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## Re-slotting to Reduce Warehouse Operating Expenses

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Email: [cpetersen@niu.edu](mailto:cpetersen@niu.edu)**ABSTRACT**

This research examines several class-based re-slotting procedures that re-assigns stock-keeping units (SKUs) in a warehouse secondary storage area to new locations based on the SKU activity. The general notion of re-slotting is to place high activity SKUs in premium locations near the pickup/drop-off points of shipping and receiving. This simulation study compares the performance of three ABC class-based rules for guiding SKU swaps between the front and rear sections. Results are generated using data provided by a large regional distributor located in the Chicagoland area. The simulation results show the class-based re-slotting heuristic provides significant savings in picker travel. While prior research regarding manual warehouse operations has focused on the picking operation, this study introduces a warehouse model that considers both the putaway and picking operations simultaneously.

**KEYWORDS:** Distribution Warehousing, Re-slotting, Order Picking, Supply Chain

**INTRODUCTION**

A warehouse, or distribution center (DC), stocks products that are redistributed to various customers including: wholesalers, retailers, and end consumers. The primary warehouse operations are often classified as either inbound or outbound. Receiving and putaway are the main inbound activities, whereas order picking and shipping are considered the main outbound activities. Receiving products, or stock keeping units (SKUs), involves many activities but the primary focus is moving the product off the trucks into the warehouse receiving area. The putaway operation then moves the individual SKUs to the proper location in the warehouse. Once orders are received from customers, order pickers gather the SKUs from the warehouse and deliver them to a designated area for packing and shipping. DCs play a critical role in a supply chain by delivering the right products to the right place at the right time in a cost effective manner.

Today's competitive environment and supply chain integration initiatives have put enormous pressure on warehouse managers to simultaneously increase the throughput rate and lower operating costs of their operations (Frazelle, 2002). Order picking constitutes 50 - 75% of the total operating costs for a typical warehouse (Bozer et al., 2010, Coyle et al., 2003), though it is not clear if this includes the costs for other warehouse operations such as putaway. Nonetheless, these operations are the primary focus for most cost reduction efforts in practice. The use of automation is frequently examined as a means for reducing labor costs associated with picking, but most companies continue using manual order picking due to variability in SKU shape and size, the variability of demand, the seasonality of the products, or the large investment required to automate an order picking system. An abundance of research addresses design and operating issues with an objective to reduce order fulfillment costs. Three broad issues are most prominent: 1) how to pick the SKUs, 2) how to route the pickers in the warehouse and 3) how or where to store the SKUs.

This research explores the third issue more closely based on an inquiry from a pharmaceutical distribution company located in the Chicagoland area. More specifically, this research explores how re-slotting SKUs reduces travel distance, or labor costs, associated with the putaway and order picking operations. Slotting, which involves the assignment of SKUs to specific warehouse locations, is a critical warehouse design decision that is often overlooked after the initial design despite managers and consultants reporting how re-slotting can reduce annual costs by 8-12% (Trebilcock, 2011; Rector, 2012). Published research supports these claims by showing how slotting affects labor costs or operator travel associated with the picking process (Renaud and Ruiz, 2008). However, no research has shown the overall effect of Re-slotting to reduce operator travel for both the putaway and order picking operations. This study will extend the existing research by studying the effect of slotting rules that use information about putaway and picking operations simultaneously. More specifically, this study will explore the effectiveness of various simple heuristic rules used to guide the re-slotting process in a manner that reduces travel distance needed to complete both warehouse operations. Simple re-slotting rules based on the number of times a SKU is putaway and/or picked during the past month are examined using a simulation-based experimental design. We will then conclude the paper by discussing managerial implications for other DCs using manual picking processes.

## LITERATURE REVIEW

The push to lower costs and improve customer service through faster response is leading many managers to implement new approaches in their warehouse and distribution facilities. Due to the significant labor costs associated with order picking, this activity has been the topic of much research. The primary focus of most research in this area has been identifying more effective picking, routing or storage policies.

**Order Picking:** Picking policies determine which SKUs are placed on a pick list and subsequently retrieved from their storage locations by a single picker during a pick tour. Strict-order picking is a common policy where pickers tour the warehouse to pick all line items or SKUs on a single order. This policy is viewed favorably by practitioners because it is easily implemented and order integrity is always maintained. Combining several orders into batches is an alternative policy that has been shown to reduce total picking time significantly (Gibson and Sharp, 1992; Petersen, 2000; De Koster et al., 1999). First-come-first-served (FCFS) batching combines orders as they arrive until the maximum batch size has been reached. Based on results found in the bin-packing literature, it is clear that other heuristics will yield fewer picking tours, which is critical for reducing total travel time across all pick tours. More complex batching techniques that consider both order size and product volumes have been proposed (Ruben et al., 1999), but the logic for these batching methods exceed the capabilities of most warehouse management systems.

