IOP Conf. Series: Materials Science and Engineering **337** (2018) 012020 doi:10.1088/1757-899X/337/1/012020

A modeling of dynamic storage assignment for order picking in beverage warehousing with Drive-in Rack system

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Abstract. This paper develops a dynamic storage assignment model to solve storage assignment problem (SAP) for beverages order picking in a drive-in rack warehousing system to determine the appropriate storage location and space for each beverage products dynamically so that the performance of the system can be improved. This study constructs a graph model to represent drive-in rack storage position then combine association rules mining, class-based storage policies and an arrangement rule algorithm to determine an appropriate storage location and arrangement of the product according to dynamic orders from customers. The performance of the proposed model is measured as rule adjacency accuracy, travel distance (for picking process) and probability a product become expiry using Last Come First Serve (LCFS) queue approach. Finally, the proposed model is implemented through computer simulation and compare the performance for different storage assignment methods as well. The result indicates that the proposed model outperforms other storage assignment methods.

1. Introduction

Storage assignment is an order picking organization and operational policies attempts to find an effective method of locating products in a warehouse to improve the operational of order picking performance [1]. De Koster et al. [2] says a storage assignment method is a set of rules which can be used to assign products into warehouse storage locations. It influences almost warehouse key performance indicators such as order picking time and cost [1].

Recent trends in the order picking operational or tactical level have resulted in order picking storage assignment design and management becoming more important and complex. One of the challenge and complexity in order picking storage assignment is storing beverage products in warehouse with drive-in rack system under dynamic orders from customer. So, beverage warehouse with drive-in rack need a dynamic storage assignment method to face the dynamic and complexity challenge in order to increase warehouse responsiveness to customer order.

Drive-in rack is a pallet rack type that has column, row and depth. Typically, Drive-In racking requires operators to drive into the racking system from one side and remove pallets from the same entry point. A simple way to identify a Drive-In Rack Systems is its LIFO queue. Product is moved in a Last-In, First-Out queue way because of the single entry and exit point. Many food and beverage industries use this rack type because of low installation cost and extremely efficient storage density. But, the problem is this rack type can increase total product expiry if the management does not set the order picking strategy well.

Dynamic storage assignment is a storage assignment in warehouse operational level which allows decision maker re-arrangement, re-warehousing, re-assignment products in storage location follows dynamic order from customer requests. According to De Koster et al. [2] the storage assignment is a set of rules which can be used to assign products to storage locations. According to previous passage, we can say that the dynamic order picking is a set of dynamic rules in a put away process which can be used to re-arrangement, re-warehousing, re-assignment product in storage location to satisfy dynamic customer request. This warehouse operational type become necessary since researcher found that the storage assignment policy can reduce travel distance, reduce picking time and congestion.

Storage assignment method has been extensively investigated. Most of researches is focused on method development with steady state assumption and no product type consideration. There are many storage assignment researches with specific warehouse case but drive-in rack has not yet led to attention now by researcher. De Koster et al.[2] says the dynamic order picking is an important future research caused by the rapid development of internet and technology to fulfil customer request more responsive. Hence, we can conclude that this research in dynamic order picking for beverage products with drive-in rack is important research.

According to the problems, complexities and challenges, the purpose of this paper is to develop a dynamic storage assignment model to solve storage assignment problem (SAP) for beverages order picking in a drive-in rack warehousing system to determine the appropriate storage location and space for each beverage products dynamically so that the performance of the system can be improved. The storage assignment model is developed under beverage limited shelf life characteristic, dynamic orders condition, product adjacency, Cube per Order Index (COI), order frequency, and arrangement rule for drive-in representation. The performance of the algorithm is validated and compared with random storage assignment approach (the most common approach for storage assignment process) by calculating rule accuracy (for product adjacency), expected total distance from storage position to loading area and probability a product become expiry using Last Come First Serve (LCFS) and First Come First Serve (FCFS) queue combination.

