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Warehouse Design under Class-Based Storage Policy of Shuttle-Based Storage and Retrieval System

B.Y. Ekren*, Z. Sari, T. Lerher*****

**Department of Industrial Engineering, Izmir University of Economics, Balcova, Izmir, 35330 Turkey (Tel: 232-279-2525; e-mail: banu.ekren@ ieu.edu.tr)*

***Manufacturing Engineering Laboratory of Tlemcen (MELT), University of Tlemcen, Algeria (e-mail: z_sari@mail.univ-tlemcen.dz)*

**** Faculty of Mechanical Engineering, University of Maribor, Smetanova 17, SI-2000, Maribor, Slovenia, (e-mail: tone.lerher@um.si)}*

Abstract: In this study, we aim to find out the best rack design for shuttle-based storage and retrieval system (SBS/RS) under class-based storage policy (CSP). SBS/RS is a new technology in automated storage and retrieval system (AS/RS) which is developed for high transaction environments where mini-load AS/RS crane may not be able to keep pace with the transaction rate needed over a given number of storage locations. We consider several rack design concepts in terms of number of aisles, tiers and bays in the warehouse. The performance of the system is evaluated in terms of utilizations of lifts and storage/retrieval devices and cycle times of storage/retrieval transactions. We utilize simulation for the modeling purpose. The results indicate that CSP works better under high rise warehouse design. So, this may create less number of lifts requirement in the system. Hence, the warehouse design with CSP may tend to have lower investment cost. By this study, we also aim to provide practitioners and academia a significant insight for SBS/RS design under several rack design concepts for CSP.

Keywords: Automated storage and retrieval system, SBS/RS, class-based storage, simulation, automated warehouse.

1. INTRODUCTION

Increasing trend towards more product variety and short response times has created a new AS/RS called SBS/RS (Carlo and Vis, 2012; Marchet et al., 2012; Marchet et al., 2013; Lerher, 2013; Lerher et al., 2013). This new technology is developed for high transaction environments where mini-load AS/RS crane may not be able to keep pace with the transaction rate needed over a given number of storage locations. Typically, an SBS/RS is comprised of multiple tiers of storage with dedicated shuttles for each level (see Figure 1). Hence, loads are stored and removed from the shelves by SBS/RS at high speed, and the shuttle's load handling equipment is designed for short handover times (http://www.dematic.com/multishuttle).

A typical design of an SBS/RS is illustrated in Figure 1 where each tier and aisle has a shuttle and a lift. Shuttles are used as storage/retrieval devices in the system to store/retrieve loads to/from storage locations. Lifts provide vertical movement for loads that are mostly transferred by small containers (i.e. totes). Because each aisle has a single lift, it mostly becomes bottleneck in the system. Therefore, an alternative SBS/RS design with a lift mechanism having two lifting tables is developed. In this design, the capacity of the lifts are doubled by the two lifting tables attached on both side of the lifting system.

In this study, we consider an SBS/RS with two lifting tables attached on left and right side of the lifting mechanism. Our aim is to explore the best rack design for SBS/RS under CSP. We utilize simulation for the modelling purpose.

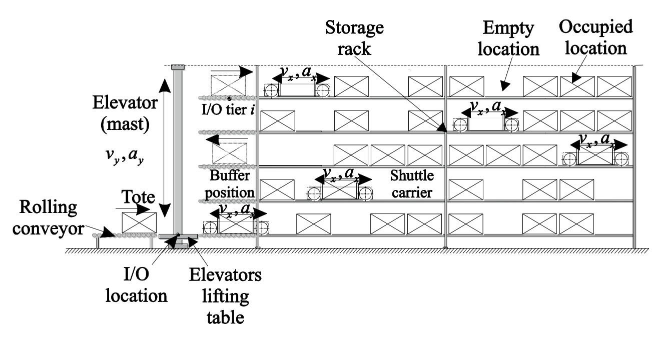

Figure 1: An SBS/RS

2. LITERATURE REVIEW

The earliest study on SBS/RS is completed by Carlo and Vis (2012) where they study a type of SBS/RS that there are two non-passing lifting systems mounted along the rack. They focus on scheduling problem where two (piece-wise linear) functions are introduced to evaluate candidate solutions.

Marchet et al. (2012) presented an analytical model to estimate the performance (the transaction cycle time and

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waiting times) of SBS/RS. They developed an open queuing network model whose performance effectiveness is validated through simulation.