Zone picking is another policy that divides the warehouse into zones and allows pickers to retrieve SKUs from within a single zone (Jane, 2000; Petersen, 2000; Petersen, Aase & Heiser, 2004). Some firms have combined batching and zoning into "wave" picking where a picker is responsible for SKUs in their zone. The benefit for these types of policies become apparent as the size of the warehouse increases, but zone picking requires secondary operations to consolidate orders from the different zones. The subject firm designed and implemented a custom zone picking policy to release pick waves that consider delivery routes containing many orders. The simplicity of their policy was easy to implement, has been well received by employees, and has proven quite effective at minimizing pick tours and travel distance.

**Routing:** Routing policies determine the picking sequence of SKUs on the pick list. Using simple heuristics or optimal procedures, the goal of routing policies is to minimize the distance traveled by the picker. Optimal procedures offer the best solution, but they may result in confusing routes (Ratliff and Rosenthal, 1983). Heuristics often yield near-optimal solutions while being easy to use (Petersen and Schmenner, 1999; Hall, 1993). Traversal routing, which

is widely used in many warehouses because of its simplicity, provides good results particularly when the pick density per picking aisle is large. When using a traversal policy, pickers must completely traverse the entire aisle once it is entered. A composite heuristic combining traversal and return routes to further reduce picker travel produced near-optimal solutions (Roodbergen and De Koster, 2001). The later approach reflects the routing policy used by the subject firm.

**Storage policies:** Storage policies, which assign SKUs to storage locations, generally fall into three broad categories. SKUs may be assigned randomly, grouped into classes with similar SKUs that are placed in the same area of the warehouse, or assigned to a location based on demand or volume. Random storage is widely used in many warehouses because it is simple to use, often requires less space than other storage methods, and results in a more level utilization of all picking aisles. Volume-based storage policies assign SKUs with the largest demand to locations near the pick-up/drop-off (p/d) point. Research shows that a within-aisle implementation of volume-based storage significantly reduces travel time (Jarvis and McDowell, 1991; Petersen and Schmenner, 1999). Class-based storage with as few as three storage classes was shown to provide nearly the same savings as volume-based storage in an automated storage and retrieval systems (AS/RS) while requiring less data processing (Hausman et al, 1976; Rosenblatt and Eynan, 1989; Eynan and Rosenblatt, 1994). While research involving automated retrieval systems is rather extensive, most warehouses utilize manual picking methods (Frazelle, 2002).

The effect of class-based storage in a manual picking environment was introduced using a sensitivity analysis (Gibson and Sharp, 1992), but the focus of their research was on batching techniques to reduce picker travel. A comparative study of a manual order picking warehouse revealed that class-based storage reduces picker travel when compared to random storage and offers similar performance as the more complex volume-based storage (Petersen, Aase & Heiser, 2004). Their research showed class-based storage policies are effective across all conditions by changing factor levels in a simulated warehouse environment, but no research documents the benefit by replicating an existing operation. The current research will test these findings using actual data provided by the subject firm.

**Current Research Extension:** This research offers several extensions that focus on storage policy, which is coined by practitioners as the slotting problem. First, this research examines storage policies by considering the effect on travel distance for both the putaway and order picking activities simultaneously. While published warehouse research frequently considers order picking activities, no research addresses the putaway activity explicitly in a manual warehouse operation. We believe this is a crucial oversight, because the travel distance and time spent performing the putaway and case picking activities are comparable for these operations according to the subject firm. This study will determine the benefit for using information about both activities when assigning SKUs to a location. To accomplish this, the authors will introduce a warehouse model having unique putaway and picking activities that are controlled and measured separately.

A second research extension involves exploring the importance of re-slotting a warehouse on a regular basis as product offerings and demand changes. While consultants and practitioners publish expected labor savings of 8-12% annually, most published research only considers slotting greenfield projects. An adaptive re-slotting approach was proposed using data mining techniques and a binary integer programming technique to assign new products to vacant locations (Chiang, Lin and Chen, 2011). However, the subject firm requested a simple heuristic technique that will help reduce operator travel and hence operating costs. Since their product offering has reasonably stable demand that follows a normal product lifecycle, the subject firm rarely experiences vacant locations. Therefore, the proposed procedures must consider re-organizing the SKUs location assignments. Kee (2003) suggested using ABC analysis for classifying SKUs into storage classes, but no studies exist that document the benefits for using such policies. This research will introduce a simple pairwise exchange heuristic that applies the well-known Pareto concept to assign SKUs to a class based on the putaway and casepick activity.

