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A CLOSED FORM MODEL FOR TRAVEL TIME OF SPLIT-PLATFORM AUTOMATED STORAGE AND RETRIEVAL SYSTEM EQUIPPED WITH TWO INPUT/OUTPUT STATIONS

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ABSTRACT: *In the previous paper of this series [Vasili et al., 2008. A statistical model for expected cycle time of SP-AS/RS: An application of Monte Carlo simulation. Applied Artificial Intelligence, 22(07-08), pp. 824 – 840], in order to reduce the average handling time of the split-platform automated storage and retrieval system (SP-AS/RS), a new configuration for the input/output (I/O) station was presented and a continuous travel time model was also developed for this new configuration. In this paper, the authors present a continuous travel time model for the SP-AS/RS having two I/O stations. In the two I/O stations layouts, the I/O stations are located at floor level on opposite ends of each aisle and each station is capable of handling input and output transactions. For each container, the input and output points can be either the same I/O station or the opposite ones. The results of this new travel time model and previous models are compared and the best model is introduced. The results show that, by the introduction of two I/O station per aisle, the performance of the SP-AS/RS can be enhanced for a range of rack configurations.*

KEYWORDS: *Automated storage and retrieval systems (AS/RS), Split-platform AS/RS, Travel time model, Dwell point policy, Input/output (I/O) Station*

1 INTRODUCTION

In a conventional storage yard for containerized cargos, containers are stacked side by side and one on top of another, and typically up to six containers. The major disadvantage of this stacking scheme is that the reshuffling procedure, which incurs additional unproductive moves, has to be performed in order to retrieve a container from a lower tier of a stack. This will make the container movers wait, and cause delays in feeding the quay cranes. Furthermore, in order to reduce the chances of retrieving containers that are not on the top of the stacks, and also due to the strength constraint of containers, the stacking height is restricted, which implies limited floor-space utilization. In this sense, a storage structure that offers random access to storage locations would be of great meaning to tackle the inherent problems caused by the stacking scheme. This has been the main motivation of the concept of applying AS/RS for storing and handling containers in a storage yard (Chen *et al.*, 2003; Hu *et al.*, 2005). In this regard, the split-platform AS/RS (SP-AS/RS) with a principle of separating horizontal and vertical transport was proposed by Hu et al. (2005), to cater for the weight and size constraints of containers and to achieve better operating flexibility. In this system, transports of the load within individual storage aisles are separated into vertical and horizontal movements and handled by different devices, namely the vertical platform (VP) and the horizontal platform (HP), respectively (Chen *et al.*, 2003) (see figure A in appendix A). The SP-AS/RS has one vertical platform for each rack and N horizontal platforms to serve N tiers of an AS/RS rack. The vertical platform provides the vertical link among different tiers of the AS/RS rack, whereas the horizontal platforms access the storage cells on a given tier. The vertical platform and the horizontal platforms may move independently and concurrently; and the separation of the mechanisms for vertical/horizontal movements also makes the platforms lighter and hence they can operate at a higher speed than the conventional design. This separation also brings the potential benefits of higher handling rate, easier maintenance, and reduced down-time. The input/output (I/O) station is located at the ground level on one end of the rack. The I/O stations are the interface with the external system that carries loads to/from the AS/RS, and the hand-over stations are the locations where a loaded VP delivers the container to an empty HP or vice versa. The VPs transfer loads in between the I/O stations and the handover stations at any tier of the storage racks, whereas the HPs provide the horizontal connection from the hand-over stations to the individual storage cells. Such a system is capable of concurrent operations, that is, the VPs and the HPs can move independently and in parallel (Chen *et al.*, 2003; Hu *et al.*, 2005).

In the AS/RS, dwell point policy is the policy to decide where the S/R machine (storage/retrieval machine or stacker crane) will stay, or dwell, when it becomes idle.

