

Discrete Model for Single Cycle Time of Multi Aisles Automated Storage and Retrieval System with Class-Based Storage

Amina OUHOUD*. Amine GUEZZEN.*
Zaki SARI*

*Manufacturing Engineering Laboratory of Tlemcen (MELT),

University of Tlemcen, Algeria (ami_ouh@yahoo.fr, guezzen_a@mail.univ-tlemcen.dz,

z_sari@mail.univ-tlemcen.dz)

Abstract: Storage policy performance in automated storage /retrieval system is generally evaluated by average single cycle time .This paper presents a mathematical model for the computation of average one-way travel distance /time for warehouse with three (ABC) class based storage. In particular the authors provide a discrete method for the analytical form evaluation of the expected mean travel time for the single command cycles in the multi aisles automated storage retrieval system. This system comprises of a set of racks disposed pairwise in parallel and separated by aisles. Each of these aisles gives access to both racks. A main aisle placed perpendicular to the rack connects all aisles. This type of AS/RS is equipped with a single storage/retrieval machine S/R that can move in three directions: vertically, along columns formants racks. Horizontally, along the aisles and transversally, along the main aisle which one of the extremities is equipped with one input output station (I/O). In order to validate the proposed models accordingly with a multi strategies analysis, a simulation has been developed. The performance of the system obtained by the adoption of the proposed analytical travel-time models under different scenarios (dimensions of the different classes), have been computed evaluated and discussed.

Keywords: multi aisles automated storage/retrieval system, single cycle time, class based storage, simulation, modeling.

1. INTRODUCTION

Within a supply chain, products as raw materials, finished products or work in process must be physically moved from the point of consumption to end-users. During this process, they can be stored in some locations places witch called automated storage retrieval system (AS/RS) for a certain period of time. Many activities are performed in a warehouse. Among them, carry, store and retrieve items. According to the Material Handling Institute of America an Automated Storage and Retrieval System (AS/RS) is a combination of equipment and controls that handle, store and retrieve materials as needed with precision, accuracy and speed under a defined degree of automation.

Between 1994 and 2004, there was a significant increase in the number of AS/RSs used in the industrial environments in the United States Roodbergen andVis, (2009) .Since the last decade, various kinds of AS/RS were developed to handle the increasing number of different types of products to be stored or retrieved. Their classification is based on their structures and their application. We can classify as follows: Unit load AS/RS, Mini-load AS/RS, Man-On-Board AS/RS, flow-rack systems, Mobil racks AS/RS and multi aisles AS/RS. The latter comprises of a set of racks disposed pairwise in parallel and separated by aisles. Each of these aisles gives access to both racks. A main aisle placed perpendicular to the rack connects all aisles. This type of AS/RS is equipped with a

single storage/retrieval machine S/R that can move in three directions: vertically, along columns formants racks. Horizontally, along the aisles and transversally, along the main aisle which one of the extremities is equipped with one input output station (I/O).

Fig.1. is a graphical illustration of multi aisle AS/RS, its components, and the adopted notations for its dimensions.

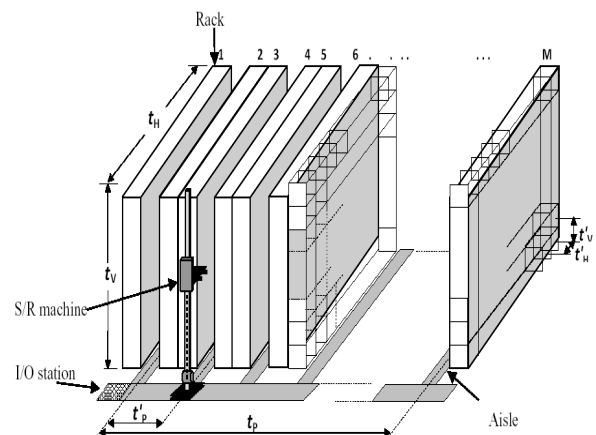


Fig. 1. Configuration of a multi aisle AS/RS

The S/R machine moves simultaneously in both horizontal and vertical directions, in order to reduce the travel time, this

is called Tchebychev travel. The S/R machine can work under two different operating modes *single and dual command cycles*, the single-command cycle means that either an item is moved from the I/O point to a storage bin or from a retrieval bin to the I/O point as shown in fig. 2a.

In the dual command mode, an item is moved from the I/O point to the storage location and next another item is retrieved from the storage location in the rack as shown in fig. 2b.