The rest of the paper is organized as follows. In the next section, we present methods framework to solve the problem. It is started by problem statement of dynamic storage assignment in beverage warehouse with drive-in rack system, then present research methodology and performance calculation. In section 3, we present a real study case to test our proposed model. In Section 4, we present computational simulation experiments. This is followed by performance comparison with random assignment approach and by the conclusion.

2. Problem Statement and Research Methodology

2.1. Problem Statement

Drive-in rack is three-dimension rack that has column, row and depth. The warehouse with this rack type has aisles, product source, loading area, storage area, picker and palletized beverage product (see figure 1). The design of adaptive order picking system for beverage warehousing with drive in rack system in this research will use the following assumptions.

- The warehouse receives product from production department
- The beverage packed into secondary packaging and stacked on pallet
- One pallet or one pallet position only storage one product type
- Order rate equal or higher than product arrival rate
- Put away and picking process follow Poisson distribution
- The warehouse only storage products with same/identic behavior

The problem of this study can be outlined in the follow manner. Orders and pallet products come to the warehouse, and picked by several pickers with limited capacity. Pallets from production area are picked and placed into specific storage area or pallet position according to storage assignment and zoning rules.

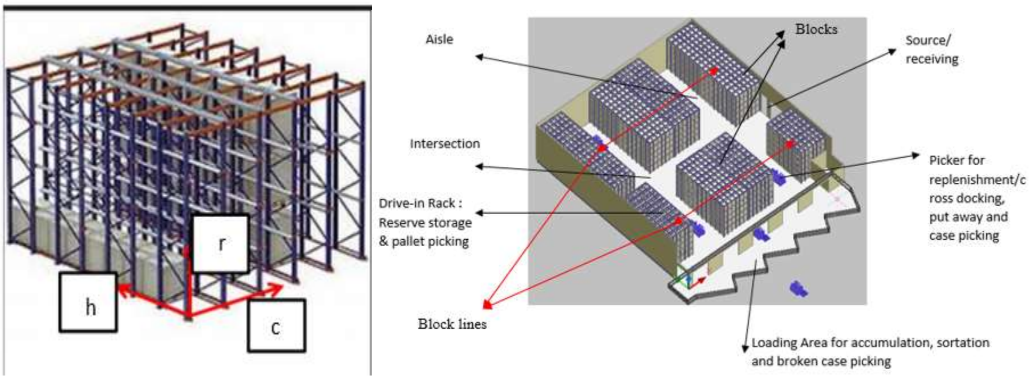

Figure 1. Drive-in rack construction and warehouse structure with drive-in rack

Because orders from customers come dynamically, the rule for storage assignment process will change follows dynamic orders from customers. So, we can reduce the total of travel distance for a specific order fulfillment case from storage position to loading area by determining the storage location dynamically according to its order frequency, shelf life and order volume. According to the problem statement the notation used in this research is presented in table 1.

Table 1. Notation used in this research

Notation	Description	Notation	Description
X	Antecedent of the rule	$irule$	Index rule generated by association rule (1,2,3,…., $nrule$)
Y	Consequent of the rule		
h	Depth index (1,2,3,….,H)	y_{irule}	Data set generated by association rule
c	Column index (1,2,3,….,C)	$\hat{y}_{irule}$	Data set generated from real order from customer
r	Row index (1,2,3,….,R)		
i	index product (1,2,3,…I)	$E(D)$	Expected total distance for specific order
$\boldsymbol{p}^{expiry}$	probability product will expiry	$d_{i \to l}$	Distance from specific product storage location to loading area l
$\boldsymbol{p}^{pick}$	Probability product will picked by operator		
		n	Total product in storage position (queue)
		γQ	Expected rate of expired product

2.2. Research Methodology

This research frameworks are adopted, combined and redesign from Pan et al. [1], De Koster et al.[2], and Chuang et al. [3] for storage assignment and order picking concepts. As we mention before that storage assignment is set of rules, so the model is designed by set of stages to find the dynamic storage assignment rule. Three stages are used to model dynamic storage assignment with the output is set of rules that represent storage assignment process in warehouse with drive-in rack.

