이중 셔틀 자동창고 시스템에서의 평균 주행시간 모델
Expected Travel Time Model of Double Shuttle Unit Load Warehousing System

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ABSTRACT

This paper considers automated storage and retrieval systems with double shuttle. We develop the travel time model based on the first come first service rule. We evaluate the performance of the double shuttle system working on the four command cycle.

1. Introduction

Much of the previous AS/RS related research papers have dealt with the storage assignment and retrieval problem in conventional unit load system. Grave, Hausman and Schwarz [6] considered three kinds of storage assignment policies (random, full turnover based and class based) in terms of the expected S/R machine travel time. Later they [5] extended the work to include interleaving, that is, the sequencing of storage and retrieve requests, and they [3] simulated the scheduling policy. Bozer and White [7] studied the similar problem where the rack is rectangular in time and computed the expected travel times for random storage assignment under both single and dual command cycles. Relaxing the assumption that the rack is square in time, Hwang, Koh, and Jang [1] determined the optimal rack shape factor for class based storage assignment.

Alternative I/O locations and rack configurations are considered by Bozer and White [7]. Also, corresponding expected travel time models were derived by them.

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Additionally, they examined various dwell point strategies for the S/R machine. All of those papers, they are assumed that the AS/RS is for conventional unit load, that is, the S/R machine handles one unit at a time.

In this study, we consider the AS/RS with double shuttle which be able to treat two unit at a time. In unit load system, dual command cycle is composed of one storage and one retrieval, whereas, in double shuttle system, two storage and two retrievals. Hwang, Kim and Koh [2] considered double shuttle in carousel system which is also a kind of AS/R system. With two shuttles, the S/R machine is able to perform two storage and two retrieval operations in a cycle. A cycle is a sequence of operations, beginning and ending with the S/R machine at the I/O station. We will call this type of operations four command (FC) cycle.

This paper is organized as follows : Section 2 presents the basic assumptions and basis of model development. Some notations and normalizaton concept are addressed in section 3. In section 4, we develop the expected cycle time models for four commands under the FCFS operating rule. respectively. Finally, concluding remarks appear in section 5.

2. Basic assumption

In accordance with Hausman et al. [6], the following assumptions are made:

(1) Each pallet holds only one part number or item type.

(2) All storage locations are the same size, as are the pallets themselves..

(3) The system is served by a S/R machine with double bucket (double shuttle) which carries two units load at a time.

(4) The S/R machine can move simultaneously in horizontal and vertical direction (Chebyshev travel)

(5) The rack length and height, and the movement speed of the S/R machine are known.

(6) The pickup/deposit (P/D) time of the S/R machine is constant for all cycles. For convenience P/D times are ignored. The P/D time is generally independent of the rack shape and the travel velocity of the S/R machine.

(7) The rack is considered to be a continuous rectangular face where the input/output (I/O) point is located at the lower left hand corner.

3. Rack Normalization and Notations

The rack face is assumed to be a continuous rectangle in the time with known dimensions. As the previous result of Bozer and White [7], the rack face will be "normalized" by the horizontal travel time, t_h and vertical travel time t_v by T, where

s_h= horizontal travel speed
s_v= vertical travel speed
L = rack length
H = rack height
t_h= time to reach the end of the rack
t_v= time to reach the top of the rack
T = Max{ t_h, t_v} = normalization constant
b = Min{ t_h, t_v} / T

The factor b has bean referred to as the "shape factor" for the rack. It will be assumed without loss of generality that $t_h \leq t_v$, and thus the rack has dimensions 1 x b as shown in Figure 1. Note that if $t_h = t_v$, then the rack is said to be squared in time.

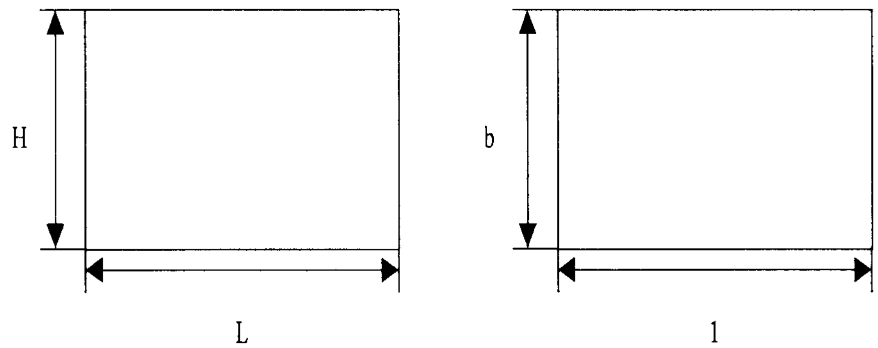

Figure 1. Rack normalization

4. Expected Four Command Cycle Time

In a FC cycle (refer to Figure 2), the shuttles of the S/R machine leave the I/O station with two storage loads and move to a desired empty rack location P_{s_1}, where one of the loads is stored. After storing the load, both the shuttles proceed to the nearest retrieval location, P_{r_1}, where a load is retrieved by the empty shuttle and the second storage load is stored in the empty rack location, P_{s_2}, created by the retrieval. Note that $P_{r_1} = P_{s_2}$, Then the shuttles proceed to another retrieval location, P_{r_2}, and execute a retrieval. Finally, the shuttles move to the I/O point.

