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Research Article

Study and Comparison of Automated Material Handling Systems used in Warehouses

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Abstract

Order picking is an important part of order processing in warehousing and dispersal operations and can be achieved using manual, automated, or semi-automated systems. This thesis evaluates two automated systems, carousel system and AS/RS (automated storage and retrieval system). The main goal of this research is to develop mathematical model to analyze the performance of both AS/RS and carousel systems under random storage assignment and class-based storage assignment.

Keywords: *AS/RS; carousel systems; throughput; SKU; mathematical models.*

1. Introduction

Warehouses can operate under different departments in the supply chain and also can be used for different purposes. However, the main reason for having a warehouse is storage. The main process followed in most storage warehouses is described below.

a) The warehouse receives any incoming products and unloads them at the receiving dock followed by quantity and quality checking and then labels or tags will be attached to them for tracking. b) Once the product details have been recorded than they will be stored in their respective storage areas. After receiving the orders from customer, the warehouse process the order by providing the following details such as product description, order quantity and product storage location. Accordingly, the picker will follow the order details and retrieve the products. c) Furthermore, Order picking is the process of accomplishing the customer requests through picking ordered items from warehouse.

According to Kong and Masel (2008) among all warehousing operations, order picking cost around tentatively 55% of the total cost as it is a labour-intensive activity for traditional manual warehouses. Therefore, order picking is a crucial activity in warehouse management, so it has to be planned and controlled effectively and efficiently. Cost of order picking is directly proportional to the operation costs of the warehouse.

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High order picking cost will further increase the operation costs of warehouse. Accordingly, order picking is considered as a crucial topic in warehouse management, and multiple researches has been done on it.

The different order picking technologies are shown in Figure 1.1. order picking is mainly divided into three types:

1) Manual order picking system
2) Semi automated and
3) Automated order picking systems.

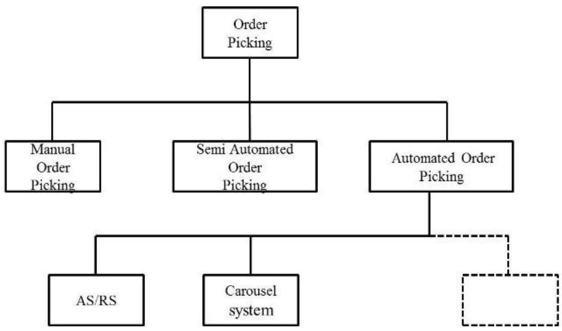

Fig1.1: Order Picking Technologies

We will be focusing on the Automated order picking systems. The automated system basically follows the parts-to-picker systems, which include automated storage and retrieval system (AS/RS), and carousel System. In these systems mostly aisle-bound cranes retrieve one or multiple unit loads (pallets or bins; in the latter case the system is also called as mini-load) and bring them to a pick position (i.e. a load/unload station). As per the customer order (details) the order picker will retain the required number of pieces and the remaining pieces will be stored to their respective locations. This type of system is also called a unit-load or end-of-aisle order-picking system. There are two main automated order picking systems are automated storage and retrieval system (AS/RS) and carousel system.

The automated storage and retrieval machine can work under different operating modes: single, dual and multiple command cycles. The single-command cycle means that either a load is moved from the load/unload station to a rack location or from a rack location to the load/unload station. In the dual-command mode, firstly the load is moved from the depot to the rack location and later another load is retrieved from the rack. In multiple command cycles, the storage/retrieval (S/R) machines have more than one shuttle and can pick up and drop off several loads in one cycle. For e.g. in a four command cycle, the S/R machine leaves the depot with two storage loads, stores them and returns with two retrieved loads. Figure 1.2 represents the simple AS/RS system, which is currently used in warehouses.