The goal of this research is to evaluate the performance of a new ABC policy applied to both putaway and casepick operations for the re-slotting process. What portion of the operator time is spent performing the putaway and casepick operations? How much should the subject firm expect to reduce operator travel with a formal re-slotting procedure performed on a regular basis? Will operator travel be less when SKUs are assigned locations based on putaway hits, casepick hits, or a combination of putaway and casepick hits? Are these operations affected more when using forklift-and-pallets that allow operators to turn around within an aisle or when using tugs-and-carts that are pulled in a serpentine manner that traverses complete aisles? The following sections provide a general description of the warehouse operation for the subject firm which we replicate using a simulation model, present the details for our experimental design, and then share results of the simulation study. This paper concludes with a summary of important managerial implications, limitations and opportunities for future research extensions.

## WAREHOUSE OPERATION OVERVIEW

This research is motivated by a pharmaceutical distribution center located in the Chicago area that requested assistance for developing a new re-slotting process. In particular, we were asked to 1) determine if re-slotting their secondary storage area will reduce operator travel time for the putaway and casepick operations and 2) to identify best practices for guiding their re-slotting process. This section summarizes key aspects of the subject firm operation including the facility layout and key business operating rules. This section also presents details for the class-based re-slotting heuristic.

**Layout and Fulfillment Process Overview:** Figure 1 shares the facility layout for the DC examined in this study. While the secondary storage is the primary focus of this research, this image illustrates additional areas that are found within many DC facilities. The two main areas in the DC are dedicated to piece picking and secondary storage. In the piece picking area, individual items on an order are picked and packed in totes corresponding to a single customer order. Piece picking is done using a combination of manual, semi-automatic, and automatic processes. This DC facility is fairly unique since it performs both individual piece picking to provide any piece quantity and a separate operation for case picking full manufacturing cases. Further details of the piece picking processes are omitted since it falls outside the scope of this study. The remainder of this paper will focus on the secondary storage area where the case picking occurs.

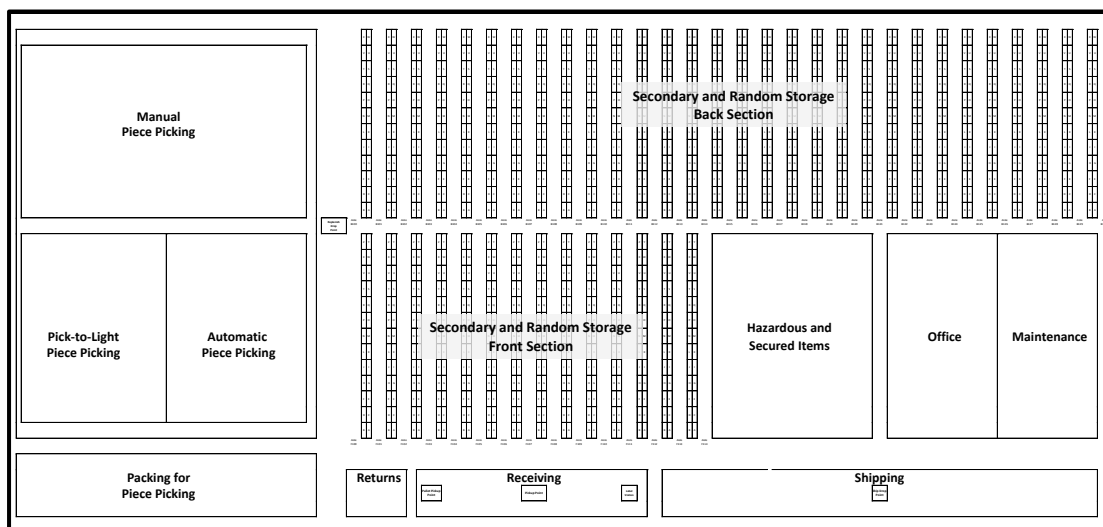


Figure 1: Warehouse Layout

The secondary storage area holds full unopened manufacturing cases for approximately half the active SKUs handled within the DC. The remaining SKUs are stored in flow racks or standard hand stack shelves located in the manual and semi-automatic piece picking areas. SKUs located in secondary storage are packaged in cardboard boxes and picked in full case quantities where each case contained 1-540 pieces. Once a case order is released and picked, it is delivered directly to the shipping area where they are packed and wrapped on a shipping pallet.

**Step 1:** Figure 2 shares the high-level flowchart for the order fulfillment process. The *Receiving* step handles 5-10 full-truck-loads (FTL) daily from the central DC as well as several FLT and less than truckload (LTL) deliveries from local vendors. The primary focus of the receiving operators is to unload pallets from the trucks and place them in the designated receiving area.