This policy for SP-AS/RS can be defined as the policy to decide where the platforms will stay when they become idle (Hu *et al.*, 2005). Machine idleness occurs when an S/R machine (or a platform in SP-AS/RS) completes a task and there is no other immediate storage or retrieval request to reassign the machine. Machine idleness is not a continuous process: idle periods are broken up by periods of busy activity by the machine. Thus every instance of a machine idleness involves a time during which the machine has no assignment (Chang and Egbelu, 1997). An effective dwell point strategy may reduce the response times of the AS/RS, since the S/R machine typically performs a sequence of operations following an idle period. Hence, if the first operation is advanced, then all operations within the sequence are completed earlier (Van den Berg, 1999).

2 LITERATURE REVIEW

The selection of the dwell point strategy has received considerable attention in the literature. Bozer and White (1984) outlined several static dwell point rules, although they provided no quantitative comparison on the performance of those rules. Egbelu (1991) presented LP-models for finding the dwell point that minimizes the expected travel time, and for finding the dwell point that minimizes the maximum travel time to the first transaction. Egbelu and Wu (1993) investigated the performance of several dwell point strategies, by means of simulation. Hwang and Lim (1993) developed a method that to find the optimal dwell point as a facility location problem with rectilinear distances. The computational complexity of that method is equivalent to sorting a set of numbers. Peters et al. (1996) presented an analytic model for finding the optimal dwell point, based on the expressions found by Bozer and White (1984). Sari et al. (2005) developed closed-form travel-time expressions for the travel time of S/R machines and analyzed them for a variety of storage rack sizes and configurations for flow-rack AS/RS. Hu et al. (2005) presented a continuous travel time model for SP-AS/RS under stay dwell point policy. Vasili et al. (2006) developed closed-form expressions for the travel time of the SP-AS/RS under return to middle (i.e., the HP returns to middle of tier and the VP returns to middle of handover station upon finishing a job), and return to start (i.e., the VP returns to the I/O station and the HP returns to the handover station upon finishing a job) dwell point policies. Vasili et al. (2008) presented a new configuration for the I/O station in SP-AS/RS and a continuous travel time model was also developed for this configuration.

3 TRAVEL TIME ANALYSIS

3.1 Assumptions and Notations

1) The rack is considered as a continuous rectangular pick face;
2) Platforms operate on single command basis;
3) Unit loads are considered;
4) Randomized storage and retrieval operation is used which means that any point within the pick face is equally likely to be selected for storage or retrieval;
5) The rack of equally sized cells is considered. Specifications of the rack and the platforms are known. The platforms accelerations/decelerations and the load transfer times are ignored without affecting the relative performance of the control policies;
6) All the requests are served on first-come-first-served (FCFS) basis.
7) During each operation, there is no prior information of subsequent job, and hence there are no concurrent movements of VP and HPs for different operations.

Note that the transfer times refer to the times needed to transfer a load between the I/O and the VP, between VP and HP, and also between HP and a storage cell. Since randomized storage is used, the expected location for a storage or retrieval request is randomly distributed between 0 and 1 in the horizontal direction, and 0 and b in the vertical direction for the normalized rack. As the value of b may represent the shape of a rack in terms of time, b is referred to as the shape factor. With AS/RS, the symmetry of the vertical and horizontal movements allows to assume that $0 < b \leq 1$. With the SP-AS/RS, b can be an arbitrary positive (Hu *et al.*, 2005). The tiers (i.e. levels) are numbered by integers from 1 onwards; the bays (i.e. columns) are numbered from 0 onwards, all according to their distances from the I/O station (figure 1). There is no storage cell in bay 0 (handover station) because it is used by VP. In order to standardize the pick face, the following notations are used: VL is the height of rack; HL is the length of the rack; vv and hv are the speeds of the VP and the HP, respectively. T_v represents the travel time required for the VP to go to the highest tier from tier 1 and T_h the time required for the HPs to go to the farthest bay from bay 0. Then $T_v = VL/vv$ and $T_h = HL/hv$ and finally $b = T_v/T_h$. With all these symbols the rack is normalized as a rectangular pick face with length of 1 and height of b in term of time.