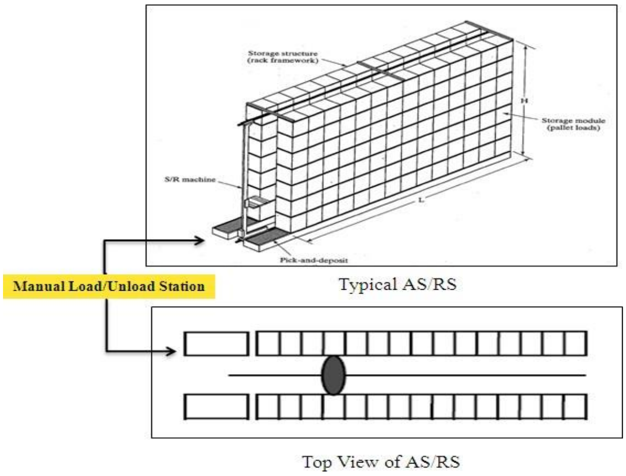

Figure 1.2: AS/RS, adapted from Groover (2007)

Carousel is also an automated storage and retrieval system. A carousel system is one of two types vertical or horizontal carousel, a vertical carousel is used for closed loop automatically controlled rotation of the basic storage unit because storage is vertical, such systems are mostly used during limited floor space. Although automatic insertion and extraction of individual items or loads is possible, it is not as common as it is with horizontal carousel applications. A horizontal carousel is a carousel that consists of a fixed number of adjacent storage columns, or bays, that are mechanically linked to either an Overhead or floor mounted drive mechanism in order to make a complete loop. Figure 1.3 represents the horizontal carousel system, which is widely used in warehouses.

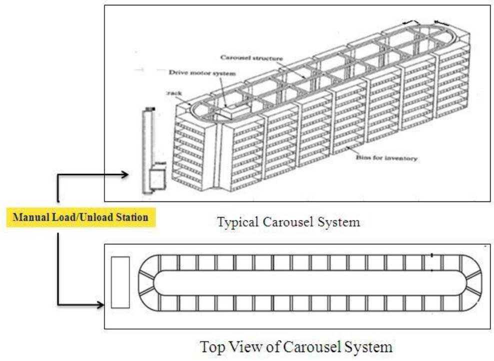

Figure 1.3. Carousel System, adapted from Groover (2007)

2. Research Objective

The main goal of this research is to develop a mathematical model for comparing the performance of AS/RS and carousel system under two different storage assignments, namely random and class-based storage assignments. The measure of performance is throughput, which is the number of SKUs (stock keeping units) retrieved per unit of time.

3. Methodology

In this section a mathematical model is developed for estimating the throughput of both systems under different storage assignments which include random and class-based storage assignments. System throughput: Operating hours/pickup or cycle time. Pickup or cycle time: It is the sum of operator pick time, machine retrieval/deposit time and machine travel time.

Table 3.1: Basic Inputs and Formulae for AS/RS and Carousel System

System	Inputs	
AS/RS AS/RS	$C\,T_{i-1} = \max\langle Th_{i-1}, Tv_{i-1}\rangle$	Crane travel time from load/unload to the previous SKU storage location
	$C\,T_i = \max\langle Th_i, Tv_i \rangle$	Crane travel time from load/unload to the SKU current storage location
	$R\,T_i = \max(Rh_i, Rv_i)$	Crane travel time from SKU current storage location to load/unload
	$Th_{i-1} = \frac{Dh_{i-1}}{Sh}$	Time taken by crane in horizontal direction to reach previous SKU storage location
	$Tv_{i-1} = \frac{Dv_{i-1}}{Sv}$	Time taken by crane in vertical direction to reach previous SKU storage location

	DT_{i-1}= Constant value	Crane deposit time value at previous SKU storage location
	CP_i = Constant value	Crane retrieval time value at current SKU storage location
	OP_i= Constant value	Operator pick time value
Carousel Carousel	$MT_{i-1} = \frac{Y_{i-1}}{V_m}$	Robot travel time from load/unload to the previous SKU storage location
	$MI_i = \max(\frac{X_i}{V_C}, \frac{Y_i}{V_m})$	Carousel indexing time for current SKU
	$MR_i = \frac{R_i}{V_m}$	Robot travel time from SKU current storage location to load/unload
	ST_{i-1}= Constant value	Robot deposit time value at previous SKU storage location
	MP_i= Constant value	Robot retrieval time value at current SKU storage location
	OT_i = Constant value	Operator pick time value