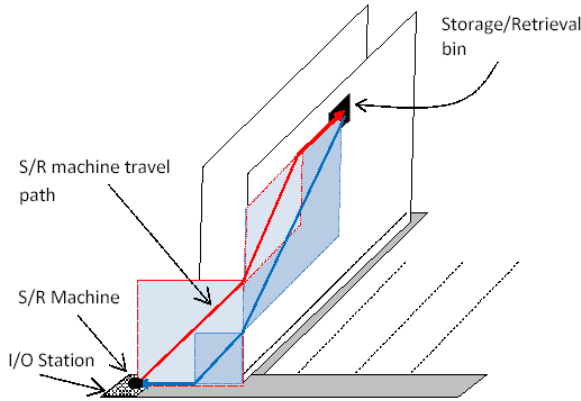


Fig. 2a. Simple cycle in multi aisle AS/RS

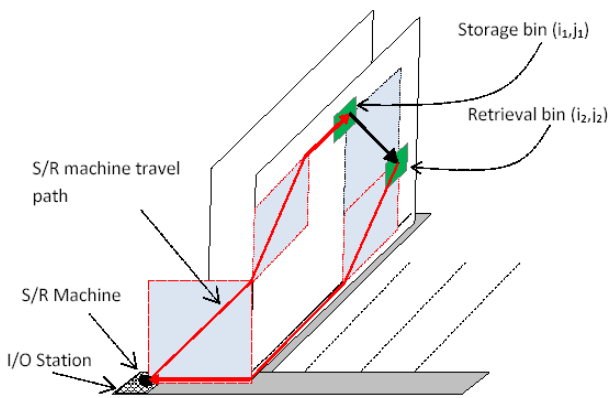


Fig. 2b. Dual cycle in multi aisle AS/RS

Several performances measures can be used to evaluate an AS/RS. Most important are: The utilization rate of the S/R machine and the average time necessary to serve storage or a retrieval request. This time is called simple cycle time. The latter is among the most important parameters of an AS/RS. It influences the overall system performances. Many works was devoted to the cycle time of the S/R machine. Most of these works concern unit load AS/RS. Hausman and Al (1976) were among the first to develop an analytical model for the analysis of unit load AS/RS. They address the problem of optimal assignment. They consider three strategies:

Random storage policy allows the products to be stored anywhere in the storage area. With this policy, all empty locations have an equal probability of having an incoming load assigned to them.

Dedicated storage policy assigns each product type to a fixed location.

Class-based storage (CBS) policy distributes the products based on their demand or movements frequency, among a number of classes, and for each class it reserves a region within the storage area. Accordingly, an incoming load is stored at an arbitrary open location within its class (randomized storage is applied within each class).

In this paper, the authors consider the cycle time of multi aisle AS/RS with class based storage policies. After a literature survey of the various approaches of storage in AS/RS, We propose a discrete mathematical expressions estimating the simple cycle time. In section 2 of this paper, some definitions and notations will be presented and will be adopted later on.

Section 3 present the description and notations of the system studied .Section 4 proposes our new mathematical model for calculating the cycle time with discrete mathematical expression of different class A, B and C. These expressions will be used in section 5 to obtain the expected cycle time with different order frequency.

This paper ends with numerical and simulation example of the presented mathematical expressions, in three different cases.

2. LITERATURE REVIEW

The issue of AS/RS has received a great deal of attention during the last two decades. Several researchers developed analytical models for evaluating the travel time for the pickup and drop off activities.

Three storage assignment rules have been compared based on expected travel time of S/R machines by Hausman and al. (1976). They pointed out that there is a significant reduction in travel time by using dedicated storage policy such as full turnover-based assignment rather than random storage policy. Graves and al. (1977) extended the work done by Hausman and al. (1976) to compare the operating performance of several storage assignment policies by using both continuous and discrete evaluation models. Each rule is compared on the basis of expected travel time of S/R machines.

Schwarz and al. (1978) studied the effects of various assumptions on AS/RS behaviour by simulation. For unit load AS/RS, Bozer and White (1984) developed and compared travel time models for single and dual command cycles. Wen and al. (2001) proposed travel time models, which consider a diversity of travel speeds with known acceleration/deceleration rates. Compacted forms of travel times cycles with class-based storage policies and full-turnover-based storage policies have been resolute. The results prove that the exponential travel time mode which is proposed and the adjusted exponential model execute satisfactorily and could be practical equipment's for designing an AS/RS in existent world applications. Mansuri (1997) has developed a computerized algorithm investigated dedicated storage allocation alternatives for an AS/RS based on cycle time of the S/R machine. Ashayeri and al. (2002) presented an exact geometry-based analytical model to compute the expected cycle travel time for an S/R crane moved in single-command, dual-command, or both where racks can be either SIT or NSIT.

Sari et al. (2007) presented closed-form, travel time expressions for a flow-rack AS/RS based on a continuous approach and compared them with simulation to demonstrate that this analytical model can estimate performance measures by requiring less computing time than simulation. In the same kind of AS/RS, a heuristic was developed by Gaouar and al. (2005), Gaouar and al., (2006) for reducing the expected retrieval time. This heuristic has allowed an improvement of the expected retrieval time. After that, Bessenouci and al. (2010) extend this work and developed two metaheuristic algorithms, called taboo search and simulated annealing. These metaheuristic algorithms are developed to control the retrieval machine of the flow rack AS/RS in order to minimize the retrieval cycle time. Results of these metaheuristic algorithms are compared to classical heuristics and analytical models found in literature of Gaouar and al.(2006).A new storage/retrieval method in Flow-Rack AS/RS, called In- Deep Class Storage was established by Cardin and al. (2012) for that Two algorithms were developed to prove the feasibility of the implementation of this method. This study showed a reduction of more than 60% of the average retrieval time, compared to a random retrieval algorithm.