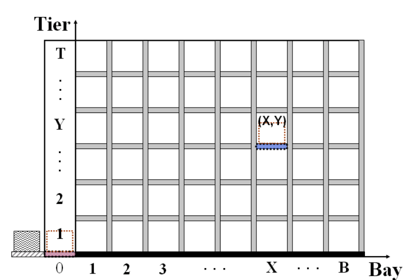

Figure 1: Definitions of open locations in SP-AS/RS

3.2 Model Development

Two I/O stations ("hybrid" arrangement): In the two I/O stations layouts, the I/O stations are located at opposite corners of the rack and each station is capable of handling input and output transactions. For each container, the input and output points can be either the same I/O station or the opposite ones. Therefore, in this layout, the storage travel time from an I/O station to a storage location is dependent on the I/O station from which the storage travel originated, and the expected retrieval travel time from a storage location to an I/O station is dependent on the I/O station at which the retrieval travel terminated. In this case, the calculations of travel time are complex, and it depends on the dwell points of platforms (or the locations of the platforms when they are idle, left I/O station, right I/O station or in-rack). Figure 2 illustrates a schematic view of a SP-AS/RS with two I/O stations.

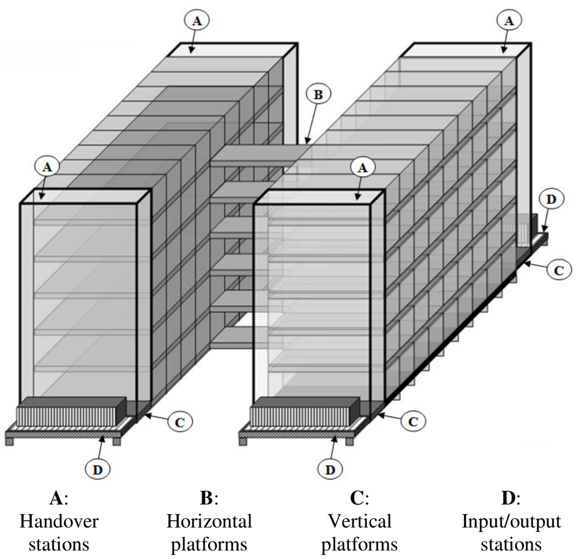

Figure 2: Structure of SP-AS-RS with two I/O stations

Since randomized storage is used, both I/O stations have the same probability of being selected, and hence the dwell point positions of the HPs should be in the same distance from both I/O stations. Therefore return to middle dwell point policy is selected for the HPs (each HP returns to middle of tier upon finishing a job) and for the VPs it is assumed that they return to I/O station upon finishing a job. Let (*x*, *y*) denotes the target point of the current job so,

$$E[T] = Max(y\,, 1/2\,) + max(x + |x - 1/2|,\ \ y),$$

where *T* denotes the cycle time for the platforms to complete one operation. Thus, it is clear that $E[T]$ denotes the mean or expected travel time for one operation. In order to simplify the calculations of the travel time for the SP-AS/RS with two I/O stations, all the possible cases based on input/output point and the cell position of a new operation, are considered separately. Figure 3 and Table 1 shows these four possible cases. Note that in each case the $E[T]$ (expected travel time) is calculated independently. Final results of all cases are added to each other through the Eq. (1) in order to achieve to the final travel time model (since all these cases have the same probability of being selected, with Eq. (1) the average of the travel time of all cases is calculated as the total travel time model).

