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Comparative Study between Continuous Models and discrete models for Single Cycle Time of a Multi-Aisles Automated Storage and Retrieval System with Class Based Storage

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Abstract: In this work, we are interested to a problem of storage assignment in automated storage and retrieval system (AS/RS), and more particularly class based storage in multi-aisles AS/RS. In the first part, we developed a continuous approach. The latter is an analytical approach based on continuous approximation of the various discrete distributions modeling the exact horizontal and vertical movements of the S/R machine in each class A, B and C. Subsequently, the proposed models are validated by comparing them with discrete model. For this, we have studied several configurations to compare the results given by the discrete model and continuous model. Finally, the obtained results show that these two models are very close to each other. This is expected because the developed expressions are continuous approximation of discrete data.

Keywords: multi-aisles AS/RS, single cycle time, class based storage, continuous model, discrete model

1. INTRODUCTION

An automated storage and retrieval (AS/RS) is considered as one of the main important tool for warehouse material handling systems, it is widely used in distribution centers and automated production environments. The AS/RSs were used not only as alternatives to traditional warehouses but also as part of modern manufacturing systems through the significant advantages they offer: namely, low labour cost; a low cost of storage; a better exploitation of storage space; better traceability of stored products and high system throughput.

These systems provide fast and efficient handling and can operate 24 hours a day with minimal human supervision. The AS/RSs require serious analysis during the initial design phase (Rouwenhorst and al. (2000), De Koster and al. (2007), Gu and al. (2007)), because at this stage the designers determine the capacity and throughput system. For example, during the design phase, managers make decisions on the rack configuration and capacity (single or double depth), the number of aisles and storage/retrieval machines (S/R machine) as well as the location of the Input/Output station (I/O station). Once the AS/RSs are implemented, a number of control decisions must be made to obtain the performance (Roodbergen and al.2009). These control decisions include decisions on storage policies, the location point of the S/R machine and scheduling...

Many works was devoted to the problem of storage assignment. Hausman and al (1976) were among the first to develop an analytical model for the expected cycle time of unit load AS/RS. In their work, the authors consider three strategies: random storage, class based storage and dedicate storage. 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.

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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 metaheuristics 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.

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 dimensional 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).

In this paper, we restrict our attention to class based storage, in this methodology of storage, the products are organized in classes by contribution to their rotation frequency.

After the state of the art, the number of class is limited to three: "A" is the class of items that have a faster rotation, "B" class includes second fastest articles, and "C" covers the rest. The average cycle time of S/R machine is an important parameter in this policy because it enables optimization when designing new systems for the design of classes and calculating the throughput of the system.

Several models have been developed to study the assignment problem (class based storage) in unit load AS/RS, but there is no paper in the literature for class based storage in multi aisle AS/RS.

In this paper, the authors consider the cycle time of multi aisle AS/RS with class based storage. Initially, they present a discrete model to determine the average single cycle time of S/R machine for each class of a multi-aisle system Ouhoud and al. (2016). Subsequently, they develop an approximated continuous model. The developed models include many results. They are an appropriate mathematical support for analyzing, assessing and optimizing storage strategy.

2. CLASS BASED STORAGE IN MULTI-AISLES AS/RS

In this research, we consider an AS/RS, where there are several aisles. Each aisle contains a storage rack in both sides. All these aisles are connected by a common aisle positioned perpendicular to racks. The system includes a deposit/delivery station (D/L station) located in the lower left corner of the AS / RS. There is also a single storage/retrieval machine (S/R) dedicated to the aisles of the system, which can move simultaneously in vertical and horizontal directions. This movement is called Chebyshev displacement. Therefore, the travel time between two points is equal to the maximum of the horizontal and vertical displacements.

Fig.1 shows a multi-aisle AS/RS with three classes based storage as well its components and notations adapted to its dimensions.