Another heuristic was developed by Yu and De Koster (2008) to optimize the performance in sequencing the retrievals in a multi-deep rack. This heuristic allowed a great improvement relative to First Come First Served (FCFS) rule.

An optimization method developed by Duc and De Koster (2007) to determine the average throughput time for an order batching problem in a 2-block rectangular warehouse by applying the well-known S-shape heuristic method.

Rosenblatt and Eynan (1989) presented an expression for the expected SC travel time in square-in-time (SIT) racks and a general n-class-based storage policy, and in 1994 the same authors extended their previous work to rectangular racks Eynan and Rosenblatt (1994).

A framework for obtaining mathematical expressions for the expected throughput rate in AS/RS systems was presented by Kim and Seidmann (1990) that developed expressions for the expected SC travel time for turnover-based storage and n-class storage. next this, Kouvelis and Papanicolaou (1995) proposed an approach for 2 class based storage in an optimally designed rack a(square rack) analyzing boundary formulas that reduce the expected SC or DC travel time and, a year later, Pan and Wang (1996) proposed a structure for the dual command cycle continuous travel time model under class-based assignment.

Hwang and Lee (1990) and Chang and al. (1995) proposed a travel time models that considered acceleration/deceleration effects of the S/R machine. Chang and Wen (1997) studied the impact of speed profiles on rack configuration and found that the expected travel times are insensitive to the minor deviation in the optimal rack configuration.

Lee (1997) presented the effect of sequencing storage and retrieval requests on the performance of unit load automated storage and retrieval systems (AS/RS) with a single-server queuing mode, where a storage request is assigned a

predetermined storage location. As results, they found that the sequencing methods can significantly reduce travel time by a storage and retrieval machine, thereby, increasing throughput. After this and in the same domain many authors like Eben-Chaime (1992); Eynan and Rosenblatt (1993); Lee and Schaefer (1996); Lee and Schaefer(1997); Mahajan and al.(1998) studied the AS/RS sequencing problem and developed heuristic algorithms that solved the unit load and the order picking problem.

Park and Webster (1989b) propose a conceptual model that can aid a warehouse schemer in the design of 3-dimensional. Park and Webster (1989a) deal with a new storage structure layout method called 'cubic-in-time', for minimizing the expected travel time of selected handling equipment in a three dimension al palletized storage system.

Park and al. (1999a, b) extended previous work to not squared racks with uniformly distributed and 2 classes based storage. Park and al. (2003a) calculate the mean and variance and its total throughput of single and dual-command travel times for NSIT racks with turnover-based storage assignment. They also show how to adjust the model if the class-based storage policies are used. In universal, AS/RSs have racks of equally-sized cells. But, in some cases, a higher exploitation of warehouse storage can be archived by using not the same sized cells

Park and al. (2005) propose the distribution of the expected dual-command travel time and throughput of SIT racks with high and low turnover class storage of a mini-load AS/RS. Bozer and White (1990) approximated the DC travel time distribution by the uniform distribution.

Van den Berg (2002) investigated and proposed an analytic expression for the optimal position for an S/R machine when the system is idle (called dwell-point positioning problem) dwell point positioning in an AS/RS.

Lee and al. (1999, 2005) develop travel time models for an AS/RS with unequal bins under a random storage assignment, and both single and dual-command cycles. They also compare through simulation the proposed continuous-rack model with a discrete-rack model and conclude that the differences in expected travel times are small.

Manzini and al. (2006) also presented an analysis of the critical parameters involved in the design of AS/RS for order picking systems managed by CBS policy Manzini and al. (2007).

3. SYSTEM DEFINITION AND ASSUMPTIONS

This section first describes the studied system. Then mathematical notations and formulas used throughout this paper are defined.

We consider an automated storage/retrieval (AS/RS) system consisting of a storage/retrieval (S/R) machine, multi storage racks, multi aisles and one I/O point positioned in the lower left corner of the aisle, origin of axis. (See Fig. 1).

The assumptions adopted in this paper are summarized as follows:

- All storage locations have the same size.
- The I/O is at the lower-left corner of the storage rack, as shown in Fig 1.

- The capacity of the machine is one item and it operates in a single-command mode; the machine either stores or retrieves one unit load each time.
- Storage/retrieval time is ignored.
- Acceleration and deceleration during the cycles are not considered.
- Items are ranked according to their marginal contribution to the total demand. An item that has a smaller contribution is indexed with a larger number. (See Fig. 3).

