UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF MULTI-OBJECTIVE OPTIMIZATION METHODS FOR INTEGRATED SCHEDULING OF HANDLING EQUIPMENT (AGVS, QCS, SP-AS/RS) IN AUTOMATED CONTAINER TERMINALS

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By

SEYED MAHDI HOMAYOUNI

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

March 2012

DEDICATION

I dedicate this thesis to my parents

for their love, endless support

and encouragement

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF MULTI-OBJECTIVE OPTIMIZATION METHODS FOR INTEGRATED SCHEDULING OF HANDLING EQUIPMENT (AGVS, QCS, SP-AS/RS) IN AUTOMATED CONTAINER TERMINALS

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Increasing demand for containerization and large containerships in service compel container terminals to improve their performance. In automated container terminals (ACTs), containers are unloaded from (loaded to) the vessels, by using quay cranes (QCs). Commonly, containers are stacked in storage yards by using automated stacking cranes (ASCs) before they delivered to final customers, or to the arriving vessels. Moreover, automated guided vehicles (AGVs) are used to connect the QCs to the storage yard. In order to increase land utilization and lower times for the storage and retrieval operations, a new storage system called split-platform automated storage/retrieval system (SP-AS/RS) has been introduced. In this system, containers are stored in racks, and two platforms are used to transfer them horizontally and vertically. Previous researches showed that integrated scheduling of handling equipment helps ACTs to improve their performance. However, there is no integrated scheduling method for QCs, AGVs, and SP-AS/RS in previous researches. In this research, the integrated scheduling is described as a multi-objective problem.

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A mixed integer-programming (MIP) model was developed to optimize the integrated scheduling of handling equipment with the objective function of minimizing total delays in tasks of QCs, in addition to total travel time of AGVs and platforms of the SP-AS/RS. The comparison of results for this method and an ACT in which ASCs are in use indicates that delays in tasks of QCs are reduced by 8.6%, on average. Moreover, the value of the objective function obtained by the proposed integrated scheduling method decreased 58%, on average, compared against non-integrated scheduling method. The integrated scheduling has been proved as a non-deterministic polynomial-time hard (NP-hard) problem, which means there is no systematic approach to obtain the optimal solution especially for relatively large cases, in reasonable computation time. Therefore, two meta-heuristic algorithms, namely genetic algorithm (GA) and simulated annealing (SA) algorithm, were developed to optimize the integrated scheduling of handling equipment. The meta-heuristic algorithms determine sequence of loading/unloading tasks; and a heuristic rule assigns the AGVs to the tasks. Results indicate that "earliest available vehicle" is the best heuristic rule for the integrated scheduling method. Moreover, it is shown that on average, the best objective values obtained by the GA and SA algorithm, are only 6.4% and 3.7% worse than the optimal ones found by the MIP model, respectively; demonstrating that both algorithms are able to achieve near optimal solutions. However, the GA outperforms the SA algorithm in medium and large size test cases. Sensitivity analysis shows that value of the objective function decreases as the number of available AGVs increases. Furthermore, it is revealed that to decrease delays in tasks of the QCs, the AGVs have to travel longer routes.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN KAEDAH PENGOPTIMUMAN MULTI-OBJEKTIF UNTUK PENJADUALAN BERSEPADU PERALATAN PENGENDALIAN (AGVS, QCS, SP-AS/RS) DALAM TERMINAL KONTENA AUTOMATIK

Oleh

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Permintaan yang semakin meningkat untuk pengkotenan dan pengkapalan secara besar-besaran dalam perkhidmatan memaksa terminal kontena untuk meningkatkan kualiti perkhidmatan mereka. Di terminal kontena automatik (ACT) kontena dipunggah dari kapal, dengan menggunakan kren jeti (QCs). Biasanya, kontena disusun dalam penyimpanan dengan menggunakan kren penyusun automatik (ASCs) sebelum mereka dihantar kepada pelanggan akhir, atau kapal yang baru tiba. Selain itu, kenderaan automatik berpandu (AGVs) digunakan untuk menyambung QCs ke kawasan simpanan. Dalam usaha untuk meningkatkan penggunaan tanah dan mengurangkan masa untuk operasi penyimpan dan dapatan, sistem penyimpanan yang baharu yang dipanggil berpecah-platform automatik penyimpanan/dapatan semula sistem (SP-AS/RS) telah diperkenalkan. Dalam sistem ini, kontena disimpan di atas rak, dan dua platform diperlukan untuk memindahkan mereka secara mendatar dan menegak. Kajian sebelum ini menunjukkan bahawa penjadualan bersepadu daripada peralatan pengendalian membantu ACTs dalam meningkatkan prestasi mereka. Walau bagaimanapun, tidak ada kaedah penjadualan bersepadu untuk QCs, AGVs, dan SP-AS/RS dalam kajian sebelum. Dalam tesis ini,

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penjadualan bersepadu digambarkan sebagai suatu masalah pelbagai-objektif. Model integer-pengaturcaraan bercampur (MIP) telah dibangunkan untuk mengoptimumkan penjadualan bersepadu dengan tujuan mengurangkan kelewatan jumlah dalam tugas QCs, jumlah masa perjalanan AGVs dan platform daripada SP-AS/RS. Perbandingan hasil bagi kaedah ini dan ACT dengan menggunakan ASCs menunjukkan bahawa kelewatan tugas berkurang sebanyak 8.6%, secara purata. Selanjutnya, nilai fungsi objektif kaedah penjadualan bersepadu dibandingkan dengan kaedah penjadualan tidak bersepadu, hasil menurun adalah sebanyak 58% secara purata. Penjadualan bersepadu telah dibuktikan sebagai masalah *non-deterministic polynomial-time hard* NP-hard, yang bererti tidak ada prosedur yang sistematik untuk mencari penyelesaian optimum terutamanya bagi kes yang agak besar, dalam masa yang munasabah. Oleh sebab itu, dua meta-heuristik algoritma, iaitu algoritma genetik (GA) dan *simulated annealing* (SA) algoritma, telah dikembangkan untuk pengoptimuman kaedah penjadualan bersepadu. Urutan tugas muatan/memunggah ditentukan oleh algoritma meta-heuristik, dan peraturan heuristik untuk tugas AGVs. Hasil menunjukkan bahawa "kenderaan paling awal yang tersedia" ialah peraturan heuristik yang terbaik untuk kaedah penjadualan bersepadu. Selain itu, secara purata, nilai objektif untuk penyelesaian terbaik diperoleh oleh GA dan algoritma SA, adalah 6.4% dan 3.7% lebih teruk daripada MIP model, masing-masing menunjukan kedua dua algoritma mampu memperolehi penyelesaian optima. Walau bagaimanapun, GA mengatasi prestasi algoritma SA dalam kes ujian saiz sederhana dan besar. Analisis sensitiviti menunjukkan niliai fungsi objektif berkurangan apabila jumlah AGV bertambah. Tambahan pula, analisis ini menunjukkan untuk mengurangkan kelewatan tugas QCs, AGVs memerlukan laluan yang jauh.

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I certify that a Thesis Examination Committee has met on 22nd March 2012 to conduct the final examination of Seyed Mahdi Homayouni on his thesis entitled "development of multi-objective optimization methods for integrated scheduling of handling equipment (QCs, AGVs, SP-AS/RS) in automated container terminals" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998 The committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution

SEYED MAHDI HOMAYOUNI

Date: 22 March 2012

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