2.2.1. Stage 1: Finding product adjacency rule.

Association rule is used in this research to find product adjacency. Association rule is an expression$X \to Y$, where X and Y are item sets [4]. X is the antecedent of the rule and Y the consequent. Different rule interestingness measures try to quantify the dependence between the consequent and antecedent. Support and confidence is used in this association rule method as rule assessment to find product adjacency of the storage assignment rule. The support $sup(X \rightarrow Y)$ of the rule is defined as the number of transactions that contain both X and Y (1), that is

$$sup\left(X \ \rightarrow \ Y\right) = sup\left(XY\right) = \left|t\left(XY\right)\right| \quad (1)$$

The confidence$con(X \rightarrow Y)$ of a rule is the conditional probability that a transaction contains the consequent Y given that it contains the antecedent X (2):

$$conf\left(X \rightarrow Y\right) \ = \ P\left(Y \mid X\right) \ = \ P\left(XY\right) / P\left(X\right) \quad (2)$$

2.2.2. Stage 2: Design class based storage rule.

The idea of class based storage is to group products into classes in such a way that the fastest moving class [2]. Each class is then assigned to a dedicated area of the warehouse. Classes are determined by some measure of demand frequency of the products, such as Cube per Order Index (COI) or pick volume. Fast moving items are generally called A-items. The next fastest moving category of products is called B-items, and so on. Product class is used in this research according to volume, frequency, shelf life and COI. COI is Average required cubic storage footage per average numbers of orders [5][6]. The higher the frequency, volume and short shelf life then the closer to the loading area and the small COI value the closer to the loading area

2.2.3. Stage 3: Design of Arrangement Rule.

The design of arrangement rule is conducted to ensure that each assignment of product follow rule that must fulfil all row first in a rack column and depth. This rule is important to avoid an empty rack between 2 assigned pallet rack positions. This research designs an arrangement rule for drive-in storage rule. The rule is modified from stack algorithm from Cormen [7]. The illustration of the rule is described as follow.

- Search empty row r in a depth h head in each column c where h,r,c is started from 1
- If row r in a depth h head in each column c is empty then assign a specific product with product adjacency and class based storage consideration
- If not, and $r \neq R$ go to step 1 with $r+1$
- If $r=R$ and $h \neq H$ then $h+1$
- If $h=H$ and $c \neq C$ then $c+1$
- If $c=C$ then warehouse status is over capacity

2.2.4. Rule Combination.

After we determine rule for product adjacency, class based storage, and arrangement rule, we propose rule combination algorithm from these rules to determine an appropriate storage location and arrangement of the product according to dynamic orders from customers. The algorithm is described as follow

- Assign product into a block according to generated rule from class based storage in a block line
- Check the adjacency. If the adjacency is appropriate then assign product according to arrangement rule. The assignment process is finish
- Else if assign in the product to another block according to adjacency rule but in the same block line then assign product according to arrangement rule
- Back to step 2

2.3. Performance Calculation

The performance calculation for storage assignment rule is considered by rule accuracy, probability expiry product and total picking distance. The formulation of rule accuracy is summation of total accurate rule compared with current data (3). Total picking distance *E(D)* is total minimum distance of travelling path (3). The probability there are *n* expiry product (4) is adopted from LCFS concept [8].

$$RuleAccuracy = \frac{1}{nrule}\sum_{irule=1}^{nrule} I(y_{irule} \rightarrow \hat{y}_{irule}),\ E(D) = \sum_{i=1}^{n} \min(d_{i\rightarrow l}) \qquad (3)$$

$$P_n^{expiry} = 1 - P_n^{pick} \text{ where } P_n^{pick} = \frac{\gamma Q}{\lambda} \qquad (4)$$

The model is compared with random policy storage approach. Random policy is most common storage assignment approach for manual or automated warehouse operation. Random policy is the simplest one among various storage policies and is applied widely in practice and often used as a benchmark to evaluate the performance of other policies in many research [2].

