UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF TRAVEL TIME MODELS FOR SPLIT-PLATFORM AUTOMATED STORAGE AND RETRIEVAL SYSTEM UNDER VARYING DWELL POINT POLICIES

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By

MOHAMMADREZA VASILI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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DEDICATION

Dedicated to my family for their love, support and encouragement.

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Chairman : Tang Sai Hong, PhD

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One important operational aspect of the SP-AS/RS, which contributes to the system response time, is the dwell point policy of the platforms. There are several dwell point policies for SP-AS/RS and an effective dwell point policy may reduce the response times of this system. The travel time analysis for SP-AS/RS has not been adequately investigated in previous research and only one reliable travel time model can be found in literature, which is under stay dwell point policy. But it is not logical to select this travel time model as the base, without any analysis of travel time models under other dwell point policies. In this research, two continuous travel time models are developed for SP-AS/RS under return to middle and return to start dwell point policies.

In the previous design of SP-AS/RS, hand-over stations and input/output (I/O) station are located at the same end of the rack. In this study a new configuration alternative for SP-AS/RS is introduced by shifting the position of hand-over stations

and I/O station to the middle of the rack. Using this configuration, the average handling time for a range of shapes can be greatly reduced. A continuous travel time model is also developed for this new configuration.

To evaluate all continuous models for their accuracy, the models are validated by using the computer simulations. A user interface computer program is developed to computerize the calculation of travel times under varying dwell point policies and find the best policy, for different configurations.

Comparing the results of new models which were developed in this thesis with previous ones, showed that for the shapes of the racks that have shape factors (b) more than 2 ($b > 2$), stay dwell point policy is more preferable. While, for the shapes that have shape factors less than or equal to 2 ($b \leq 2$), a new configuration of SP-AS/RS gives the better results in the case of average operation time. The most preferable shapes for AS/RS are those that their shape factors are less than or equal to 2 ($b \leq 2$). Therefore in many cases the new configuration performs better than previous design under varying dwell point policies, but generally the optimal rack design will largely depends on the characteristics of different applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBINAAN MODEL-MODEL MASA PERGERAKAN UNTUK SISTEM SIMPANAN DAN PEROLEHAN PELANTAR SEKAH AUTOMATIK DALAM PELBAGAI POLISI TITIK TETAP

Oleh

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Satu aspek operasi penting SP-AS/RS yang menyumbang masa tindak balas sistem ialah polisi titik tetap platfom. Wujud beberapa polisi titik tetap "dwell point policies" untuk SP-AS/RS dan satu polisi titik tetap yang efektif boleh menggurangkan masa tindak-balas sistem ini. Analisis mengenai masa pergerakan untuk SP-AS/RS belum dikaji secukupnya oleh kajian terdahulu. Cuma ada satu model masa pergerakan dalam sorotan persuratan iaitu mengenai polisi titik tetap. Memilih model masa pergerakan sebagai asas, tanpa menganalisa model-model pergerakan lain dalam polisi titik tetap adalah sesuatu perbuatan yang tidak munasabah. Dalam kajian ini, dua model masa pergerakan yang berterusan telah dibina untuk SP-AS/RS telah dibangunkan di bawah polisi titik tetap iaitu 'balik ke titik tengah' dan 'balik ke titik mula'.

Rekaan terdahulu SP-AS/RS stesen penyerahan dan stesen input/output (I/O) adalah terletak di penghujung yang sama. Dalam kajian ini, kajian mengenai konfigurasi

baru SP-AS/RS telah diperkenalkan dengan mengalih posisi stesen penyerahan dan stesen input/output (I/O) kepada rak adalah di bahagian tengah. Dengan menggunakan konfigurasi ini, ianya boleh mengurangkan dengan banyaknya masa pengendalian bagi purata bentuk. Masa pergerakan yang berterusan juga dibina dalam konfigurasi baru ini.

Untuk menilai model-model berterusan secara tepat, pengesahan model ini dibuat dengan menggunakan simulasi pengkomputeran. Pengguna program komputer antaramuka dibangunkan untuk mengkomputerkan kiraan masa pergerakan di bawah pelbagai polisi titik tetap dan polisi terbaik dicari bagi konfigurasi yang berlainan.

Perbandingan keputusan model-model berlainan menunjukkan rekabentuk rak yang mempunyai faktor bentuk yang lebih daripada 2 ($b > 2$) kedudukan polisi titik tetap adalah lebih banyak dipilih, sementara faktor bentuk yang kurang daripada atau sama dengan 2 ($b \leq 2$) dalam rekabentuk baru SP-AS/RS memberi keputusan yang terbaik dari segi purata masa operasi. Antara bentuk yang paling diminati untuk AS/RS adalah fakta-fakta bentuk yang kurang atau sama dengan 2 ($b \leq 2$). Kesimpulannya dalam kebanyakan kes, konfigurasi baru boleh mengatasi rekabentuk semasa dalam pelbagai polisi titik tetap, tetapi kebiasaannya rekabentuk rak yang optima banyak bergantung kepada ciri-ciri aplikasi yang terlibat berlainan.