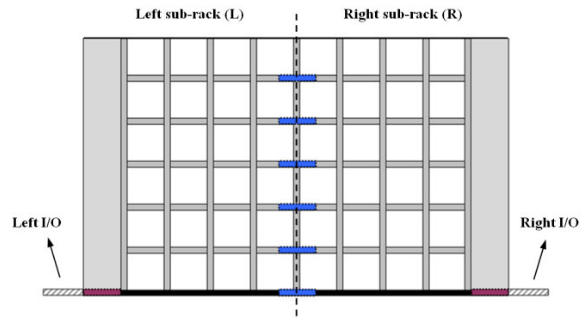

Figure 3: An illustration of sub-racks in the SP-AS/RS with two I/O stations

Case No.	I/O point of new operation	Cell position of new operation	Expected value of travel time
1	Left I/O station	Left sub-rack	$E[T_1]$
2	Right I/O station	Right sub-rack	$E[T_2]$
3	Left I/O station	Right sub-rack	$E[T_3]$
4	Right I/O station	Left sub-rack	$E[T_4]$

Table 1: The possible cases based on input/output point and the cell position of a new operation

$$E[T] = \frac{1}{4}\sum_{i=1}^{4} E[T_i] \tag{1}$$

3.2.1 Calculation of $E[T_1]$

Let (*x*,*y*) denotes the target point of the current job. Figure 4 illustrates the cycle time of a storage operation for the case 1. For a retrieval operation the cycle time is just the reverse of storage operation, but the travel time of retrieval operation is same as storage operation. According to Table 1 and figure 4, for $E[T_1]$, $x \le \frac{1}{2}$ therefore,

$$E[T_1] = E\left[Max\left(y\,,\tfrac{1}{2}\right)\right] + E\left[max\left(x + \tfrac{1}{2} -\ x, y\right)\right], \text{ and}$$

$$E[T_1] = 2 \times E\left[Max\left(y\,,\tfrac{1}{2}\right)\right]. \tag{2}$$

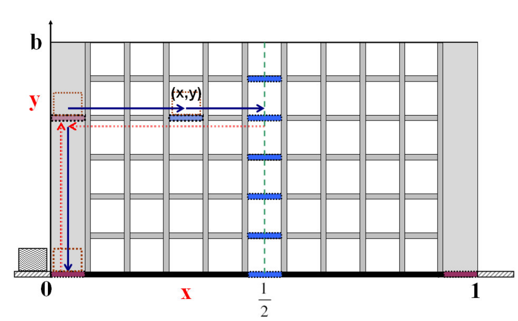

Figure 4: An illustration of storage operation for the case 1

For the case 1, $0 \le \mathrm{y} \le b$, since randomized storage is used so, $E[y] = \frac{0+b}{2} = \frac{b}{2}$. It can be obtained that,

$0 \le y \le b$ so	If $b \le \frac{1}{2}$	then $y \le \frac{1}{2}$, so $Max\left(y, \frac{1}{2}\right) = \frac{1}{2}$
$0 \le y \le b$ so	If $b \ge \frac{1}{2}$	for $0 \le y \le \frac{1}{2}$ $p^* = \frac{\frac{1}{2}-0}{b} = \frac{1}{2b}$ $Max\left(y, \frac{1}{2}\right) = \frac{1}{2}$
		for $\frac{1}{2} \le y \le b$ $p^{**} = \frac{b-\frac{1}{2}}{b} = \frac{2b-1}{2b}$ $Max\left(y, \frac{1}{2}\right) = y$

According to above considerations,

$$E\left[Max\left(y, \tfrac{1}{2}\right)\right] = \frac{1}{2b}E\left[\frac{1}{2}\right] + \frac{2b-1}{2b}E[y],$$
$$= \frac{1}{2b}\left(\frac{1}{2}\right) + \frac{2b-1}{2b}\left(\frac{b}{2}\right) = \frac{2b-1}{4} + \frac{1}{4b}.$$

and

$$E\left[Max\left(y, \tfrac{1}{2}\right)\right] = \begin{cases} E\left[\frac{1}{2}\right], & b \le \frac{1}{2}, \\ \frac{1}{2b}E\left[\frac{1}{2}\right] + \frac{2b-1}{2b}E[y], & b \ge \frac{1}{2}. \end{cases}$$
$$= \begin{cases} \frac{1}{2}, & b \le \frac{1}{2}, \\ \frac{2b-1}{4} + \frac{1}{4b}, & b \ge \frac{1}{2}. \end{cases} \quad (3)$$