3. A Case Study in a Beverages Warehousing with Drive-in Rack System

This study case derived from x company produces 5 beverage products (Tea based, Milk Based, Jelly based packed in secondary packaging and stacking on pallet). They have warehouse with 3000 racking pallet position with drive-in rack, 4 forklifts and 5 hand pallets, source product from production department, and the construction of warehouse.

4. Result and Discussion

The rule combination algorithm is integrated with computer Graphical User Interface (GUI) to create computer-based model for simulation purpose. The GUI is developed by using java programming. Figure 2 shows part of the computer-based model from rule.

Figure 2. Part of the computer based model for assignment in drive-in rack

The grey square represents aisle lanes, the red square represents full storage position and green square represent the storage position already assigned but not full yet. Each storage position in the GUI combined with graph model and stack algorithm as drive-in rack representation. The GUI represents a block rack which is combined with association rule, class based storage, and arrangement algorithm.

This research implements the storage assignment model for study case in the x company. For 5 products with specific volume, frequency, shelf life, and COI, 5 top rules result are

- [product2] → [product5, product3]: confidence: 0.5857142857142857
- [product2, product1] → [product5, product3]: confidence: 0.5714285714285714
- [product1] → [product5, product3]: confidence: 0.5384615384615384
- [product1] → [product2, product5]: confidence: 0.5384615384615384
- [product3] → [product2, product5]: confidence: 0.5189873417721519

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e.g. first rule mean product 2 must assigned near product 5 and 3 and so on. This research compares the rule for 20 instance current data and got the accuracy of rule is 93%.

Table 2. The study case dynamic storage assignment result from proposed model

Product (before and After Data Change)				Frequency Order (Pallet/Shift)	COI	Block
Before	Expiry	After	Expiry			
2	6 months	5	3 months	23	1.09	A
1	6 months	3	6 months	18	1.39	B
5	3 months	1	6 months	16	1.56	C
3	6 months	2	6 months	14	1.79	D
4	1.5 years	4	1.5 years	5	5	E

This accuracy means there are 93% matching rule compared with current data instance. For class based storage we got the position of each product as presented in table 2. From table 2 For this study case we set scenario by switch product's order pattern. The proposed model can determine an appropriate storage location of the product according to dynamic orders from customers (data pattern change). According to table 2 the block changed when the data changed. For example, product 2 must assign in block A because has lowest value of COI and higher order frequency, and then the product 2 assign in block D because the frequency and COI changed.

This paper use order case 8 pallet products 4, 6 pallet products 3 are total distance picking 0.8 km and total distance put away 0.98 km comparing with random storage 1.4 and 1.8 km. From the study case with case "there are probability 10 product will expire", this research found the probability of expiry product from the proposed model is 0.01 comparing with random storage assignment with the probability is 0.3. So, we conclude that our proposed storage assignment model outperforms random storage assignment approach.

Table 3. Comparing the result with random storage assignment approach

Model	Before data pattern change		Before data pattern change	
	Picking distance	Put away distance	Picking distance	Put away distance
Proposed Model	0.8	0.98	0.89	1.5
Random Assignment	1.4	1.9	1.2	1.8

5. Conclusion and Future Research

This research focused on dynamic storage assignment with the main task is generate rule for storage assignment process in beverage warehousing with drive-in rack system. The proposed model was compared with random storage assignment approach as the benchmark and this research found the proposed model is outperforms the benchmark. For further research, this research suggests considering other warehouse operational process i.e. cross docking, considering motion and handling aspect and it impact to order picking, considering shipping process, because the available of truck can affect warehouse operational, build a system that integrating this model with RFID technology and other warehouse technology, other type of warehouse i.e. Drive-thru, forward-reserve warehouse etc., and considering other type of product.

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