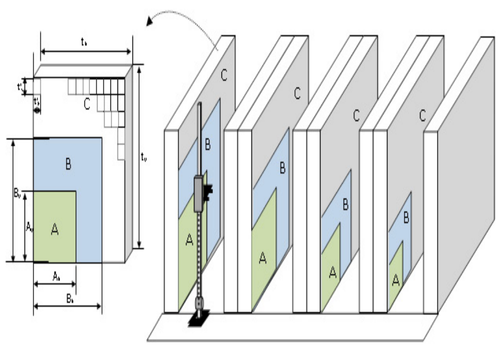

Fig. 1. Class based storage in multi-aisles AS/RS

2.1 Notations

The following notation is introduced:
M : The number of racks in the system;
M/2 : The number of aisles in the system;
N_H : The number of bins per line
N_V : The number of bins per column;
N : The entire number of bins; N = M.NH.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(SC) : Expected single cycle time;
E(SCBS): Expected single cycle time in class based storage;

3. DISCRETE MODELS OF A MULTI AISLE AS/RS IN CLASS BASED STORAGE

The discrete model applied in the previous model, allows us to develop a system of mathematical expressions for the computing the travel time of the multi aisle AS/RS with class based storage assignment Ouhoud and al. (2015). The travel time model depending on the value of the order picking proportion α, β and γ is presented as follow

$$\overline{E(SCBS)} = \alpha\overline{E(sca)} + \beta\overline{E(scb)} + \delta\overline{E(scc)} \qquad (1)$$

Where:
$\overline{E(sca)}$: Expected single cycle time of class A
$\overline{E(scb)}$: Expected single cycle time of class B
$\overline{E(scc)}$: Expected single cycle time of class C

4. CONTINUOUS MODEL OF A MULTI AISLE AS/RS WITH CLASS BASED STORAGE:

The main idea of this method is based on continuous approximation of probability laws modelling the movements of the S/R machine. (Guezzen and al. 2013)

4.1 Average single cycle of Class A

Take a bin in class A with the coordinate (i, j). Knowing that i and j are independent random variables representing the horizontal and vertical travel time to the location considered. The total displacement to this rack is: Max (i, j), which implies that the simple cycle time is: 2. Max (i, j).
The laws of probability of two random variables allow knowing the chances of occurrence of different values of these variables. In this case, the law of the variable i and j is determined by the set of probabilities:
g (k) = g (i = k) with a distribution function given by: G (k) = p (i ≤ k); and h (k) = h (j = k) with a distribution function given by: H (k) = p (j ≤ k)

4.1.1Horizontal travel time

Fig. 2 represents a top sight of a multi aisle AS/RS. On this figure, we can see that the horizontal travel time i of the S/R machine in class A is the sum of two travels, noted i_{Pa} and i_{ha} respectively.

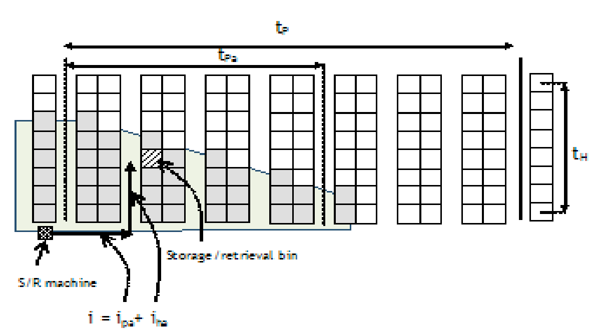

Fig.2.Horizontal travel time of the S/R machine in class A.

i_{Pa} and i_{ha} represent travel durations. Each one of these two variables is a discrete random variable. Fig.3.a and fig.3.b represents discrete uniform and triangular distributions of i_{Pa} and i_{ha} respectively.

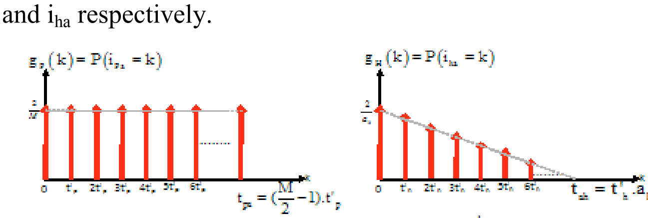

Fig.3. Exact discrete distribution of variable i_{pa} et i_{ha}.

The exact distribution $g_p(k)$ can be approximated by the continuous uniform distribution as shown in fig 4.a., while the exact distribution $g_h(k)$ can be approximated by the continuous triangular distribution as shown in fig 4.b.