**Step 2:** *Putaway* largely depends on case quantity and the cubic volume of the cases received for a SKU. Full pallets of a single SKU are putaway using a forklift. SKUs received involving larger case quantities ( $\geq 12$ ) are often combined onto a single mixed pallet. The remaining SKUs are arranged on carts assigned to a putaway zone. Tugs are then used to pull 2-4 carts for each putaway tour. The *Putaway* process also depends on whether the putaway zone location is in the *Secondary and Random Storage* areas or one of the *Piece Picking* areas. This research is concerned with re-slotting the secondary storage. Therefore, the *Putaway* process for *Random Storage* and *Piece Picking* areas is considered out of scope for this research. The subject firm turns their inventory approximately once a week on average, therefore this *Case Putaway* operation requires significant time and labor cost each day.

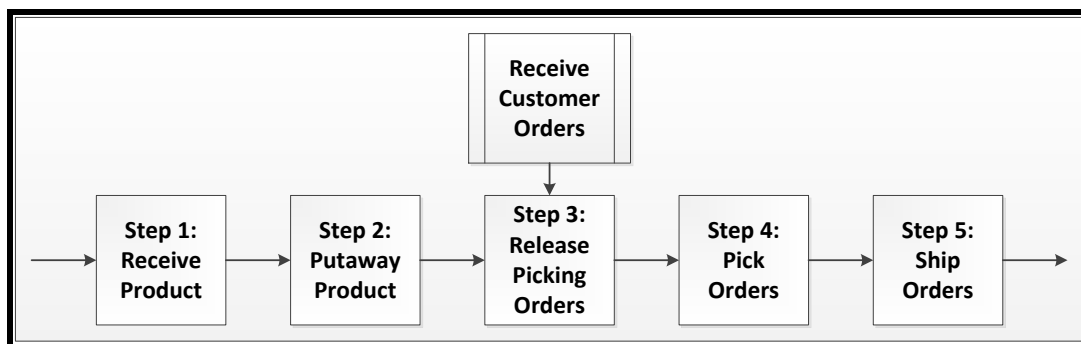


Figure 2: High-level Order Fulfillment Process Flowchart

**Step 3:** *Releasing Picking Orders* is managed by the warehouse management system (WMS). To establish wave release orders, the WMS system considers all orders placed during the day, the promised delivery time which is generally promised the same day or by the following morning, and the external delivery route. Again, this step is beyond the scope of this research, but the wave designation for every SKU ordered represents a major constraint for their order fulfillment process.

**Step 4:** *Pick Orders* involves both piece picking and casepicking operations. Full cases are picked by operators from the secondary storage locations using tugs and carts, though a few pallet picks are used for large cubic volume orders sent to other DCs. Once the operators complete their assigned picking tour, the carts are then delivered to drop point in shipping area. Individual piece parts involving partial cases are always picked from one of the three piece picking areas. Again, the travel distance associated with piece picking operations are outside the scope of this research. It is also worth noting that the WMS system may release a customer order into a full casepick order and a second piece pick order. For example, a customer order for 15 bottles of aspirins will likely be released as one case pick order and one piece pick order of three bottles if the full case contains 12 bottles.

The final step of the process, *Ship Orders*, involves both packing and shipping functions. All aspects of this step are outside the scope of this research except the location of the

shipping drop point which is relevant to the case picking process when calculating operator travel distances.

**Summary of Additional Facility Details and Key Business Rules:** The following list summarizes information about the warehouse modeled in this research:

- The Secondary and Random Storage Area has 44 picking aisles each containing 12 or 13 bays on a side. There are front and back cross-aisles and a third cross-aisle located approximately halfway back that partitions the area into a front section and a back section (see Figure 1).
- The picking aisles have racks on each side and are wide enough for two-way travel.
- Racks are approximately 25' tall with the secondary storage locations assigned to the lower 7-9'. The remaining space located above the secondary storage is designated as Random pallet storage. Operations associated with random storage are outside the scope of this project.
- The rack design within an aisle is identical for each bay, but the racking design varies between aisles. In general, aisles are designed to handle either 1) full pallets, 2) half pallets with a 2' hand-stack shelf, 3) four hand-stack shelves, or 4) five flow racks.
- Flowracks are 7' deep by spanning across two racks located back-to-back from adjacent aisles. Full cases are loaded into a flow rack from the back side of the flowrack.
- Three pallets are assigned within each bay. Each hand-stack level for a bay has 6 locations and each flow rack level has 8 locations.
- The case capacity of a location depends on the bay configuration and the size of the full manufacturing case for the SKU assigned to the location.
- Each case picking tour begins at the label station located at the right hand side in the receiving area and ends at the drop point located in the middle of shipping.
- Each putaway tour begins and ends at the pickup points located in receiving.
- Case picking is done manually using pallets, mixed pallets or tugs/carts depending on the cubic volume and quantity of cases for each SKU. Case picking is only done from the secondary storage areas. No cases are picked from the piece picking area.
- Secondary storage putaway is done manually using pallets, mixed pallets or tugs depending on the cubic volume and quantity of cases for each SKU.
- Each SKU is assigned to only one secondary storage location, but several adjacent locations may be grouped together as designated as a single location for a SKU.
- Each location is assigned only one SKU.
- There are currently 5 putaway zones assigned to the secondary storage area.
- There are 10 wave releases each night that corresponds to distinct delivery routes. A FTL trailer assigned to each route is located in a unique shipping bay.
- The SKU demands generally follow the 80-20 rule in that a few items account for the majority of the units demanded. The number of SKU 'hits' for both putaway and casepick also follow this principle. A 'hit' is defined as the number of times a location is visited and it also corresponds to an order line item.
- Current practices of the subject firm involve re-slotting SKUs with large annual cubic volumes due to the attention drawn to moving full pallets. They also re-slot the 25-50 SKUs having the highest annual dollar volume for security reasons and SKUs with demands that are rapidly increasing.

**SKU Classification Strategy:** To operationalize the re-slotting heuristic, SKUs are first assigned to one of four classes using the Pareto 'ABC' concept commonly applied to inventory management practices. For this re-slotting problem, high-activity SKUs during the prior month are assigned to the 'A' class. SKU activity or 'hits' or visits is defined as the number of times a SKU appears as a line item on an order pick list. This also corresponds to the number of times a SKU location is visited during the casepicking operation. This differs from other ABC classifications which commonly use total annual units sold or total annual dollar value for the SKUs. The classification strategy for this research uses 'hits' because the number of location visits has a greater effect on operator travel than the quantity picked. Warehouse managers

generally use this measure of 'hits' because subsequent items picked on the same pick tour costs very little.

Similar classifications are generated for three rules which are compared in this research: Casepick hits, Putaway hits and Combined Casepick and Putaway hits. Table 1 summarizes the number of SKUs and Total Hits corresponding to each class for the three rules. For the subject firm of this research, a SKU visited more than 40 times for the casepick operation corresponds to a very high-activity SKU picked 2 or more times per weekday assuming there are approximately 4 weeks or 20 weekdays per month. When applying the concept to the Putaway data, however, high-activity 'A' SKUs correspond to 8 or more hits per month, or about twice weekly. This suggests the putaway operation tends to involve few trips having more cases compared to the casepick operation.

Table 1: SKU Classification Summary

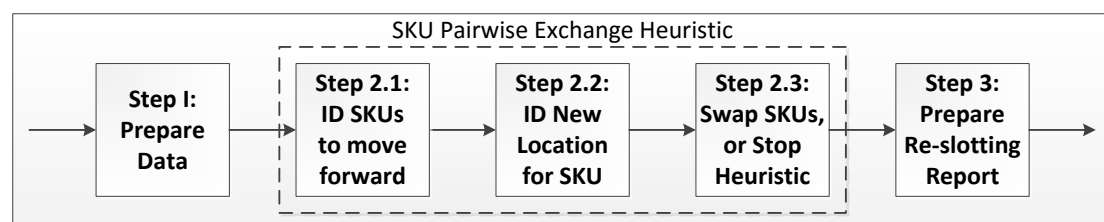
Casepicks				Putaway				Casepicks and Putaway Combined			
Class	Mthly Hits	SKUs	Total Hits	Class	Mthly Hits	SKUs	Total Hits	Class	Mthly Hits	SKUs	Total Hits
A	>40	311	41,997	A	>8	306	3,527	A	>40	373	45,678
B	20-39	298	8,222	B	4-7	1,397	6,825	B	20-39	451	11,428
C	2-19	2,541	15,815	C	2-3	2,193	5,241	C	2-19	4,155	25,738
D	0-1	6,967	719	D	0-1	6,221	2,319	D	0-1	5,138	1,821
Totals		10,117	66,753	Totals		10,117	17,912	Totals		10,117	84,665

Further analysis of this data reveals the 10,117 SKUs located in Secondary Storage are picked on average 6 times per month, while SKUs are received and putaway an average of 2 times per month. This illustrates the subject firm operates a reasonably lean warehouse with excellent inventory turns.