Later, Marchet et al. (2013) studied main design trade-offs for SBS/RS using simulation. They complete their study for several warehouse design scenarios for tier captive shuttles. They provide several performance measures from the pre-defined designs including cost.

Recently, Lerher (2013) and Lerher et al. (2013) have studied energy efficient SBS/RS design. They considered energy regeneration and energy efficiency concept in the models. The proposed models enable reduction of energy consumption and so CO_2 oscillation, which is vital from economic and environmental point of view.

None of the above studies consider CSP for SBS/RS and compare the performance of the systems for different rack design configurations. In this study, we consider CSP in SBS/RS design and experiment several rack configurations to find out the best one under this storage policy. The performance of the system is evaluated in terms of utilization of lifts and shuttles, average cycle time of storage and retrieval transactions and, number of jobs waiting in queues of lifts and shuttles as well as waiting times in these queues. We utilize simulation for the modelling purpose and show our results in a table.

3. SIMULATION MODELLING OF THE SBS/RS

The SBS/RS warehouse considered in the simulation model consists of racks, lifts, and shuttles. Shuttles are tier-captive and their main duty is to store/retrieve totes to/from the storage locations. Racks (on either side of an aisle) consist of bays, and each bay can hold one tote. Because each aisle of the studied SBS/RS is identical in terms of number of tiers and bays, we simulate a single aisle. The lifts are located at the end of aisles and can carry two totes, independently. Transaction seizes the available lift based on the dual command (DC) scheduling rule. Each aisle has an I/O point. The other assumptions that are used in our simulation model are summarized below:

- Arrivals follow a Poisson process and the mean arrival rates for S/R transactions are equal and $\lambda_S = \lambda_R$ = 2,400 totes per hour.
- The time for loading and unloading the totes to/from shuttles/lifts are assumed to be 3 seconds each.
- The shuttles' and lifts' acceleration and deceleration delays are considered to be 2 m/sec2.
- If the S/R transaction is located at the first tier then, lift is not used.
- The I/O location is located at the first tier of each aisle.
- There are two buffer positions at each tier where lifting tables discharge and charge the loads.
- The maximum velocities of shuttles and lifts are considered to be 2 m/sec.

We consider the velocity of lifts and shuttles as well as the distance metrics of the warehouse from Lerher et al., (2013). The simulation model is completed using ARENA 14.0 a commercial simulation software and assumed to be a non-terminating system, allowing us to conduct a steady state analysis. The length of each simulation run is one year. The warm-up period is defined to be three months by the eye-ball technique. The model is run for 10 independent replications.

The verification of the simulation model is completed by debugging the model via the trace module in the simulation software. The validation of the model is completed by comparing our average travel time of lifts with the analytical model results in Lerher et al., (2013).

3.1 Scenarios for Simulation Runs and Results

Simulation runs are conducted based on the Table 1 scenarios. In this table, T, B, A, Q stand for number of tiers, bays, aisles and number of storage locations in the warehouse, respectively. For the Q value, we assume that based on the maximum space utilization of racks at a time 10,000 number of storage locations are required. Based on Table 1, we consider seven T values: 14-20, and four A values: 5-8. We calculate the B values so that the multiplication of T, B, and A provides half of the Q value (due to the two sided storage columns). For instance, in the first scenario of Table 1, T and A values are defined to be 14 and 7, respectively. Hence, the B value is obtained to be 51 by rounding to the nearest integer (5,000/(14×7)). In SBS/RS, because each tier has a shuttle, lifts usually become bottleneck. The scenarios of T, B and A are defined by considering reasonable utilization values (i.e., mostly between 60% - 95%) of the bottleneck resources (i.e., shuttles) to be obtained.

The scenarios based on T, B and A are implemented for the CSP in the SBS/RS. Storage-location assignment in warehouses is an important task since it affects productivity of other warehouse processes. The CSP policy distributes the products, among a number of classes, and for each class it reserves a region within the storage area. In CSP A-class of items are usually stored at the closest available location. Hence, the cycle times are usually low and so the throughput rates are high compared to a random storage policy. In the simulation model, we implement the CSP as follows:

In the *class-based storage policy*, the items are categorized into three classes – A, B, and C. Because lifts are mostly bottlenecks in the system, each class is assigned to a dedicated tier(s) in the warehouse. For instance, class A items are stored at the closest tiers to the I/O-point and class C the farthest. Particularly, in the simulation model, we create A class of items with 80% probability and assign them to the first 20% of the total tier. For instance, if there are 14 tiers in a scenario, with 80% probability (A-class items), an item is stored at the first 3 tiers (20% × 14) randomly; with 15% probability (B-class items) it is stored at the following 30% tiers randomly (30% × 14) - tiers 4-7 -, and with 5% probability it is stored at the remaining tiers: 8-14, randomly.

