1-1-2010

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Proceedings of the 2010 Industrial Engineering Research Conference
A. Johnson and J. Miller, eds.

Assigning Storage Locations in an Automated Warehouse

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Abstract

A common rule for retrieval from Automated Storage and Retrieval Systems (AS/RS) is to follow a first-in-first-out (FIFO) discipline. In many cases FIFO priority is set by date of manufacture. In some cases, however, the material may be stored in the warehouse according to a FIFO priority which depends on something other than the date of manufacture of that material, such as rules based on shipping container number or date of entry to warehouse. In this case, there needs to be a systematic approach to assigning a range of FIFO priority. A simulation model is developed to test the impact to an AS/RS of different FIFO schemes including assigning priority by arrival date, arrival shift, and container; with an associated range of tolerances for each case. The model is able to handle multiple aisles, multiple levels, and multiple depth-of-storage locations and is scalable in all these dimensions. We consider performance metrics such as average time for storage and retrieval, average time spent relocating items, and total number of crane movements required. The model is exercised in a case study with an automotive manufacturer receiving parts from multiple supplier sources into an AS/RS. Results show that a reduction of up to 20% in non-value-added moves can be achieved.

Keywords
Automated Warehouse, AS/RS, Simulation, Business Case Study, FIFO Priority

1. Introduction

In large scale manufacturing environments, warehouse design and operating logic are crucial elements which directly affect throughput in the plant. Material must be pulled efficiently from the warehouse and delivered to the production floor in a manner timely enough to not constrain the process. To aid in this process, many firms have turned to Automated Retrieval and Storage Systems (AS/RS) for their warehouse needs. In an ideal situation the AS/RS would have immediate access to all inventory in the warehouse. In practical operation however, budget and floor plan constraints may lead to tradeoffs in design which limit performance for the practitioner. To accommodate these constraints, some firms implement AS/RS with *n*-deep storage (see Figure 1). In this case the problem of blocking is introduced. Needed material may be stored behind other material, requiring relocation in order to provide access; such relocation is a non-value-adding activity which consumes resources and may eventually cause manufacturing process constraint from material delivery. As the amount of inventory in the warehouse increases towards capacity this becomes a larger problem and more seriously impacts speed of retrieval.

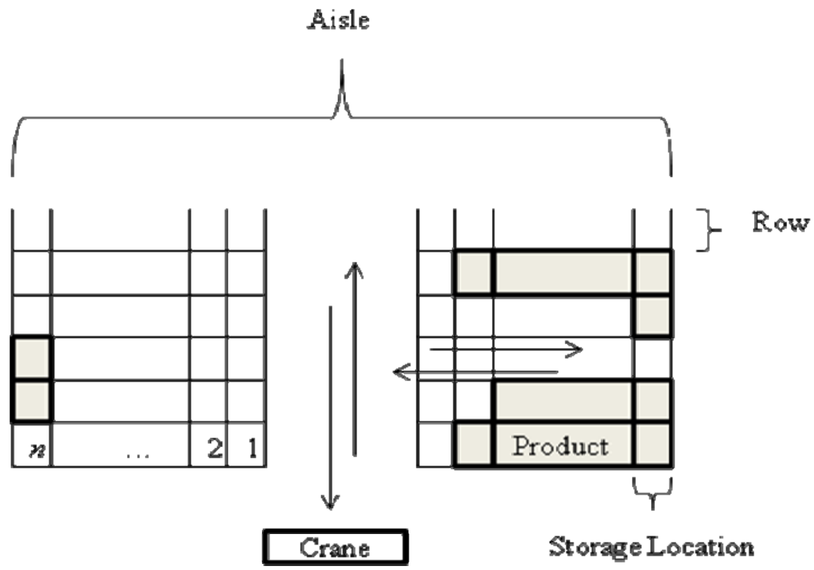

Figure 1: *n*-Deep Storage Layout

Under such a design the best retrieval logic is not obvious. Conventional wisdom suggests that material should be removed from the warehouse in the same order in which it was stored using a first-in-first-out (FIFO) strategy, primarily due to quality and traceability concerns. In the *n*-deep storage case this poses a problem – the "oldest" material in the warehouse is the material that is most likely to be blocked.