**Class Based Re-slotting Heuristic:** The proposed heuristic uses a pairwise exchange strategy, where high-activity SKUs located in the back of the warehouse are moved into the Front Section. This is the same logic used by the volume-based and class-based storage policies presented in the current literature where SKUs with the highest demand are located near the pick-up/drop-off (p/d) points. For both the putaway and casepick operations, this entails moving the A, B and C SKUs from the back section to the front section of the *Secondary Storage area*.

Step 1: Prepare Data – acquire data providing the current SKU locations, released casepick orders for the past month, and cases putaway into the secondary storage area for the past month. Confirm the casepick and putaway data is not aggregated across multiple picks or putaways. Determine the activity of each SKU for each operation, and then apply the ABC SKU classification strategies to determine which SKUs are A, B, C or Ds for each of the three rules.

Step 2: Pairwise Exchange – This step involves exchanging a high-activity SKU currently located in the back section with a low-activity SKU located in the front section. On occasion, there may be an open location in front which should be filled with a high-activity SKU currently located in the back section, but this does not happen frequently for the subject firm.



Figure

3: Re-slotting Procedure Flowchart

The pairwise exchange heuristic may be characterized as having three sub-steps as shown in Figure 3. Using the ABC classifications generated during Step 1, Step 2.1 identifies a SKU

in the rear section having an 'A' classification or the next highest designation. Step 2.2 then identifies a location having a SKU with a 'D' designation or the lowest possible designation. Substep 2.3 involves the pairwise swap, and it also provides a stopping criteria. As long as the SKU moving forward has a higher ABC designation than the SKU moving back, accept the pairwise exchange and repeat step 2. In other words, a SKU in the back section having a 'C' designation would be swapped with a SKU in the front section having a 'D' designation. However, it won't be swapped with a SKU in the front section having a 'C' designation. The later scenario reflects the stopping criteria where no further attempt is made to identify a pairwise exchange. Step 3 involves preparing a report listing all exchanges identified during Step 2.

## EXPERIMENTAL DESIGN

The primary goal of this research is to determine if re-slotting the secondary storage area will reduce operator travel time for both the putaway and casepick operations. An abundance of research has examined many factors affecting travel time for order picking, but no research has explored the importance of the putaway operation. More specifically, this research will explore the following questions:

1. How do the putaway and casepick operations compare with regard to travel distance needed to perform the operations? Exploring this question will indicate the importance of each operation with regard operating costs and hence establish the relative importance of these operations for the subject firm.
2. How much will travel distance be reduced using the pairwise exchange heuristic to re-slot the secondary storage area?
3. Which of the three classification strategies perform best for the putaway and casepick operations?

**Simulation Model:** To answer these questions, a simulation model was created using structured queries on a SQL Server. The benefits for using this type of model entailed the direct access to actual data from the subject firm including item master data, casepick orders, putaway items and the wave release times for SKUs located in the secondary storage area. The simulation-based study replicated the operations described earlier using actual data for one month. Figure 4 summarizes the experimental design for the simulation study used to answer the three questions identified above. Data for 20 weekdays were used as a basis for the simulation study. Also included in the data set are data for 5 Saturdays which the subject firm operates with a skeleton crew to fulfill same-day emergency orders. The primary performance metric tracked by this study is total operator travel. Results are reported using two explanatory variables. The first variable corresponds to the two operations (putaway and casepicks), whereas the second variable considers the type of equipment used (fork lifts with full pallets, fork lifts with mixed pallets, and tugs/carts. Additional secondary metrics reported include: 1) number of tours, 2) number of aisles visited, and 3) cubic volume.