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In the name of Allah, the Most Compassionate, the Most Merciful. All praise is due be to Allah, Lord of the Worlds, The Most Compassionate, the Most Merciful. Sovereign of the Day of Judgement. You alone we worship, and to You alone we turn for help. Guide us to the straight way; The way of those whom You have favoured, Not of those who have incurred Your wrath, Nor of those who have gone astray (Al-Fatiha, the Opening chapter of the Holy Quran).

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I certify that an Examination Committee has met on ……to conduct the final examination of Mohammadreza Vasili on his Master of Science thesis entitled "Travel Time Models Development for Split-Platform Automated Storage and Retrieval System under Varying Dwell Point Policies" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MOHAMMADREZA VASILI

Date: *13TH MARCH 2007*

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LIST OF ABBREVIATIONS / GLOSSARY OF TERMS

ABC curve	To consider the turnover of pallets, the well-known ABC curve is used**,** which can be expressed as G(i)=is, 0<s<1, where G(i) is the cumulative percentage of demand in full pallet loads, i is the percent of inventoried items, and s is the skewness of the ABC curve.
AGV	Automated Guided Vehicle
Aisle	Space between storage compartments (racks) in which the S/R Machine operates.
AS/RS	Automated Storage and Retrieval Systems
b	Shape factor
Bay	One series of vertical storage locations when considered as a set
Carousel	A carousel storage system consists of a series of bins or baskets suspended from an overhead chain conveyor that revolves around a long oval rail system. Carousels can be classified as horizontal and vertical.
Carriage	That part of an S/R Machine by which a load is moved in the vertical direction.
Class-based storage policy	This policy distributes the products, based on their demand rates, among a number of classes and reserves a region within the storage area for each class. Accordingly, an incoming load is stored at an arbitrary open location within its class.
COI	Cube-per-Order Index: The COI of an item is defined as the ratio of the item's total required space to the number of trips required to satisfy its demand per period.
Conveyor(s)	Fixed path handling systems that carry, queue and position loads.
DC	Dual Command
Dedicated storage policy	This policy is in fact extreme case of the class-based storage policy too. Dedicated storage policy considers one class for each product.
Deep Lane Storage	Storage depth which is greater than two loads deep on one or both sides of the aisle.
DNN	Dynamic Nearest Neighbor

Double Deep Storage	Loads that are stored two deep on each side of the aisle.
DPP	Dwell Point Problem
Dwell point policy	The policy to decide where the S/R machine (or platforms in SP-AS/RS) will stay when it becomes idle.
EDD	Earliest Due Date (also known as shortest due time, SDT)
FEU	40-feet equivalent unit container
FCFS	First Come First Served
FI-FO	First In-First Out
FLPrd	facility location problem with rectilinear distances
GRP	Glass fiber-Reinforced Plastic coating
Handover station	The location for movement of VP
HL	Length of the rack
Horizontal Carousels	As a storage device, a horizontal carousel consists of a fixed number of adjacent storage columns or bays that are mechanically linked to either an overhead or floor mounted drive mechanism to form a complete loop. Each column is divided into a fixed number of storage location or bins which in most applications are constructed of a welded wire frame. Loads consisting of containers or totes may be inserted and retrieved either manually or by an automatic inserter/extractor mechanism. However, rotation of the carousel, whereby a specific storage location is brought to the picking location, is almost always controlled automatically.
HP	Horizontal Platform (responsible for horizontal movements)
hv	Speed of the HPs
I/O station	Input/Output station
Mini-Load	A Storage and Retrieval concept whereby materials are accessed by bringing the container to the operator. The term is typically used in small parts applications and/or where the weight of the container does not exceed 750 lbs.
MIP	Mixed Integer Programming

MPGA simulation	Multi-Pass and Genetic Algorithm simulation
NN	Nearest-Neighbor
NCA-SP-AS/RS	New Configuration Alternative for Split Platform AS/RS
P & D Stations	A location at which a load entering or leaving storage is supported in a manner suitable for handling by the S/R Machine. (Prior usage has also called this the Transfer/Station, 1/0, Pickup and Delivery Station, Feed/Discharge Station, etc.).
Platforms	Separated Storage/Retrieval devices in SP-AS/RS.
Rack	One storage compartment consists of tier and bay.
Randomized storage policy	This policy is in fact extreme case of the class-based storage policy. Randomized storage considers a single class of product
Return to middle dwell point policy	The VP returns to the middle of Handover station and the HP returns to the middle of tier upon finishing a job.
Return to start dwell point policy	The VP returns to the I/O station and the HP returns to the handover station upon finishing a job.
SC	Single Command
SDT	Shortest Due Time (also known as earliest due date, EDD)
Shuttle	The load supporting mechanism on the carriage which provides for movement of loads into or out of storage compartments and P & D Stations.
Single Deep Storage	Loads which are stored one deep on each side of the aisle
SL	Shortest-Leg
SP-AS/RS	Split-Platform Automated Storage and Retrieval Systems
SPT	Shortest Processing Time (also known as shortest total-travel, STT)
S/R machine (Stacker crane)	Storage/Retrieval machine in AS/RS
Stay dwell point policy	The platforms (VP and HP) remain where they are after completing a storage/retrieval operation