Once an *n*-deep AS/RS is in place, a firm has limited options for solving performance issues. Current approaches to address this problem of blocked access center on efficient planning of storage and use of automated crane idle time to rearrange inventory (*i.e.*, "housekeeping"). The efficacy of the planned storage approach is limited by available space and uncertainty of requirement sequence. The housekeeping approach consumes energy and resources that could otherwise be put toward movement of material to the floor. Warehouse systems are typically very large capital expenses and are unlikely to be substantially altered on a large scale as requirements evolve after implementation.

In the following paper we examine the approach of relaxing strict first-in-first-out retrieval logic to assess the effect on *n*-deep AS/RS performance. The model is used to examine the cases of assigning FIFO priority by shipping container, by shift received, and by day received with tolerance explored for each case. We first provide the background of a case study for improvements to an existing *n*-deep storage AS/RS in an automotive manufacturing facility. We then present the model approach and form, and give results from its application to the automotive supply warehouse.

2. Background

We briefly describe related work. For a comprehensive and recent review of research related to warehouse operations we refer the reader to Gu et al. [1]. In their review, Gu et al. categorize research related to warehouse operations into two main groups, storage and picking. The problem we examine falls into the subcategory of "storage location assignment problem". They mention that this research is typically divided based on the type of information used for storage: item, product, or no information. The problem we examine uses both product and item information to determine storage location. Part information is clear, as will be explained in Section 4: like parts are stored together when possible. The item information we concern ourselves with is FIFO date. Our research explores the impact of FIFO tolerances on warehouse performance. Research using item information assumes full information is known about the item; this includes not only when the item arrives but also when the item will leave. The optimal solution of the problem with full item information is computationally impractical for real warehouse operations because of the large problem size [1].

The problem of blindly adhering to global FIFO without regard for local cost optimization is addressed by Berier et al. [2]. They explore the maximum tolerable disturbance to the FIFO policy before local cost saving falls below the cost of violating the FIFO policy. Bekki et al. explore how simulation accuracy can degrade when FIFO policy is violated in a manufacturing system [3]. Venkateswaran and Son examine simulation stability across the supply chain using transform techniques [4]. Their results provide guidelines on frequency of updating information within the model.

Other researchers apply heuristics based on item information, such as the Duration-of-Stay (DOS) heuristic provided by Goetschalckx and Ratliff [5], where parts are stored based on the expected number of days that they are expected to remain in the warehouse. Dekker et al. [6] present a case study of a warehouse for a wholesaler of tools and garden equipment. Their goal is to determine a combination of storage location assignment and storage retrieval policies that improve efficiency. Their storage location approach is based on an ABC classification system, which groups product based on type, fragility (some products are breakable) and demand. Differences between Dekker et al.'s case study and the one presented here are that their warehouse is not automated and does not contain *n*-deep storage. While classification in terms of DOS or demand might be an avenue worth exploring in future research, the manufacturer wanted to work within the existing framework, which uses FIFO date along with part number to determine how parts should be stored. If performance improvement can be achieved within the existing framework this reduces the need for expensive software programming and data management costs. Thus the question becomes: What is an adequate FIFO tolerance for working within the existing framework? Most work in the literature related to FIFO rules is concerned with the impact of different priority rules (e.g. FIFO versus least-recently-used (LRU)) on warehouse performance. For example, Van den Berg and Towsley [7] estimate the miss ratio (probability that a wanted part is not available) as a function of different priority rules, including FIFO. However, existing literature does not specify what adequate tolerances are for FIFO implementation in practice (it would be impractical to retrieve parts from a warehouse in the exact same order as they arrived). Next, we present a case study of determining appropriate FIFO tolerances to be used in warehouse location assignment for an automotive manufacturer.

3. Case Study

The portion of the automotive supply warehouse of interest is known as the Dynamic Picking System (DPS), an automated warehouse used to supply primary materials to an automotive manufacturing plant. The DPS warehouse consists of eight aisles each of which is exclusively served by one of eight cranes. Each aisle has a left and a right side with a depth of three storage locations (the first and eighth aisles have a left and right side with a depth of four storage locations, respectively). The storage locations are stacked eight locations high and there are 58 storage rows from the front of the warehouse to the back. This provides a total of 23, 200 storage positions in the warehouse.