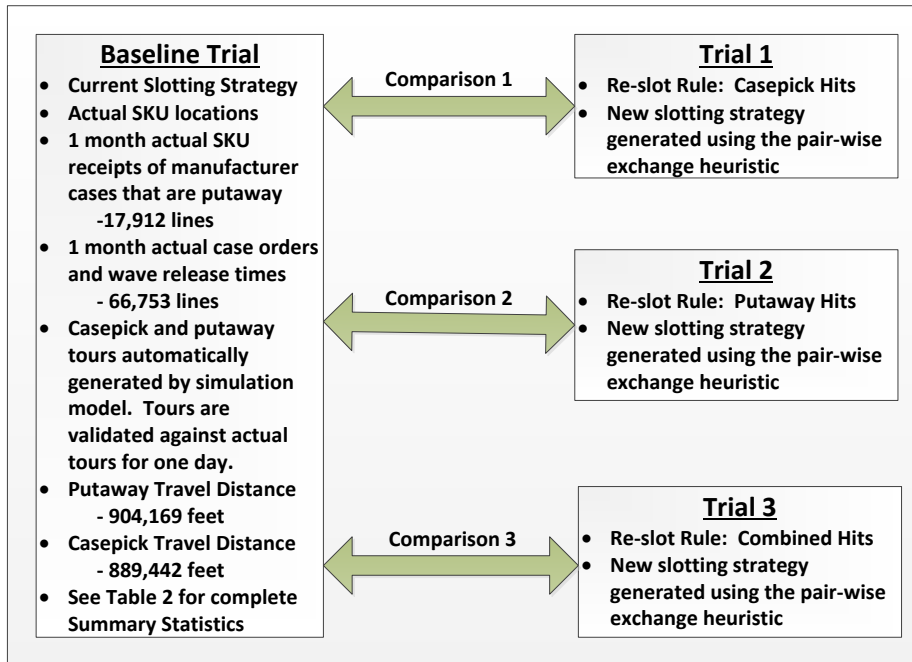


Figure 4: Warehouse Simulation Experimental Design

The simulation study is replicated 4 times, where each trial has a sample size of 25 operating days. The first (baseline) trial uses the current slotting configuration. The remaining three trials involve re-slotting the warehouse using the pairwise exchange heuristic with the three ABC classification rules: casepick hits, putaway hits and combined hits. The only experimental factor for this study is the ABC classification rule, but two explanatory variables are used to provide further insights during the analysis.

Results for the Baseline Trial provide the basis to which the remaining three trials are compared. As summarized in Figure 4, the data set includes 17,912 lines of putaway data and 66,753 lines of casepicking data. Further summary statistics for the Baseline Trial are found in the next section.

## RESULTS

Results for the Baseline Trial are shared in Table 2. Comparison of the Combine Total column reveals the travel distance required to complete the putaway and casepick operations are similar for the subject firm: putaway was 904,189 feet and casepick was 889,445 feet. Therefore, it is reasonable to assume managers should consider both operations when re-slotting the secondary storage area.

Casual observation of the Baseline Trial results reveals several additional insights worth noting. The travel distances for the putaway operation are similar ranging from 241,548' for the Mixed Pallet putaways to 367,007' for the Tug/cart putaways. This mix is common for many DCs that use a mix of fork lifts and tugs for this operation. The travel distance for the casepick operation, however, is heavily weighted toward the use of Tugs/carts. This is expected for a pharmaceutical distributor because more of their daily business entails small frequent orders to many customer. Therefore, most of the orders are picked by operators using a tug with 3-4 carts in tow. Mixed pallets are not used for this operation because 98.6% of the casepick orders (65,818 of 66,753) involve fewer than 12 cases. Of the remaining 953 lines, 349 lines involve full pallet picks. Therefore, the subject firm decided to only use tugs/carts when casepick orders do not involve full pallet picks.

Table 2: Baseline Trial Summary Statistics

	Pallet w/ 1 Item		Mixed Pallet		Tug w/ Carts		Combined Total	
Putaway	Lines	393	Lines	1,677	Lines	15,842	Lines	17,912
	Tours	407	Tours	355	Tours	455	Tours	1,217
	Aisles	393	Aisles	776	Aisles	1,171	Aisles	2,340
	Vol. (FT3)	26,707	Vol. (FT3)	9,767	Vol. (FT3)	28,861	Vol. (FT3)	65,335
	Travel (FT)	295,614	Travel (FT)	241,548	Travel (FT)	367,007	Travel (FT)	904,169
CasePick	Lines	290	Lines		Lines	66,463	Lines	66,753
	Tours	349	Tours		Tours	555	Tours	904
	Aisles	290	Aisles		Aisles	2,381	Aisles	2,671
	Vol. (FT3)	20,596	Vol. (FT3)		Vol. (FT3)	57,791	Vol. (FT3)	78,387
	Travel (FT)	258,676	Travel (FT)		Travel (FT)	630,766	Travel (FT)	889,442
Combined Total	Lines	683	Lines	1,677	Lines	82,305	Lines	84,665
	Tours	756	Tours	355	Tours	1,010	Tours	2,121
	Aisles	683	Aisles	776	Aisles	3,552	Aisles	5,011
	Vol. (FT3)	47,303	Vol. (FT3)	9,767	Vol. (FT3)	86,652	Vol. (FT3)	143,722
	Travel (FT)	554,290	Travel (FT)	241,548	Travel (FT)	997,773	Travel (FT)	1,793,611

Results in Table 3 summarize the performance of all trials. Comparison of trial results reveal the Combine Rule, which considers both casepick and putaway hits, performs best with an 18.4% reduction in total travel distance. However, the results for Trials 1 and 2 reveal similar results (15.5% and 14.7%) when using data from either operation alone. These findings are significant since this supports the anecdotal results suggested throughout the business literature indicating a 10-12% improvement is expected.