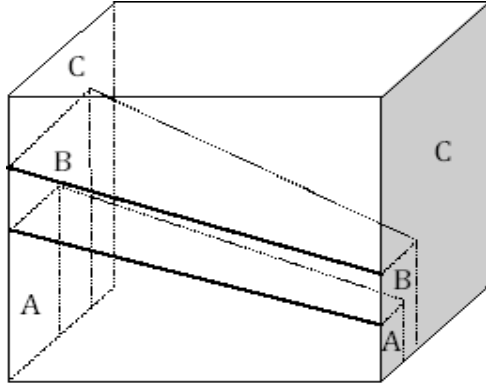


Fig. 3. Scheme definition of class based storage in multi aisles AS/RS

Also the following notation is introduced:

- M: The number of racks in a multi aisle AS/RS;
- M/2: The number of aisles in a multi aisle AS/RS;
- N_H: The number of bins per line
- N_V: The number of bins per column;
- N: The entire number of bins;

$$N = M.NL.NV$$

- A_H: Boundary limits per line of class A;
- B_H: Boundary limits per line of class B;
- A_V: Boundary limits per column of class A;
- B_V: Boundary limits per column of class B;
- t'_H: The horizontal travelling time from a cell to the next cell;
- t'_V: The vertical travelling time from a cell to the next cell;
- t'_P: The travelling time from an aisle to the nearest one in a multi aisle AS/RS and t'_P=3*t'_H
- t_H: Time necessary to traverse the length of a rack or the length of an aisle;
- t_V: Time necessary to traverse the height of a rack;
- t_P: Time necessary to traverse the main aisle in a multi aisle AS/RS;
- E (sca): Expected single cycle time of class A;
- E (scb): Expected single cycle time of class B;
- E (scc): Expected single cycle time of class C;
- E (SCBS): Expected single cycle time;

4. SOLUTION METHODOLOGY FOR CLASS-BASED STORAGE POLICY

Several mathematical models of the S/R machine cycle time exist in the literature. In this section, we are interested to develop discrete models for single cycle time of each class in multi aisle AS/RS.

First, the exact storage or retrieval average cycle time can be obtained by summing the time of storage or retrieval of allocations, and then dividing by the number of locations. Sari (2003)

As shown in Fig. 2a and given that the machine can move simultaneously in the horizontal and vertical direction (Chebyshev travel), the travel time between the I/O station and the coordinates of bins (i, j) is:

The horizontal displacement to reach this cell
t'_{H.i} + t'_{P.(k-1)}

The vertical displacement needed to reach this same cell
t'_{V.(j-1)}

Thanks to Tchebychev travel, the total time that machine S/R puts to reach this rack is the maximum between horizontal and vertical displacement.

t(i, j) = the Tchebychev travel between the I/O point and the random S/R location (i, j), with:

$$t(i, j) = \text{Max}[(t'_{H.i} + t'_{P.(k-1)}), t'_{V.(j-1)}]$$

To calculate the average cycle time for all the cells.

$$\overline{E(SC)} = \frac{4}{N} \sum_{k=1}^{M/2} \sum_{i=1}^{N_H} \sum_{j=1}^{N_V} \text{max}[(t'_{H.i} + t'_{P.(k-1)}), t'_{V.(j-1)}] \quad (1)$$

Now, considering the case where there are three different classes (A, B and C), which is the most popular one in practice.

4.1 Discrete model of single command cycle time of class A

Similar to the study presented in the section 4 the average cycle time depends on the number of bins in each class.

So, it is necessary to calculate the total number of bins in this class which we note N_A.

Before to compute the number of bins in class A, we should know the number of aisles where there are the products of class A. There are two cases:

Case n°1:

Class A is in the M racks. So; the number of aisles that contain the class A equals the number of aisles of the system M/2. As shown in fig. 4.

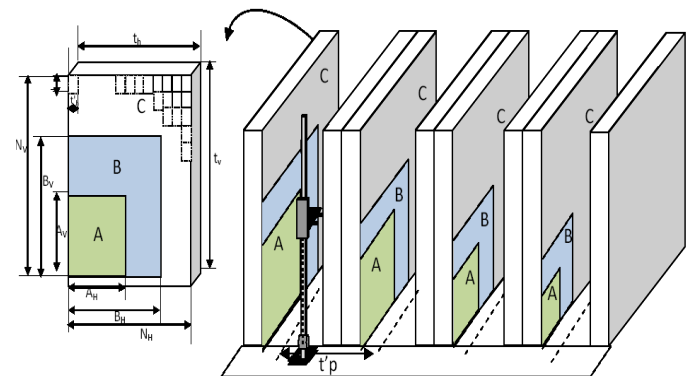


Fig.4. Case1: class A in all the system

Case n°2

Class A is located in a set of racks lower then M. So; the number of aisles which include Class A equal to $\frac{A_H \cdot t_{H'}}{t_P} + 1$ as shown in fig.5.

With:

$\frac{A_H \cdot t_{H'}}{t_P}$ is rounded to integer.

