution should be assumed in the model and its specific parameters are chosen based on historic or projected data and / or expert judgement.

Once a computational model of the system is fully functional, it needs to be validated to ensure that it represents the conceptual model or physical systems as closely as possible. This validated model is now a playground where decision makers can test hypotheses and perform what-if analysis by modifying the inputs and discovering its effect on the performance of the system. The assessment should be done using statistical inference tools since the performance indicators (i.e., throughput, service level, cycle time, etc.)

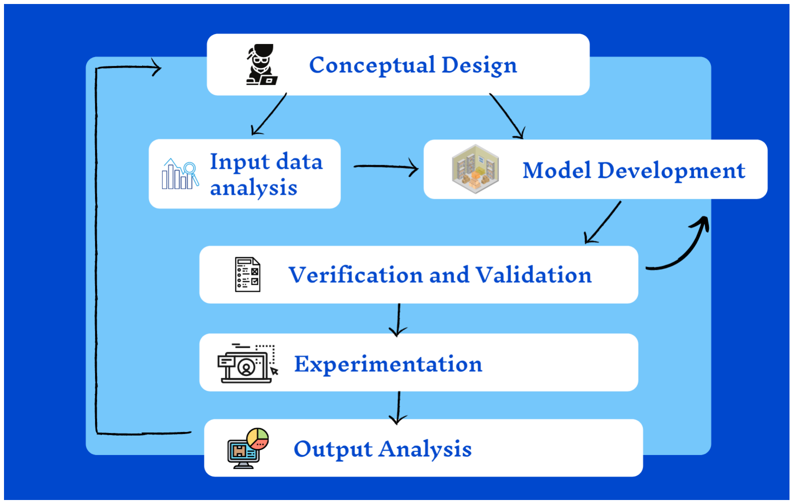


Figure 8: Simulation modeling framework. Adapted from Jeffrey S. Smith, David T. Sturrock and W. Kelton. "Simio and Simulation: Modeling, Analysis, Applications. Fourth Edition" [22]

are random variables and must be treated as such. Should an alteration considered by the decision maker bring a performance improvement that is statistically significant, then this change can be enacted by the decision maker in the conceptual model or physical system, to close the loop depicted in Figure 8.

As mentioned before, the forward pick area is not static. The SKUs and their storage quantities along with their placement change as demand and product lines change. Therefore, re-layout is important too. In re-layout, an existing design is modified. For the forward area, this is likely to take the form of the assignment problem, the space allocation problem, and/or the product allocation problem (see Figure 6). Changes to the physical layout, storage, or equipment would rarely take place. But changes to the product mix and location in the forward area may happen relatively often. Along with the improved operational benefits resulting from any change, costs associated with rearrangements and with operational disruptions need to be considered. Of course, such changes in the forward area are also good candidates for modeling and what-if analysis by discrete-event simulation. The virtual forward pick area can be altered readily and the ensuing results in operations gauged.

4 Concluding Remarks

A strategy commonly used in a warehouse to prevent the picking operators from excessive traveling between picking locations while processing customer orders is to establish a forward pick area; a separate compact area within the warehouse where the picking activities take place. The decision on whether or not to establish a forward pick area depends on the extent to which the savings in labor and the consequent improvement in customer service due to faster order processing outweigh the extra cost of replenishing the forward area, and the reduction in effective warehouse space. As pointed out in [24], in the case of manual, case-picking warehouses, unless the number of picks per line is extremely high, thus resulting in a very low number of lines per picking trip, a forward area is usually justified. For a comprehensive review of the design aspects that need to be taken into consideration when designing a warehouse, including a forward pick area, the reader is referred to the work of Thomas and Meller [24].

When a forward area is to be implemented, four important classes of decisions need to be made, namely sizing, assignment, space allocation, and product allocation. The first two deal with the size of the forward area and the set of SKUs that should be assigned to it, respectively. Once these decisions are made, space and product allocation, respectively, deal with the amount of space assigned to each SKU in the forward area and the actual storage location where the SKU should be placed. These problems are commonly solved using a cost-minimization approach aiming at minimizing the distance traveled by the pickers as a proxy for operational cost. However, this single objective approach has been recently challenged by several researchers, as there is strong empirical evidence that there exists a trade-off between the well-being of the operators and the efficiency of the picking process, suggesting that the ergonomic aspects of the system should be brought also into the analysis. Better integrating the human aspect into the design of forward pick areas and on selecting the best operational policies is an important topic for further research.

Our current research aims at addressing the effect of demand correlation on the solutions of the problems mentioned above. As two or more SKUs are frequently ordered together in the same order, it makes sense to connect product correlation with product proximity in the forward area. Another aspect that to be addressed is that realistically sized instances of these problems are still challenging to solve by means of exact approaches because of the high computational power required. This necessitates the development and use of powerful and robust heuristic methods.

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