STT	Shortest Total-Travel (also known as shortest processing time, SPT)
T_C	The transfer time (this refers to the time needed to transfer a load between VP and HP, or between HP and an AS/RS cell)
T_{C0}	The transfer time (this refers to the time needed to transfer a load between the I/O station and the VP)
T(DC)	Dual Command Cycle: The time between actuation of the S/R Machine and completion of a cycle in which one load is stored and another load is retrieved and the S/R Machine is ready to start a new cycle
TEU	20-feet equivalent unit container
T_h	Maximum time for HP to go to the farthest point of each tier
Tier	A set of storage locations having a common elevation
T(QC)	Quadruple command cycles
Transfer time (Pickup and Deposit time)	The time needed to transfer a load between VP and HP, or between HP and a SP-AS/RS cell and also the time needed to transfer a load between the I/O station and the VP.
Travel time	The service time for a transaction, include platforms movement time and transfer times.
T(SC)	Single Command Cycle: The time between actuation of the S/R Machine and completion of a cycle in which one load is stored or retrieved and the S/R Machine is ready to start a new cycle.
T(SxC)	Sextuple command cycles
TT	Total Travel-time
TUL	Transport Unit Load
Turnover-based storage	The storage rack is partitioned into number of zones, which is equal to the number of product types. The zone closest to the P&D station is assigned to store pallets of highest turnover rate. When searching for an empty location, if an empty location cannot be found in its own zone, the next lower turnover zone will be searched. If all the lower turnover zones are full, then the next higher turnover zone is searched.
T_v	Maximum time for VP to go to the farthest point of bay 0

Unit Load	Any load configuration handled as a single item
Vertical Carousels	As a storage device, a vertical carousel provides for closed loop automatically controlled rotation of the basic storage unit, which in this case may be a shelf that can be subdivided into multiple bin locations. However, a shelf or a given vertical position need not be divided in order to handle large items such as a bolt of fabric or a roll of carpet. Because storage is vertical, such systems are popular when conserving floor space. Although automatic insertion and extraction of individual items or loads is possible, it is not as common as it is with horizontal carousel applications.
VL	Height of the rack
VL-AS/RS	Vertical Lift Automated Storage /Retrieval System
VLSM	Vertical lift storage modules
VP	Vertical Platform (responsible for vertical movements)
vv	Speed of the VP
WIP	Work-In-Process

CHAPTER 1

INTRODUCTION

1.1 Preface

This chapter recalls the scientific environment of this thesis. Among the topics it covers are brief reviews of some main subjects used in this research, problem statement, objectives and scope of study.

1.2 Brief reviews of current concepts and interpretations

Material handling is defined simply as moving material. It is the function of moving the right material to the right place, at the right time, in the right amount, in sequence, and in the right position or condition to minimize production costs. Material handling can be broadly defined as all movement of materials in the manufacturing environment. A great variety of material handling equipment is available commercially. One category of material handling equipment is the fixed-area equipment such as automated storage and retrieval systems (AS/RSs) (Meyers and Stephens, 2005).

In the broadest sense, an AS/RS is one that automatically stores incoming material and extracts material from storage without direct handling by a human worker (Eastman, 1987 and Lindkvist, 1985). Groover (2001) has defined AS/RS as "a storage system that performs storage and retrieval operations with speed and

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accuracy under a defined degree of automation". Automated storage and retrieval systems (AS/RSs) are major material handling support systems that have been widely used in automated factories and distribution centers. The basic components of the AS/RS are storage racks, storage/retrieval (S/R) machines, input/output (I/O) stations, and interface conveyors. AS/RSs are operated and controlled by a computer that can collect important information and provide a high degree of inventory visibility, which can then be used by manufacturing, distribution, accounting, sales, etc, (Meller and Mungwatana, 1997).

Stacker cranes used by the conventional AS/RS are inadequate for handling heavy loads such as container cargos which are typically above 20 tons. However, for such applications, to handle extra heavy loads at high speed, a split-platform AS/RS (SP-AS/RS) is proposed by Hu et al. (2005). High lifting capacity enables the SP-AS/RS to deal with all the different types and sizes of containers which pass through the interchange point. Unlike stacker cranes, the S/R mechanism in SP-AS/RS has one vertical platform (VP) and N horizontal platforms (HP) to serve N tiers of an AS/RS rack (Hu et al., 2005).

In AS/RS, dwell point policy is the policy to decide where the S/R machine 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). 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). In this thesis three prevalent