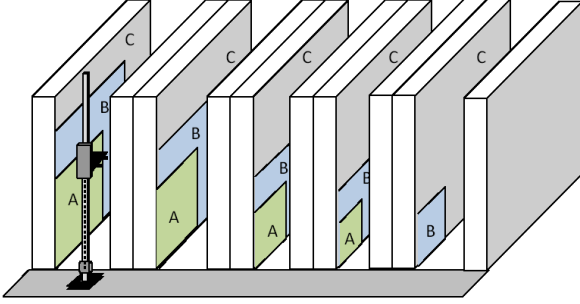


Fig.5. Case 2: Class A in some racks <M

For each case, the number of aisles containing the class A (A_k) equals the minimum between the two cases

$$A_k = \min \left(\frac{M}{2}, \frac{A_H \cdot t_{H'}}{t_P} + 1 \right)$$

So,

$$N_A = 2 * \sum_{k=1}^{A_k} A_V (A_H - 3(k-1))$$

Using this equation, the expected single command cycle time of class A $\overline{E}(sca)$ can be evaluated as:

$$\overline{E}(sca) = \frac{4}{N_A} \cdot \sum_{k=1}^{A_k} \sum_{i=1}^{A_H - 3(k-1)} \sum_{j=1}^{A_V} t(i, j) \quad (2)$$

4.2 Discrete model of single command cycle time of class B

In the same manner we can calculate B_k and N_B which respectively represents the number of aisles where is located class B and the total number of bins in this class so:

$$B_k = \min \left(\frac{M}{2}, \frac{B_H \cdot t_{H'}}{t_P} + 1 \right)$$

$$N_B = 2 * \sum_{k=1}^{B_k} B_V (B_H - 3 * (k-1))$$

Omitting the mathematical details, the expected single command cycle time of class B, $\overline{E}(scb)$ can be evaluated as

$$\overline{E}(scb) = \frac{4}{N_B} \sum_{k=1}^{B_k} \left[\sum_{i=A_H - 3(k-1) + 1}^{B_H - 3(k-1)} \sum_{j=1}^{B_V} t(i, j) + \sum_{i=1}^{A_H - 3(k-1)} \sum_{j=A_V + 1}^{B_V} t(i, j) \right] \quad (3)$$

4.3 Discrete model of single command cycle time of class C

Concerning Class C the number of bins in this class will be: $N_C = N - N_A - N_B$

Similarly to (2) (3). The expected single command cycle time of class C, $\overline{E}(scc)$ can be evaluated as

$$\overline{E}(scc) = \frac{4}{N_C} \sum_{k=1}^M \left[\sum_{i=B_H - 3(k-1) + 1}^{N_H} \sum_{j=1}^{N_V} t(i, j) + \sum_{i=1}^{B_H - 3(k-1)} \sum_{j=B_V + 1}^{N_V} t(i, j) \right] \quad (4)$$

4.4. Single Command Cycle Time with class based storage

The multiplication of (2) (3) and (4) by its order picking proportion α, β and γ respectively gives the cycle time $\overline{E}(SCBS)$ as follow:

$$\overline{E}(SCBS) = \alpha \overline{E}(sca) + \beta \overline{E}(scb) + \gamma \overline{E}(scc)$$

$$\begin{aligned} \overline{E}(SCBS) = & \alpha \left[\frac{4}{N_A} \cdot \sum_{k=1}^{A_k} \sum_{i=1}^{A_H - 3(k-1)} \sum_{j=1}^{A_V} t(i, j) \right] + \beta \\ & \left[\frac{4}{N_B} \sum_{k=1}^{B_k} \left[\sum_{i=A_H - 3(k-1) + 1}^{B_H - 3(k-1)} \sum_{j=1}^{B_V} t(i, j) + \sum_{i=1}^{A_H - 3(k-1)} \sum_{j=A_V + 1}^{B_V} t(i, j) \right] \right] + \gamma \\ & \left[\frac{4}{N_C} \sum_{k=1}^M \left[\sum_{i=B_H - 3(k-1) + 1}^{N_H} \sum_{j=1}^{N_V} t(i, j) + \sum_{i=1}^{B_H - 3(k-1)} \sum_{j=B_V + 1}^{N_V} t(i, j) \right] \right] \quad (5) \end{aligned}$$

Where:

α : order picking proportion of items of class A

β : order picking proportion of items of class B

$\gamma = (1 - \alpha - \beta)$: order picking proportion of items of class C

5. PRESENTATION OF THE CASE STUDY

In this section, an illustrating example for the travel time $\overline{E}(SCBS)$ analysis is presented for selected configuration of multi aisle AS/RS (Table 1)

Table 1. System parameters

Total system capacity (N) M=8, NI=20, Nh=20	N=3200
Time displacement ($t_{H'}$, $t_{V'}$, t_P) unit time	(10,10,30)
Boundary limit of class A (A_H, A_V)	(10,10)
Boundary limit of class B (B_H, B_V)	(15,15)
Boundary limit of class C (N_H, N_V)	(20,20)

The authors consider three different storage classes, namely: A, B and C. In the class A, frequently ordered items occupy only a very small place of the total storage space. Typically, items occupying less of the storage space are responsible for 80% (α) of the picks. In the class C, no distinction between items classes in the term of order frequency and required space can be made; items are randomly located within the warehouse. Finally, the class B is between the two above mentioned patterns. The order picking proportion (α, β, γ) are listed in Table 2