Subsisting the above expression into Eq. (2)

$$E[T_1] = 2E\left[Max\left(y, \tfrac{1}{2}\right)\right] =$$
$$\begin{cases} 1, & b \le \frac{1}{2}, \\ \frac{2b-1}{2} + \frac{1}{2b}, & b \ge \frac{1}{2}, \end{cases} = \begin{cases} 1, & b \le \frac{1}{2}, \\ \frac{2b-1}{2} + \frac{1}{2b}, & b \ge \frac{1}{2}. \end{cases} \quad (4)$$

3.2.2 Calculation of $E[T_2]$

Figure 4 shows that the specifications of the sub-racks are exactly identical, therefore the calculations for $E[T_2]$ are same as corresponding calculations for $E[T_1]$:

$$E[T_2] = \begin{cases} 1, & b \le \frac{1}{2}, \\ \frac{2b-1}{2} + \frac{1}{2b}, & b \ge \frac{1}{2}. \end{cases} \quad (5)$$

3.2.3 Calculation of $E[T_3]$

Let (x,y) denotes the target point of the current job. figure 5 illustrates the cycle time of a storage operation for the case 3. For a retrieval operation the cycle time is just the reverse of storage operation, but the travel time of retrieval operation is same as storage operation. According to table 1 and figure 5, for $E[T_3]$, $x \ge \frac{1}{2}$ therefore,

$$E[T_3] = E\left[Max\left(y, \tfrac{1}{2}\right)\right] + E\left[max\left(2x - \tfrac{1}{2},\ y\right)\right]. \quad (6)$$

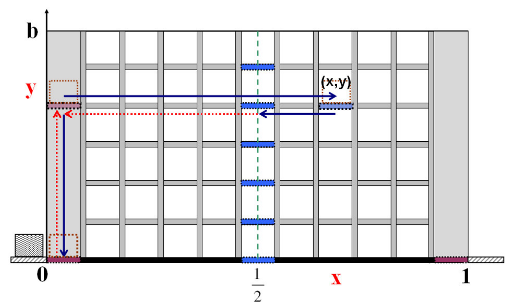

Figure 5: An illustration of storage operation for the case 3

Note that, for $E\left[Max\left(y, \frac{1}{2}\right)\right]$ in Eq. (6), it was calculated in section 3.2.1 through Eq. (3). For $E\left[max\left(2x - \frac{1}{2},\ y\right)\right]$ in Eq. (6), let Z denotes $\max\left(2x - \frac{1}{2},\ y\right)$ then $F_Z(V) = P(Z \le v)$, and because $\left(2x - \frac{1}{2}\right)$ and y are independent from our analysis of the platforms mechanism so,

$$F_Z(V) = P(Z \le v) = P(2x - \tfrac{1}{2} \le v) \times P(y \le v).$$

The limitation of x in this case is $\frac{1}{2} \le x \le 1$ and as randomized storage is used, the value of x is equally likely to occur anywhere in the range between the $\frac{1}{2}$ (smallest value of x) and 1 (the largest value of x) so the distribution of x is uniform distribution. The limitation of y in this case is $0 \le y \le b$ and as randomized storage is used, the value of y is equally likely to occur anywhere in the range between the 0 (smallest value of) and b (the largest value of y) so the distribution of y is uniform distribution. Let (x, y) denotes the target point of the current job so the probability density functions for x and y with uniform distribution are,

$$f_x(v) = \begin{cases} \frac{1}{1-\frac{1}{2}}, & \frac{1}{2} \le v \le 1, \\ 0, & elsewhere. \end{cases} \quad \text{and}$$

$$f_x(v) = \begin{cases} 2, & \frac{1}{2} \le v \le 1, \\ 0, & elsewhere. \end{cases} \quad (7)$$

$$f_y(v) = \begin{cases} \frac{1}{b-0}, & 0 \le v \le b, \\ 0, & elsewhere. \end{cases} \quad \text{and}$$

$$f_y(v) = \begin{cases} \frac{1}{b}, & 0 \le v \le b \\ 0, & elsewhere \end{cases} \quad (8)$$