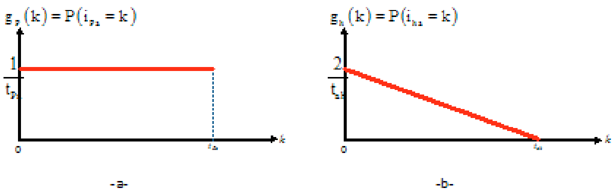

Fig.4. Approximate continuous distributions of the random variables i_{pa} et i_{ha}.

$$g_p(k) = P(i_{pa} = k) = \begin{cases} \dfrac{1}{t_{Pa}} & si \quad 0 \le k \le t_{Pa} \\ 0 & else \end{cases} \tag{3}$$

$$g_h(k) = P(i_{ha} = k) = \begin{cases} \dfrac{2(t_{ah} - k)}{t_{ah}^2} & si \quad 0 \le k \le t_{ah} \\ 0 & else \end{cases} \tag{4}$$

The horizontal movement of the S/R machine is the sum of two movements: $i = i_{Pa} + i_{ha}$. So to calculate the distribution of the variable i (denoted g(k)), we must calculate the convolution of the two functions g_p (k) and g_h (k).

$$\begin{aligned} g(k) &= g_p(k) * g_h(k) \\ &= \int_{-\infty}^{+\infty} g_p(t).g_h(k-t).dt \\ &= \int_{-\infty}^{+\infty} g_h(t).g_p(k-t).dt \end{aligned} \tag{5}$$

The calculation of convolution consists in calculating the product surface $g_P(u).g_H(k-u)$. The function $g_H(k-u)$ is simply the original function $g_H(k)$ inverted in time to give $g_H(-u)$, then translated k.

After calculating all the surfaces obtained, the convolution product is obtained for all k:

$$g(k) := \begin{cases} -\dfrac{k\,(k - 2\,tah)}{tpa\; tah^2} & k \le tah \text{ and } 0 < k \\ \dfrac{tpa - 2\,k + 2\,tah}{tah^2} & tah < k \text{ and } k \le tpa \\ \dfrac{(-tpa + k - tah)^2}{tpa\; tah^2} & tpa < k \text{ and } k \le tpa + tah \end{cases} \tag{6}$$

The distribution function G(k) of the variable i is given by the following expression:

$$G(k) = \begin{cases} -\dfrac{1}{3}\dfrac{k^2(k - 3t_{ah})}{t_{pa}.t_{ah}^2} & 0 < k \le t_{ah} \\ \dfrac{1}{3}\dfrac{(6k - 3t_{pa})t_{ah} - t_{pa}^2 - 3k^2 + 3t_{pa}k}{t_{ah}^2} & t_{ah} < k \le t_{pa} \\ \dfrac{1}{3}\dfrac{-t_{ah}^3 + 3t_{ah}^2 k - 3(k - t_{pa})^2 t_{ah} + (k - t_{pa})^3}{t_{pa} t_{ah}^2} & t_{pa} < k \le t_{pa} + t_{ah} \\ 1 & t_{pa} + t_{ah} < k \end{cases} \tag{7}$$

4.1.2Vertical travel time

Let us now study the vertical movement of the S/R machine. The random variable j modelling this vertical movement follows a uniform probability law.
The probability density of this vertical displacement can be represented by the following function:

$$h(k) = P(j = k) = \begin{cases} \dfrac{1}{t_{va}} & if \quad 0 \le k \le t_{ah} \\ 0 & else \end{cases} \tag{8}$$

Consequently:

$$H(k) = P(j \le k) = \begin{cases} 0 & \text{if} \quad k \le 0 \\ \dfrac{k}{t_{va}} & \text{if } 0 < k \le t_{va} \\ 1 & \text{if} \quad k > 0 \end{cases} \tag{9}$$

4.2. Average cycle time of class A

Let F(k) be the cumulative density function of Max(i, j).

$$\begin{aligned} F(k) &= P(Max(i, j) \le k) \\ &= G(k).H(k) \Rightarrow f(k) = F'(k) = g(k).H(k) + G(k).h(k) \end{aligned} \tag{10}$$