Table 2. Order picking proportion

Assignment	Class A	Class B	Class C
Class based storage	80%	15%	5%
Medium	50%	30%	20%
Random	33.33%	33.33%	33.33%

Applying (5), the exact $\overline{E(SCBS)}$ value can be easily determined for AS/RS parameters listed in table 1, operating with a 3-CBS product assignment listed in table 2. The results of this inputs parameter can be summarized in table 3

Table 3. Results

Assignment	$\overline{E(SCBS)}$
Class based storage	184.33
Medium	238.18
Random	275.18

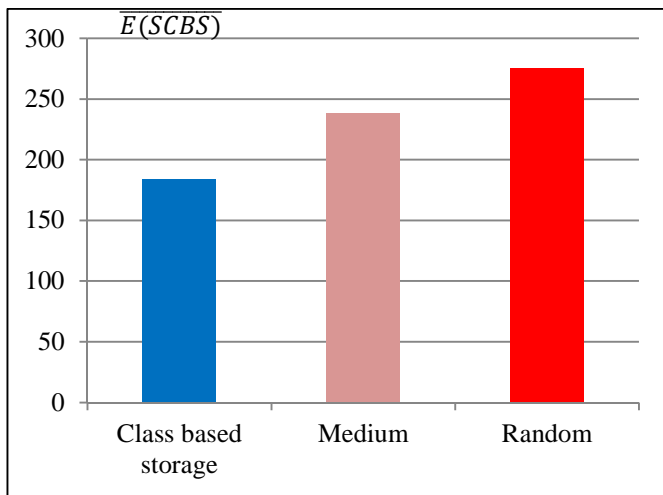


Fig. 6. Comparison between different strategies

Reading these results, and as shown in fig. 6 it is clear that class based storage is very efficient. It is noticeable that there is a reduction of expected single cycle time in class based storage compared to the random storage.

6. SIMULATION STUDY

The simulation is a process which comprises:

- Develop the model of the real system studied.
- Conduct experiments on this model.
- Interpret the observations provided by the progress of the model and make system decisions.

In this paper, Simulation is a technique applied to storage systems, to study the behavior of this system by building a software model of it.

The purpose may be to understand the dynamic behavior of our system, comparing configurations, evaluate different control strategies, evaluate and optimize performances.

A simulation study was performed in order to validate the mathematical expression suggested for the single cycle time with class based storage. To do so, a model was built on Rockwell software Arena. The model was generated using VBA function. The main objective of using Visual Basic was to be able to adapt these functions very easily in others AS/RS configurations. This section presents the assumptions made in the model, the validation process and the experiments that were run.

6.1 Experimental design

This section presents the experiments that were run to validate the mathematical expression presented before; the aim of this section is to describe a classical configuration of the rack and of the behavior of the demand.

First, simulation experiments are performed with multi aisle AS/RS which is assumed to have one S/R machine at lower-left corner of the storage rack. There are 8 racks and 4 aisles. The size of one rack is 20 bins in horizontal and 20 bins in vertical, so the total number of bins in the system is 3200. The other Parameters used in the simulation model was listed in the previous table Table 1.

Then, about the order picking proportion of items were defined and are described on Table 2.

Fig. 7. presents the flowchart which models the functioning of our model.

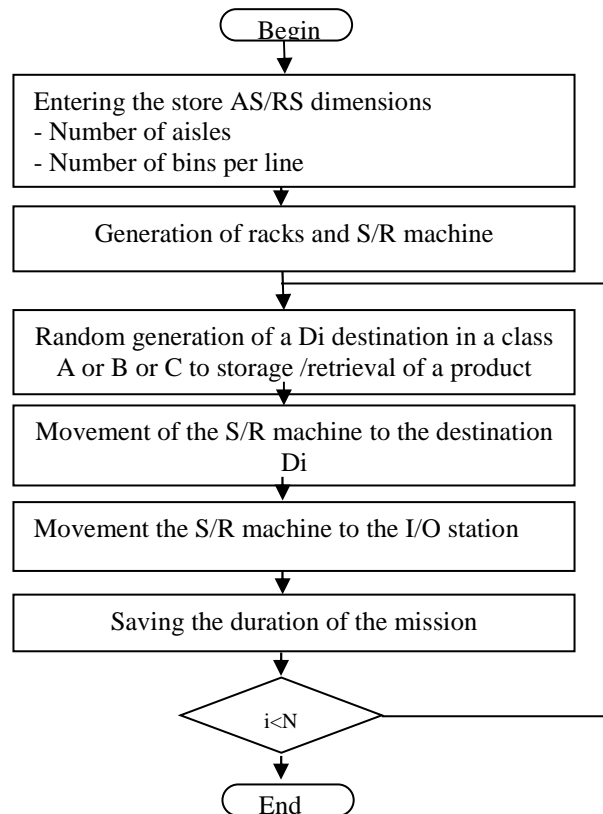


Fig. 7. Simulation flowchart

6.2 Simulation and result analysis

A simulation study was run on Rockwell software Arena. For each experiment 5 replications were made, each of them involving 100 000 observations.