Further exploration of Table 3 suggests the casepick operation will benefit more than the putaway operation by re-slotting the secondary storage area. When using the combined rule, travel distance to complete the casepick operation is reduced 26.8% whereas the putaway operation improves by 10.0%. This difference is significant, but both represent meaningful savings for any business.

Table 3: Simulation Study Summary Statistics

	Baseline Trial		Trial 1 Casepick Rule		Trial 2 Putaway Rule		Trial 3 Combined Rule	
		Total	Total	% Reduction	Total	% Reduction	Total	% Reduction
Putaway	Tours	1,217	1,209	0.7%	1,212	0.4%	1,211	0.5%
	Aisles	2,340	2,149	8.2%	2,047	12.5%	2,074	11.4%
	Travel (FT)	904,169	849,845	6.0%	815,404	9.8%	813,358	10.0%
CasePick	Tours	904	854	5.5%	864	4.4%	854	5.5%
	Aisles	2,671	1,825	31.7%	2,110	21.0%	1,749	34.5%
	Travel (FT)	889,442	665,757	25.1%	715,217	19.6%	650,629	26.8%
Total	Tours	2,121	2,063	2.7%	2,076	2.1%	2,065	2.6%
	Aisles	5,011	3,974	20.7%	4,157	17.0%	3,823	23.7%
	Travel (FT)	1,793,611	1,515,602	15.5%	1,530,621	14.7%	1,463,987	18.4%

Results in Table 3 also support some intuitive results where the Casepick Rule has a greater effect on the casepick operation (25.1%) when compared to the benefit of using the Putaway rule (19.6%). Similarly, the Putaway Rule has a greater effect on the putaway operation (9.8%) compared to the benefit when using the Casepick Rule (6.0%). Further observation reveals the reduction in travel time is always best when using the Combined Rule, though the differences appear to be statistically insignificant for some circumstances. This dominance reflects the combined effort of the two rules where each rule identifies a unique subset of SKUs that should be moved from the rear section to the front section. By combining the casepick hits and the putaway hits, a small subset of SKUs improve their ABC designation so they are included in the pairwise exchange heuristic.

The results in Table 4 transforms the data from the last row in Table 3 by normalizing the travel distance measures with the number of SKUs moved. Data reveals the Casepick rule results in fewer SKUs moved when compared to the Putaway and Combined rules. This explains the normalized results in the last row which shows the Casepick Rules provides the greatest “bang for the buck.” For every 1000 moves, the Casepick Rule resulted in an 8% reduction in travel distance, whereas the Putaway and Combined rules yielded a 4.7-5% reduction in travel distance. This analysis was requested by the subject firm because the estimated they could move approximately 1,000 SKUs on a weekend day using 6 operators.

*Table 4: Simulation Results Normalized by Total SKUs Move*

	Casepick Rule		Putaway Rule		Combined Rule	
	1,944 SKUs Moved		3,117 SKUs Moved		3,675 SKUs Moved	
	Total	% Reduction	Total	% Reduction	Total	% Reduction
<b>Travel Reduction (ft)</b>	1,515,602	15.5%	1,530,621	14.7%	1,463,987	18.4%
<b>Reduction per 1000 moves</b>	143,009	8.0%	84,373	4.7%	89,694	5.0%

## CONCLUDING REMARKS

This study has explored using ABC analysis and a class-based storage strategy to re-slot the secondary storage area of a major pharmaceutical distributor. The results show significant reduction in travel distance for both the putaway and casepick operations. Prior research focused only on the order picking operation for DCs using manual operations. This research has shown additional benefits will be observed by considering SKU activity, or hits, of both operations when re-slotting a warehouse operation. The level of improvement supports the claims made in the business literature. Assuming operator travel accounts for approximately 60% of the putaway and picking operations, managers should expect a labor saving of approximately 11% (60% x 18.4%)

The results of this study naturally have some limitations since they are based on the data for one operation. However, detailed analysis not included in this paper reveal meaningful improvements are expected for the different equipment configurations whether businesses use fork lifts to handle pallets or tugs and carts that traverse the aisles in an orderly manner. These observations certainly suggest more detailed studies are justified to explore the re-slotting problem for various operating environments.

This study clearly shows that the pairwise exchange heuristic was effective for re-slotting the secondary storage area of the subject firm. While these results are not compared to an optimal solution, performance metrics provided by managers of the subject firm suggested they were one of the more efficient DCs for the corporation. Nevertheless, the findings of this initial study suggest further detailed studies are warranted to compare results of class based, volume-based, and optimal re-slotting procedures.

## REFERENCES

References available upon request.