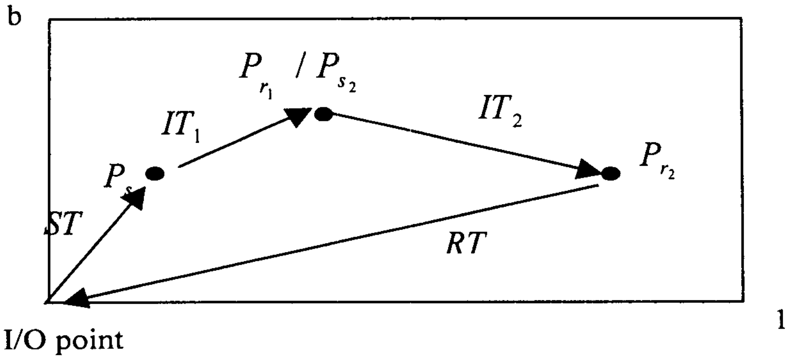

Figure 2. Four command cycle

The four command cycle time FC in the system can be expressed as

$$FC = ST + IT_1 + IT_2 + RT \tag{1}$$

where ST = the shuttle movement time from I/O point to the first storage point,

IT_1 = the first interleave time from P_{s_1} to P_{s_2},

IT_2 = the second interleave time from P_{s_2} to P_{r_2},

and RT= the shuttle movement time from P_{r_2} to the I/O station.

To find the expected FC cycle time, we have to know the expected value for the first interleave time (IT_1). For the other travel time (ST, IT_2, RT), we can utilize the result of Bozer and White [7] for single shuttle system.

Let TB_{ij} be the travel between time from ith order point to jth order point,

$$IT_1 = \text{Min} \{ TB_{P_{r1} P_{r1}},\ TB_{P_{r1} P_{r2}} \} \tag{2}$$

Utilizing cumulative and probability density function of IT_1, we can summarized the Expected travel time model for $_{IT1}$ is

$$E(IT_1) = \frac{1}{[illegible]} + \frac{b^2}{[illegible]} - \frac{31b^2}{[illegible]} + \frac{5b^4}{[illegible]} - \frac{11b^5}{[illegible]} \tag{3}$$

Thus, expected FC cycle time is

$$E(FC) = \frac{23}{[illegible]} + \frac{5b^3}{[illegible]} - \frac{23b^3}{[illegible]} + \frac{5b^4}{[illegible]} - \frac{11b^5}{[illegible]} \tag{4}$$

Now, we describe the comparison with the expected dual command operation for single shuttle system to illustrate the efficiency of double shuttle system. Let e represent time to pick up or deposit a load, the round trip time to perform one transaction (storage plus retrieval) in dual command for the single shuttle system is given as $E(DC) + 4e$. On the other hand, for the double shuttle system, the round trip time is presented as $E(FC) + 6e$, because the pickup or deposit operation by double shuttle at the I/O point can be performed simultaneously at one time.

Therefore, the throughput per unit time, α for single shuttle and β for double shuttle are $\alpha = 2 / [E(DC) + 4e]$ and $\beta = 4 / [E(FC) + 6e]$.

Figure 3 shows that the impact of P/D time on throughput increase for the case of $T = 2$(min), b = 0.8, 1.0. As the P/D time increases, the throughput decreases steeply, and is relatively sensitive.

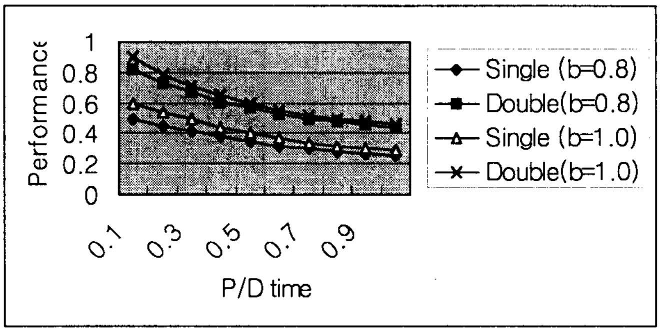

Figure 3. Single shuttle vs. double shuttle

5. Conclusions

In this paper, we dealt with a double shuttle AS/R system which performs four transactions at a round trip. The mathematical model for the four command cycle time of the double shuttle system was derived. Also, we compared the performance of the system in comparison with the traditional single shuttle system. As previously mentioned, we could observe double shuttle system is very efficient in the view of performance.

References

1. Hark Hwang, S.G. Koh & G.S. Jang, A study on class based turnover assignment in automated storage/retrieval system with continuous rectangular rack face in time,*Journal of he Korean Institute of I.E.*, Vol.14, No.1, pp 31-42, 1989.
2. Hark Hwang, C.S. Kim & K.H. Koh, Performance analysis of carousel systems with double shuttle, *Computers & Industrial Engineering*, Vol.36, No.2, pp. 473-485, 1999

3. L.B. Scharz, S.C.Graves & W.H. Hausman, Scheduling policies for Automatic Warehousing Systems : Simulation Results, *AIIE Transactions*, Vol. 10, No.3, pp.60-270, 1995.
4. M.Held and R.M. Karp, he traveling salesman problem and minimum spanning trees, *Operations Research*, Vol.18, No.6, pp. 1138-1162, 1988
5. S.C.Graves, W.H. Hausman & L.B. Scharz, Storage retrieval interleaving in automatic warehousing systems, *Management science,* Vol.23, No.9, pp. 935-945, 1977
6. W.H. Hausman, L.B. Scharz & S.C.Graves, Optimal storage assignment in automatic warehouseing system, *Management science,* Vol.22, No.6, pp. 629-638, 1976
7. Y.A.Bozer & J.A.White, Travel time model for automated storage/retrieval system, *IIE Transactions,* Vol.16, No.4, pp. 329-338, 1984