The results given in table 4 presents analytical and simulation results for different scenarios. Column 1 provides 3 cases with presented above in table 2. Column 2 shows the travel time determined by the simulation models. A column 3 provides the same travel time using analytical models. And finally columns 4 present the percent error between the analytical and simulation travel time models.

Table 4. Experiment results for the three scenarios

Replications	E(SCBS) simulation	E(SCBS) analytical model	Error (%)
1. Class based storage (80%, 15%, 5%)			
1	194.17		
2	188.23		
3	188.32		
4	183.17		
5	183.99		
average	187.64	184.33	1%
2. Medium (50%, 30%, 20%)			
1	246.49		
2	243.40		
3	245.59		
4	234.77		
5	236.95		
average	241.44	238.18	1%
3. Random storage (33.33%, 33.33%, 33.33%)			
1	276,58		
2	290,06		
3	293,14		
4	280,23		
5	276,32		
average	283,266	275.18	2%

Table 4 provides very interesting results. First of all, the results given by simulation are very close to the discrete equation results. The largest relative error was 2%.

Secondly, and even more important, Significant potential reductions in simple cycle time in automatic warehousing systems seem to be possible, based on class-based storage strategy rather than random policies.

7. CONCLUSIONS

This work explains an analytical model the expected SC cycle times for multi aisles AS/RS with 3 classes based storage (CBS) storage allocation of products. This is a discrete approach that can also be applied to n-CBS AS/RSs.

This study showed a reduction of the average single cycle time delay in class based storage compared to a random storage.

The closed form expected travel time expression, presented in this work, can be used to: establish performance standards on existing systems, evaluate throughput performance for multi aisle AS/RS design configurations as well as compare it with other types of AS/RS for choice decision and a good management of this kind of installation. In addition, they can be used as a basis of comparison for evaluating performance improvements of different storage techniques and for the developed heuristics in this field.

In the same optics, the researchers currently think of the possibility to develop a discrete expression for dual cycle time in the same system, and then extend this work by computing and validating the results of the dual cycle time with simulation model.

REFERENCES

- Ashayeri, J., Valkenburg, M.W.T., Heuts, R.M., Veraart, H.C., Wilhelm, M.R. (2002). A geometrical approach to computing expected cycle times for zone based storage layouts in AS/RS. *International Journal of Production Research*, 40(17), 4467-4483.
- Bessenouci, H.N., Sari, Z., Ghomri, L. (2010). Metaheuristic based control of a flow-rack automated storage retrieval system. *Journal of Intelligent Manufacturing*, 23 (4), 1157-1166.
- Bozer, Y.A., and White, J.A. (1984). Travel time model for automated storage /retrieval systems. *IIE Transactions* 16(4), 329-338.
- Cardin, O., Pierre, C., Sari, Z., Meghelli, N. (2012). Performance evaluation of In-Deep Class Storage for Flow-Rack AS/RS. *International Journal of Production Research*, pp.6775-6791.
- Chang, D.T., Wen, U.P. (1997). The impact on rack configurations on the speed profile of the storage and retrieval machines. *IIE Transactions*-29, 525-531.
- Chang, D.T., Wen, U.P., and Lin, J.T. (1995). The impact of acceleration and deceleration on travel time models for automated storage and retrieval systems. *IIE Transactions* 27(1), 108 - 111.
- Eben Chaime, (1992). Operations sequencing in automated warehousing systems. *International Journal of Production Research*, 30(10), 2401-2409.
- Eynan, A., Rosenblatt, M.J. (1994) Establishing zones in single-command class-based rectangular AS/RS. *IIE Transactions*, 26(1), 38-46.
- Eynan, A., Rosenblatt, M.J. (1993). An interleaving policy in automated storage and retrieval systems. *International Journal of Production/Research*, 31(1):1-18
- Gaouar, N., Sari, Z., Ghouali, N. (2005). Développement d'une Heuristique de Stockage/Déstockage pour un Système AS/RS à Convoyeur Gravitationnel. *6^{ème} Congrès International de Génie Industriel, (GI'2005)*, 7-10 Juin 2005, Besançon Micropolis, France
- Gaouar, N., Sari, Z., Ghouali, N. (2006). Modélisation et implémentation d'une Heuristique de