We assume that the storage bays within the designated tiers are assigned to be randomly.

Recall that the performance of the system is measured in terms of utilization of lifts (*U_L*) and shuttles (*U_S*), average cycle time of storage (*C_S*), and retrieval (*C_R*) transactions. The simulation results are summarized in Table 1. It should be noted that the results provided in this table are the average values of ten replications and the *C_S* and *C_R* values are measured in minute unit. The simulation results are obtained at 95% confidence level. In Table 1, the performance measure *U_S* is provided for shuttles serving class *A*. This is because these shuttles become bottleneck in the system.

Table 1: SBS/RS scenarios and simulation results

T	*B*	*A*	*Q*	*U_L*	*U_S*	*C_R*	*C_S*
14	51	7	9996	Blocked	Blocked	Blocked	Blocked
14	45	8	10080	0.56	0.96	3.46	3.49
14	40	9	10080	0.43	0.65	0.59	0.63
15	56	6	10080	Blocked	Blocked	Blocked	Blocked
15	48	7	10080	0.56	0.93	2.05	2.08
15	42	8	10080	0.49	0.75	0.75	0.79
16	52	6	9984	Blocked	Blocked	Blocked	Blocked
16	45	7	10080	0.56	0.89	1.46	1.50
16	39	8	9984	0.49	0.73	0.68	0.72
17	49	6	9996	Blocked	Blocked	Blocked	Blocked
17	42	7	9996	0.57	0.86	1.20	1.18
17	37	8	10064	0.50	0.71	0.64	0.67
18	56	5	10080	Blocked	Blocked	Blocked	Blocked
18	46	6	9936	0.74	0.79	0.94	0.97
18	40	7	10080	0.63	0.63	0.60	0.64
19	53	5	10070	Blocked	Blocked	Blocked	Blocked
19	44	6	10032	0.74	0.77	0.87	0.90
19	38	7	10108	0.63	0.61	0.58	0.62
20	50	5	10000	0.89	0.99	16.59	16.37
20	42	6	10080	0.74	0.75	0.81	0.84
20	36	7	10080	0.63	0.60	0.56	0.59

We summarize our observations from Table 1 as in below:

- From Table 1, we observe that shuttles serving for *A*-class items tend to become bottlenecks in the system.
- When we consider *T* as 18-20, all the performance measure values are typically better than the ones in scenarios having 14-17 tiers. Hence, we conclude that CSP works better under high rise warehouse design than low rise design.
- In Table 1, the system is blocked when the number of aisles is low in the warehouse. This is probably because, under this condition the arrival rate to an aisle increases (which is calculated by 2,400 transactions/h / *A*). Under this condition to obtain the required *Q* value, the number of bays tends to increase. As a result of this, shuttles serving *A*-class of items become bottleneck. It should be noted that in a scenario within a constant *T*, the performance of the system becomes better when *A* increases (in this case *B* decreases).
- Based on the utilization values, the plant manager may prefer the design with 20, 42, 6 for *T*, *B*, *A*, respectively. In this scenario, the utilization values of lifts/shuttles are around 75%.

4. CONCLUSIONS

In this study, a simulation based warehouse design analysis for SBS/RS is presented. We believe that by this study, we provided significant design insights for SBS/RS for both practitioners and academics. In the study, the warehouse design is considered in terms of number of tiers, bays and aisles in the rack configuration. We explore the best rack design for class-based storage policy. We evaluate the performance of the system for several rack designs. The performance of the system is evaluated in terms of utilizations of lifts and storage/retrieval devices and cycle times of storage/retrieval transactions. We utilize simulation for the modelling purpose. Simulation results are summarized in a table. Based on this table, it is observed that CSP works well under high rise warehouse design than low rise warehouse design. Within a fixed tier scenario, the performance of the system becomes better when the number of aisles increases (in this case bays decreases).

This study can be extended in many directions. For instance, the design scenarios may be extended by including different arrival rate scenarios as well as velocity profiles for lifts and shuttles. Besides, different storage policies (e.g., random storage policy, closest available location, etc.) as well as operational policies (scheduling rules, shuttles that can travel between tiers, etc.) may also be considered in the design scenarios and compared with each other.

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