The manufacturer receives parts for storage from worldwide suppliers. The parts are transferred by container and each container may contain multiple lots and a lot may span multiple containers. The containers are received and stored unopened in a holding area. Each container is given a priority level at this stage, based on the container inventory and planned need for the parts in the warehouse. Containers are unloaded either by priority level or by immediate need for a part. Once a container is opened for unloading, each part within that container is assigned a FIFO date. The entire container receives a simultaneous FIFO date – each part in the container is considered equivalent by the storage system. With this assignment system we can potentially have two lots with the same FIFO date and one lot with multiple FIFO dates. When a part is ordered, the DPS software will select the oldest part in the system by FIFO date. When multiple available parts have the same FIFO date, the system will choose the part that is most accessible, typically meaning looking for parts that are unblocked and/or closest to the front of the warehouse. This describes the retrieval policy currently in place.

The retrieval system as operating under the described conditions requires a high degree of rearrangement moves during normal operation, and additional arrangement time is used outside of production time to "clean up" the inventory arrangement. There have been instances of warehouse efficiency levels dropping low enough to require manual intervention for line supply. Note that the existing FIFO priority assignment policy does not maintain lot integrity, nor does it restrict suspect material to single supplier production runs. However, examination of relaxing the existing constraint is undertaken with an air of caution, as expanding FIFO priority range also expands required quarantine volume in the case of a quality issue.

4. Model of AS/RS

To test the effects of different FIFO policies, we developed a simulation model of the automotive manufacturer's warehouse. This model was written in JAVA and represents a single aisle from the manufacturer's DPS warehouse with three depth locations on either side of the aisle. Modeling a single isle is justified as the aisles are independent from one another in regards to crane operation, and there is no reshuffling between aisles. Most important is the logic for storing items in the warehouse. An emphasis must be placed on "clean channels" for peak performance (a clean channel is a row which contains identical items with the same FIFO date). The priority for storing a part is as follows (the tie-breaker within any priority is the row closest to the front of the warehouse within that priority):

1. Search the aisle for a row which contains one or two items that are identical (same part number) to the item being stored and have been assigned the same FIFO date.
2. Search the aisle for an empty row.
3. Search the aisle for a row which contains two "mixed" items (items of different type or FIFO date).
4. Search the aisle for a row which contains an item with a different type and FIFO date.

Note that only rows are considered in the storage policy, this is because parts stored in a row are always "pushed back" as far as possible within that row. For example, in Figure 1 if a part is placed in row two on the left, it will be places in location *n-1*, while if a part is placed in row two on the right it will be stored in location two. Furthermore, only single command cycles are executed (these policies apply in the actual warehouse). Retrieval of parts is based on the part request sequence. Actual crane speeds, rest positions, and load/unload times were used. The model was validated using one month's worth of historical data. Validation of the model showed our model to be a reasonable approximation of the actual system. Each simulation begins with an empty warehouse. There is a "warm-up" period of 50,000 moves where the inventory in the warehouse is initialized and the warehouse moves to a steady state configuration. Input and Output moves are alternated. Using an actual parts profile from the automotive manufacturer we established a list of part numbers to be stored in the aisle. Each part included a relative frequency based on the historical data provided by the manufacturer. We tested the following polices in our simulation:

- **FIFO by Container –** The current system used by the manufacturer. FIFO dates are assigned to parts in batches. For our system batches of 25 parts were established. Testing did not show sensitivity to small changes in batch size.
- **FIFO by Shift –** Each part unloaded in the same shift receives the same FIFO date (there are 2 shifts per day and the second shift straddles multiple days).
- **FIFO by Day –** Each part unloaded in the same day receives the same FIFO date.

Note that this change to storage policy by FIFO date assignment also consequently affects the part retrieval sequence, as retrieval is maintained to strict FIFO, with target location selection latitude allowed across a single FIFO level.

5. Case Study Results

The model was run to simulate the warehouse at three different capacity (fullness) levels: 100%, 90%, and 80%. We point out that these capacities do not include a 10% buffer space built into the warehouse to allow for reshuffling, that is 100% means there are only 10% of storage locations unused. This convention is used as it is what is adopted by the manufacturer. Each scenario was run for 10 replications and the time for each move was recorded as well as the total number of moves. The average times per move of each type are presented in Table 1. In Table 2 we present the average total time spent on each type of move as well as the average total number of reshuffles; results shown in Table 2 are normalized.