- Stockage/Déstockage pour un Système AS/RS à Convoyeur Gravitationnel. *6^{ème} Conférence Francophone de Modélisation et Simulation (MOSIM'06)*, 3-5 avril 2006, Rabat, Maroc.
- Graves, S.C., Hausman, W.H., and Schwarz, L.B. (1977) Storage retrieval interleaving in automatic-warehousing systems. *Management Science*, 23(9):935 - 945.
- Hausman, W.H., Schwarz, L.B., Graves, S.C. (1976). Optimal storage assignment in automatic warehousing systems. *Management Science*, 22(6):629-638.
- Hwang, H. and Lee, S.B. (1990). Travel time models considering the operating characteristics of the storage and retrieval machine. *International Journal of Production Research*, 28(10), 1779-1789.
- Kim, J., Seidmann, A. (1990). A framework for the exact evaluation of expected cycle times in automated-storage systems with full turnover item allocation and random service requests. *Computers and Industrial Engineering*, 18(4), 601- 612.
- Kouvelis, P. and Papanicolaou, V. (1995). Expected travel time and optimal boundary formulas for a two class based automated storage and retrieval system. *International Journal of Production-Research*, 33(10), 2889-2905
- Le-Duc, T., and De Koster, R.M.B.M. (2007). Travel-time estimation and order batching in a 2 block warehouse. *European Journal of Operational Research*, 176(1), 374-388
- Lee, H.F., Schaefer, and S.K. (1996). Retrieval sequencing for unit load automated storage/retrieval systems with multiple openings. *International Journal of Production Research*, 34(10), 2943 - 2962.
- Lee, H.F., Schaefer, and S.K. (1997). Sequencing methods for automated storage / retrieval systems with dedicated storage. *Computers and Industrial Engineering*, 32(2), 351- 362.
- Lee, Y.H., Lee, M. and Hur, S. (2005). Optimal design of rack structure with modular cell in AS/RS. *International Journal of Production-Economics*, 98(2), 172- 178
- Lee, Y.H., Jin, S., Tanchoco, J.M.A., (1999). Performance estimation models for AS/ RS with unequal sized-cells. *International Journal of Production-Research*, 37(18), 4197- 4216.
- Mahajan, S., Rao, B.V. and Peters, B.A. (1998). A retrieval sequencing-heuristic for miniload end of aisle automated storage /retrieval systems. *International Journal of Production-Research*, 36(6), 1715- 1731.
- Mansuri, M. (1997). Cycle time computation, and dedicated storage assignment, for AS/R systems. *Computers and Industrial Engineering*, 33, 307-310.
- Manzini, R., Gamberi, M., Persona, A., and Regattieri, A. (2007). Design of a class-based-storage picker to product order picking system. *International Journal of Advanced Manufacturing Tech*, 32(7-8), 811 - 821
- Manzini, R., Gamberi, M. and Regattieri, A. (2006). Design and control of an AS/RS. *International Journal of Advanced Manufacturing Technology*, 28(7):766 - 774.
- Material Handling Institute Material Handling Institute, Inc. (1977). Considerations for planning and installing an automated storage/ retrieval systems AS/RS, *Document-100 7M*.
- Pan, C.H., Wang, C.H. (1996). A framework for the dual command cycle travel-time model in automated warehousing systems. *International Journal of Production-Research*, 34(8), 2099- 2117.
- Park, B.C., Foley, R.D., Frazelle, E.H. (2005). Performance of miniload system with two class storage. *IIE Transactions*.
- Park, B.C., Foley, R.D., White, J.A., Frazelle, E.H. (2003a). Dual-command travel-times and miniload system throughput with turnover based storage. *IIE Transactions*, 35, 343-355.
- Park, B.C., Frazelle, E.H. and White, J.A. (1999b). Buffer sizing models for end of aisle order-picking systems. *IIE Transactions*, 31(1), 31-38.
- Park, B.C., Frazelle, E.H., and White, J.A. (1999a). Buffer sizing models for end of aisle order picking systems. *IIE Trans* 31(1):31-38
- Park, Y.H., Webster, D.B. (1989b). Modeling of three dimensional warehouse System. *International-Journal of Production/Research*, 27(6), 985-1003.
- Park, Y.H., Webster, D.B. (1989a). Design of class based storage racks for minimizing travel-time in a three dimensional storage system. *International-Journal of Production/Research*, 27(9), 1589-1601.
- Roodbergen, K., Vis, I. F. A. (2009). A survey of literature on automated storage and retrieval systems. *European Journal of Operational-Research*, 194, p.343-362
- Rosenblatt, M.J., Eynan, A. (1989). Deriving the optimal boundaries for class based automatic storage /retrieval systems. *Management Science* 35(12), 1519_1524.
- Sari, Z., (2003). Modélisation, analyse et évaluation des performances d'un AS/RS à convoyeur gravitationnel. Phd Thesis, university of Tlemcen, Algérie.
- Sari, Z., Grasman, S.E., Ghouali, N. (2007). Impact of pickup/delivery stations and restoring conveyor locations on retrieval time models of flow-rack automated storage and retrieval systems. *Production Planning and Control*, 105-116
- Schwarz, L.B., Graves, S.C. and Hausman, W.H. (1978). Scheduling policies for automatic warehousing systems: simulation results, *AIIE Transactions*, 10(3), 260-270
- Van den Berg, J.P. (2002). Analytic expressions for the optimal dwell point in an automated storage and retrieval system. *International Journal of Production Economics* 76, 13-25.
- Wen, U.P., Chang, D.T. and Chen, S.P. (2001). The impact of acceleration and deceleration on travel time models in class based automated AS/RS systems, *IIE Transactions* 33, 599-608
- Yugang, Yu. and De Koster, R.B.M. (2008). Designing an optimal turnover based storage rack for a 3d compact AS/RS. *International Journal of Production Research*, 46(06), 1551-1571