Now if M denotes $2x-\frac{1}{2}$, then $P\left(2x-\frac{1}{2}\le v\right)=P\left(x\le\frac{v+\frac{1}{2}}{2}\right)$, based on Eq. (7),

$$F_M(v)=\int_{\frac{1}{2}}^{\frac{v+\frac{1}{2}}{2}} 2\,dv = v-\frac{1}{2} \quad \text{therefore,}$$

$$F_M(v)=\begin{cases}0, & v\le\frac{1}{2},\\ v-\frac{1}{2}, & \frac{1}{2}\le v\le\frac{3}{2},\\ 1, & v\ge\frac{3}{2}.\end{cases}$$

and for $P(y\le v)$ considering Eq. (8) then:

$$F_y(v)=\begin{cases}0, & v\le 0,\\ \frac{v}{b}, & 0\le v\le b,\\ 1, & v\ge b.\end{cases}$$

When $b\le\frac{1}{2}$

$$F_z(v)=\begin{cases}0, & v\le\frac{1}{2},\\ v-\frac{1}{2}, & \frac{1}{2}\le v\le\frac{3}{2},\\ 1, & v\ge\frac{3}{2}.\end{cases}$$

$$f_z(v)=\begin{cases}1, & \frac{1}{2}\le v\le\frac{3}{2},\\ 0, & otherwise.\end{cases}$$

When $\frac{1}{2}\le b\le\frac{3}{2}$

$$F_z(v)=\begin{cases}0, & v\le\frac{1}{2},\\ \frac{2v^2-v}{2b}, & \frac{1}{2}\le v\le b,\\ v-\frac{1}{2}, & b\le v\le\frac{3}{2},\\ 1, & v\ge\frac{3}{2}.\end{cases}$$

$$f_z(v)=\begin{cases}\frac{4v-1}{2b}, & \frac{1}{2}\le v\le b,\\ 1, & b\le v\le\frac{3}{2},\\ 0, & otherwise.\end{cases}$$

When $b\ge\frac{3}{2}$

$$F_z(v)=\begin{cases}0, & v\le\frac{1}{2},\\ \frac{2v^2-v}{2b}, & \frac{1}{2}\le v\le\frac{3}{2},\\ \frac{v}{b}, & \frac{3}{2}\le v\le b,\\ 1, & v\ge b.\end{cases}$$

$$f_z(v)=\begin{cases}\frac{4v-1}{2b}, & \frac{1}{2}\le v\le\frac{3}{2}\\ \frac{1}{b}, & \frac{3}{2}\le v\le b\\ 0, & otherwise\end{cases}$$

According to above considerations, the expected value of Z is,

$$E[Z]=\int_v v f_z(v)dv \quad \text{and}$$

$$E[Z]=\begin{cases}1, & b\le\frac{1}{2},\\ \frac{8b^2-3b}{12}+\frac{9-4b^2}{8}-\frac{1}{48b}, & \frac{1}{2}\le b\le\frac{3}{2},\\ \frac{4b^2-9}{8b}+\frac{5}{3b}, & b\ge\frac{3}{2}.\end{cases} \tag{9}$$

Therefore subsisting Eqs. (3) and (9) into Eq. (6),

$$E[T_3]=\begin{cases}\frac{3}{2}, & b\le\frac{1}{2}\\ \frac{8b^2+3b}{12}+\frac{9-4b^2}{8}+\frac{11}{48b}-\frac{1}{4}, & \frac{1}{2}\le b\le\frac{3}{2}\\ \frac{4b^2-9}{8b}+\frac{2b-1}{4}+\frac{23}{12b}, & b\ge\frac{3}{2}\end{cases} \tag{10}$$