We can distinguish four possible cases in the calculation of F(k):

1st case: $0 < t_{va} \le t_{pa}$

2nd case: $t_{pa} < t_{va} \le t_{ah}$

3rd case: $t_{ah} < t_{va} \le t_{pa} + t_{ah}$

4th case: $t_{pa} + t_{ah} < t_{va}$

The expected value of Max(i, j) is obtained as follows:

$$E(Max(i, j)) = \int_{-\infty}^{+\infty} k.f(k).dk \tag{11}$$

As f (k) is reduced to zero outside the interval [0, tpa+ tah], so equation (17) can be reduced to the following equation as:

$$E(Max(i, j)) = \int_{0}^{tpa+tah} k.f(k).dk \tag{12}$$

We find, finally, a system of equations which represents the average single cycle time of S/R machine to visit all bins of class A.

4.3. Average cycle time of class B

Following the same steps of calculation presented in the previous section, we calculate the average single cycle time of the area which covers class A and class B at the same time. Knowing that this area is limited by: t_{bh}, t_{pb} and t_{vb}.

$$E(scb) = \frac{E(scba).(N_A + N_B) - E(sca).N_A}{N_B} \tag{14}$$

4.4. Average cycle time of class C

We have, now, the values of E (sca) and E (scb), the average time to find a simple cycle in the class C. It is then sufficient to calculate the average:

$$E(scc) = \frac{E(sc).N - E(scb).N_B - E(sca).N_A}{N_c} \quad (15)$$

Where E(SC) is the expected single cycle time of a multi aisle with random storage developed by Guezzen and al.(2013)

$$E(SC) = t_P + t_h + \frac{t_V^3}{12t_P t_h} + \frac{(t_V - t_P - t_h)^3 \mathrm{Max}(t_V - t_P - t_h, 0) - (t_V - t_P)^3 \mathrm{Max}(t_V - t_P, 0) - (t_V - t_h)^3 \mathrm{Max}(t_V - t_h, 0)}{12 t_P t_h t_V} \quad (16)$$

5. COMPARAISON AND VALIDATION RESULTS

To evaluate the accuracy of mathematical expressions developed in the section three and four, we have taken a variety of configurations with multiple dimensions of class A, B and C. We conducted a comparison of the results given by the continuous expression with those given by the discrete expression, knowing that it gives accurate results. The results are shown in fig 5

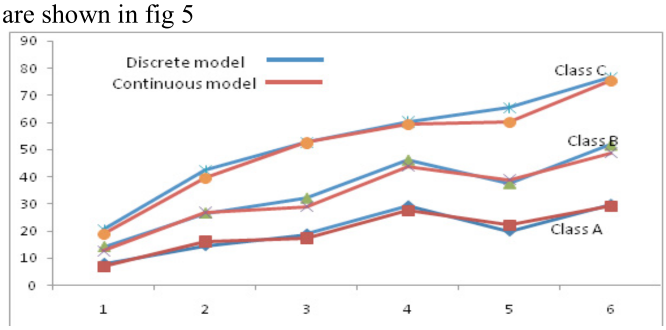

Fig. 5.Comparison between the results given by the continuous model and discrete model for the three classes

Fig. 5 shows the results of these two models are very close to each other. Small average travel time differences were found according to the different analytical approaches developed previously. This is predictable because the developed expressions are a continuous approximation of discrete data.

6. CONCLUSION

In this paper, we developed analytical expressions for storage/retrieval average cycle time of a multi-aisles AS/RS with class based storage (A,B,C). These expressions are determined using the continuous approach which considers the side of the rack as a plane where storage or retrieval can be performed at any point. These approximate expressions were compared, for validation, with the exact expressions obtained from the discrete approach. From this validation, a number of conclusions can be made. We summarize here the essential:

-The Continuous model was approached but is in the simple form analytical expressions and calculable by hand.
-The Discrete model is an exact but very complex model. It requires the times of computer calculation for obtaining the cycle time for a given configuration.

The expressions of storage/retrieval average cycle time developed in this study can be used to:

-Compare the results given by this policy of storage with others types of storage assignment for example random storage.

- Optimize the cycle time and design new systems.

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