Table 1: Average Time of Crane Movement per Task in Seconds

		Capacity		
		100%	90%	80%
Current	Total Time	42.96	41.34	40.82
	Input Time	38.27	37.40	37.59
	Output Time	42.03	41.36	41.45
	Output Time + Reshuffling	47.65	45.28	44.04
	Reshuffling	10.64	10.14	10.83
FIFO by Shift	Total Time	40.52	40.14	40.52
	Input Time	36.18	36.58	37.86
	Output Time	40.33	40.89	41.55
	Output Time + Reshuffling	44.86	43.71	43.18
	Reshuffling	10.75	10.31	11.25
FIFO by Day	Total Time	40.46	40.10	40.27
	Input Time	36.10	36.54	37.59
	Output Time	40.29	40.85	41.30
	Output Time + Reshuffling	44.81	43.67	42.94
	Reshuffling	10.69	10.37	11.20

Table 2: Normalized Results of Crane Task Total Completion Times

		Capacity		
		100%	90%	80%
Current	Total Time	100.00%	100.00%	100.00%
	Input Time	100.00%	100.00%	100.00%
	Output Time	100.00%	100.00%	100.00%
	Output Time + Reshuffling	100.00%	100.00%	100.00%
	Reshuffling	100.00%	100.00%	100.00%
	# of Reshuffles	100.00%	100.00%	100.00%
FIFO by Shift	Total Time	94.33%	97.10%	99.27%
	Input Time	94.56%	97.80%	100.71%
	Output Time	95.97%	98.86%	100.24%
	Output Time + Reshuffling	94.14%	96.53%	98.05%
	Reshuffling	80.49%	71.97%	62.92%
	# of Reshuffles	79.64%	70.82%	60.61%
FIFO by Day	Total Time	94.18%	97.01%	98.65%
	Input Time	94.35%	97.70%	99.99%
	Output Time	95.87%	98.77%	99.63%
	Output Time + Reshuffling	94.04%	96.44%	97.51%
	Reshuffling	80.34%	71.80%	63.54%
	# of Reshuffles	79.94%	70.22%	61.47%

6. Discussion and Conclusion

For the given case study, the performance gains from changing FIFO policies ranged from 0% to 6% for the total performance of the system as measured by time of storage and retrieval. Input and output times showed similar gains. As expected, the gains were larger when the system was operating at a higher capacity, as this is the situation where the most inefficient housekeeping crane movements can be eliminated.

The most striking gains came from the number of reshuffling moves that were performed. Each alternative FIFO policy showed 20% to 40% reduction in non-value-added reshuffling moves. There were no statistically significant performance differences between the FIFO by Shift and FIFO by Day policies. As expected the percent reduction in time spent reshuffling aligns with the percent reduction in reshuffling moves.

The model developed has allowed assessment of a number of cases of FIFO priority assignment strategies. Time of operation was nominally improved, but the key result is up to 40% reduction in the number of non-value-added moves. By extending the tolerance of FIFO, a risk exposure to extended traceability and quality concerns is assumed. That is to say, if a finished product quality issue is identified to a point in time of manufacture, the quarantine effort will be increased as all parts of a given FIFO level should be included. This risk/benefit decision is left to the individual manufacturer.

Therefore, the above improvements should be considered with respect to the change in risk of increasing containment costs in case of a spill. However, it should be noted that some improvement strategies examined can potentially *decrease* this risk through lot control. For example, parts in lower container quantity that were previously assigned the same FIFO priority across multiple shipments on the same day may now only be assigned by container. This is locally suboptimal but applying the rule across all inventory improves warehouse operation as a whole.

In the future, revised FIFO recommendations will be combined with additional warehouse management approaches such as zoning based on usage frequency, automated strategic placement of incoming material based on history, and identification of impending saturation. Additionally, the examination of dual cycles will be included, as this is a commonly-implemented pick strategy. The developed model will be used to assess these additional strategies to assess the separate and combined effect of each improvement approach.

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