3.2.4 *Calculation of* $E[T_4]$

Figure 5 shows that the specifications of the sub-racks are exactly identical, therefore the calculations for $E[T_4]$ are same as corresponding calculations for $E[T_3]$:

$$E[T_4]=\begin{cases}\frac{3}{2}, & b\le\frac{1}{2},\\ \frac{8b^2+3b}{12}+\frac{9-4b^2}{8}+\frac{11}{48b}-\frac{1}{4}, & \frac{1}{2}\le b\le\frac{3}{2},\\ \frac{4b^2-9}{8b}+\frac{2b-1}{4}+\frac{23}{12b}, & b\ge\frac{3}{2}.\end{cases} \tag{11}$$

3.2.5 *Final Travel Time Model*

Subsisting Eqs. (4), (5), (10) and (11) into Eq. (1) yields,

$$E[T]=\frac{1}{4}\sum_{i=1}^{4}E[T_i]=$$

$$\begin{cases}\frac{5}{4}, & b\le\frac{1}{2}\\ \frac{8b^2+15b}{24}+\frac{9-4b^2}{16}+\frac{35}{96b}-\frac{3}{8}, & \frac{1}{2}\le b\le\frac{3}{2}\\ \frac{4b^2-9}{16b}+\frac{6b-3}{8}+\frac{29}{24b}, & b\ge\frac{3}{2}\end{cases} \tag{12}$$

4 TRAVEL TIME AND THROUGHPUT RESULTS

In order to obtain the travel time and throughput results, these specifications are used: (1) the number of total cells in the rack is 600; (2) the height of each cell is 4.5 m, and the width is 4.5 m; (3) the VP travels at 1 m/s and the HPs travel at 2 m/s. Here, the throughput is defined as the reciprocal of the average travel time for the S/R mechanism to handle a job. Parts of the results are shown in Table 2. Suppose that rack dimensions and the platforms speeds are such that VL = 40 m, HL = 144 m, vv = 1.00 m/s, and hv = 2.00 m/s. Using the approach explained earlier, so T_v= VL/vv = 40/1.00 = 40 Sec. and T_h= HL/hv = 144/2.00 = 72 Sec. Therefore b= T_v/T_h = 40/72 = 0.56.

No. of tiers	No. of bays	Cells in rack	Shape factor (b)	Travel time model results (Sec.)	Throughput results (loads/h)
1	288	288	0.01	810	4.44
9	32	288	0.56	87.38	41.20
12	24	288	1.00	68.06	52.89
17	17	288	2.00	74.51	48.32
24	12	288	4.00	102.23	35.21
48	6	288	16.00	211.48	17.02
96	3	288	64.00	429.54	8.38
288	1	288	576.00	1295.16	2.78

Table 2: travel time and throughput results for SP-AS/RS with two I/O station

Hence, the normalized rack is 0.56 time units long in the vertical direction and 1.0 time units long in the horizontal direction. Furthermore, the expected travel time for this rack with two I/O station is obtained by substituting the b=0.56 into Eq. (8), so $E[T] \approx 1.2146$ time units. To obtain the results corresponding to the original rack, the above travel time is denormalized to obtain $\overline{E[T]} = E[T] \times T_h \approx 1.2146 \times 72 \approx 87.38$ Sec.

Figures 6 and 7 illustrate influence of shape factor on expected travel time and throughput performance for various rack configurations using two I/O stations, respectively. From these figures it is observed that using two I/O stations, the optimum travel time and the optimum throughput performance are obtained around $b = 1$.