Table 3.2: Summary of Outputs for AS/RS

		AS/RS
Random	Expected cycle time	$E[T_{pi}] = \frac{2}{N(N-1)} \sum_{i-1=1}^{N-1} \sum_{i=2}^{N} (CT_{i-1} + CT_i + RT_i) + DT_{i-1} + CP_i + OP_i$
	Throughput	$T_a = \frac{\text{operating hours per day}}{E[T_{pi}]}$
Class-based	Expected cycle time	$E[T_o] = \sum_{k=1}^{3} P_k E[T'_{pi}]$
	Throughput	$T'_a = \frac{\text{operating hours per day}}{E[T_0]}$

Table 3.3: Summary of Outputs for Carousel

		Carousel
Random	Expected cycle time	$E[T_{qi}] = \frac{2}{N(N-1)} \sum_{i-1=1}^{N-1} \sum_{i=2}^{N} (MT_{i-1} + MI_i + MT_i + MR_i) + ST_{i-1} + MP_i + OT_i$
	Throughput	$T_c = \frac{\text{operating hours per day}}{E[T_{qi}]}$
Class-based	Expected cycle time	$E[T'_o] = \sum_{k=1}^{3} P_k E[T'_{qi}]$
	Throughput	$T'_c = \frac{\text{operating hours per day}}{E[T'_o]}$

4. Analysis and Results

This section presents the mathematical models to compare performance of AS/RS and carousel. Excel is used to perform the mathematical operations.

4.1: Case Study

Table 4.1 provides a summary of the input parameters that are used as inputs to both mathematical and simulation models. All the values are based on practical situations, which can be referenced from AFT–system specifications (2012), Schaefer carousel system (2011), Hwang and song (2004).

Table 4.1: Input Parameters and Value used in the Case Study

		AS/RS	Carousel
Inputs	**Height**	H = 25ft[1]	H= 25ft
	Overall Length	W=100ft[1]	W=100ft
	Speed of crane in horizontal direction	S_h = 180ft/min[1]	N/A
	Speed of crane in vertical direction	S_v =90ft/min[1]	N/A
	Speed of carousel	N/A	V_c=90ft/min [2]
	Speed of robot	N/A	V_m=160ft/min [3]
	Number of storage racks	1500[2]	1500[2]
	Number of rows	25	N/A
	Number of columns	30	60
	Number of bins in each column	N/A	25
	Probability of lth level of fast-moving SKUs in level loading per order	P_1 =0.8 P_2 =0.15 P_3 =0.05	P_1=0.8 P_2=0.15 P_3=0.05
	Crane deposit/retrieval time	4 sec	N/A
	Robot deposit/retrieval time	N/A	4 sec
	Operators pick time	6 sec	6 sec

[1] data is adapted from AFT – system specifications (2012). [2] data is adapted from Schaefer Carousel system (2011). [3] data is adapted from Hwang and Song (2004).

The sequence of calculation will be followed, as theexpected number of SKUs needs to be picked. Also, the average system throughput time includes travel time, machine retrieval or storage time and operator picking time taken for average number of SKU's.

The main outputs of the systems can be seen in Table 4.2. All the calculations are contributing to the final system throughput. Comparisons between each output also can be seen in Figures 4.2, 4.3 and can obtain the conclusion that carousel system with the class-based assignment method has the best system performance in finishing an order in about 29.81 seconds and the best throughput with capacity of processing almost 120.75 orders per hour, this as expected is the most throughput.

Table 4.2: Main Outputs of Mathematical Model

	Systems Performance	
	AS/RS	
	Random	Class-based
Expected cycle time (sec)	61.93	38.14
Throughput (orders/hour)	58.12	94.37
	Carousel	
Expected cycle time (sec)	45.56	29.81
Throughput (orders/hour)	79	120.75

The reason for the difference in cycle time in random and class-based systems can be explained by the assigning of fast moving SKU's near to load/unload station. As a result, by adapting this method, the total picking time in class-based assignment is shown to be comparatively less than the same order components in random assignment. Since the orders are being handled instantaneously, the average cycle time needs to be presented in order to measure the system throughput in one system.

There will be nearly 120.75 orders to be fulfilled in carousel with class-based in one operating hour without external limits considered. In addition, the outputs demonstrate that the storage policy serves an important function in increasing the system throughput.

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