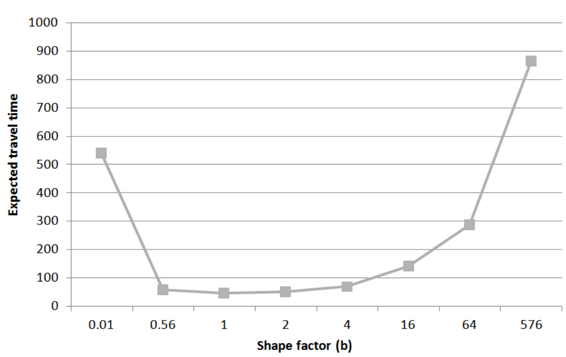

Figure 6: Influence of shape factor on expected travel time of the system

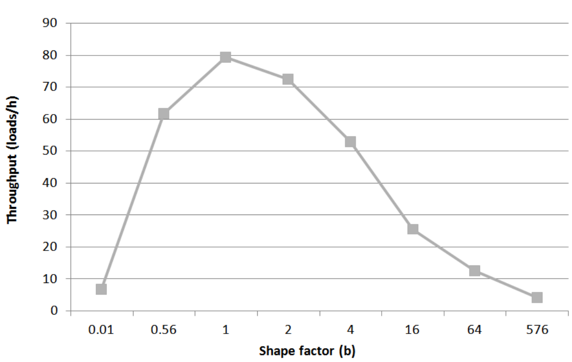

Figure 7: Influence of shape factor on throughput performance of the system

All the existing travel time models for SP-AS/RS are compared through Table 3. It can be observed that for the racks with the shape factors of more than 2 ($b > 2$), stay dwell point policy is more preferable, and for the racks with the shape factors of less than 2 ($b < 2$), new configuration of SP-AS/RS represents better results in compare with other policies. However, when the shape factor is equal to 2, the travel time model under two I/O stations provides the best result with respect to system travel time.

5 CONCLUSION

In this study a continuous travel time model was developed for the SP-AS/RS having two I/O stations. In the two I/O stations layouts, the I/O stations are at the opposite corners of the rack at the end of each aisle, located at floor level and each station is capable of handling input and output transactions. For each container, the input and output points can be either the same I/O station or the opposite I/O stations. Comparing the results of different models (average operation time) shows that, for the racks with the shape factors of more than 2 ($b > 2$), stay dwell point policy is more preferable, and for the racks with the shape factors of less than 2 ($b < 2$), new configuration of SP-AS/RS represents better results. Likewise, when the shape factor is equal to 2, the travel time model under two I/O stations provides the best results with respect to system travel time. However, in the broadest sense, the optimal rack design will largely depends on the characteristics of the demand in different applications.

APPENDIX A

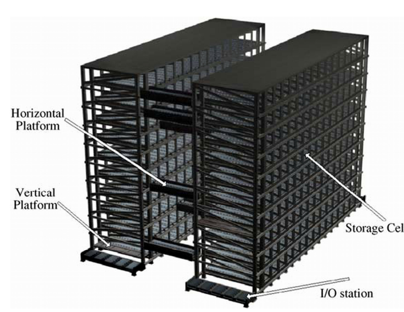

Figure A: Structure and principal constituents of a SP-AS/RS (Hu *et al.*, 2005)

No. of tiers	No. of bays	Shape factor (b)	Policy A	Policy B	Policy C	Policy D	Policy E
1	288	0.01	541.97	810.00	650.25	**326.26**	810
9	32	0.56	80.35	96.69	94.15	**60.05**	87.38
12	24	1.00	74.84	94.50	85.50	**63.00**	68.06
17	17	2.00	80.36	105.59	89.25	79.69	**74.51**
24	12	4.00	**99.43**	136.97	112.50	109.13	102.23
48	6	16.00	**183.73**	268.98	216.56	216.14	211.48
96	3	64.00	**361.73**	539.24	432.07	432.02	429.54
288	1	576.00	**1080.56**	1619.72	1296.00	1296.00	1295.16

Policies A, B, and C represent stay, return to middle and return to start dwell point policies respectively. Policy D represents new configuration and Policy E denotes the travel time for SP-AS/RS with two I/O stations. The Results for policy A are from Hu et al. (Hu et al., 2005); for policies B & C are from Vasili et al. (Vasili et al., 2006) and for policy D are from Vasili et al. (Vasili et al., 2008).

Table 3: travel time and throughput results for SP-AS/RS with two I/O station

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