UNIVERSITI PUTRA MALAYSIA

DEVELOPEMENT OF CAPABILITY-BASED VIRTUAL CELLULAR MANUFACTURING SYSTEMS IN DUAL-RESOURCE CONSTRAINED SETTINGS OVER SEMI-DISTRIBUTED LAYOUTS

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By

MARYAM HAMEDI

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

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DEDICATION

With gratitude to my dear parents, my beloved spouse, Reza, and my new born son, Rayan

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Virtual Cellular Manufacturing Systems (VCMSs) as a highly flexible manufacturing concept have been designed to improve the performance of classical Cellular Manufacturing Systems (CMSs) and job shop manufacturing environments by creating virtual grouping resources. The underlying concept as one of the main applications of Group Technology (GT), which is based on batch production oriented, is particularly valuable during high demand variety and variability with increases in machines types required by parts for processing.

This research develops a new system named Capability-Based VCMSs (CBVCMSs), which considers the overlapping machine capabilities, worker skills, and part process plans by defining Resource Elements (REs). Formation of CBVCMSs is performed through formulating a new Mixed-Integer Non-Linear Programming (MINLP) mathematical model in a static manner. A Goal Programming (GP) approach simultaneously considers several objectives and constraints while all components of

the system are generated at the same time. Moreover, the formulated model is defined based on the design issues of Dual-Resource Constrained (DRC) settings, i.e., parts processing will be delayed if either workers, machines, or both are not available. Workers must be flexible since in DRC settings the number of machines exceeds the number of workers. In this research, workers are assumed to have different levels of cross-training (multi-level) and proficiency (heterogeneous). The performance of the developed CBVCMSs is improved by utilizing a novel layout namely Semi-Distributed Layouts (SDLs) using Genetic Algorithms (GAs).

Since the cell formation problem in CMSs is NP-hard and this complexity will be increased for the development of CBVCMSs especially for DRC settings, Multi-Objective Tabu-Search (MOTS) is investigated to achieve global or near-to-global optimum solutions for the developed model.

The results obtained from different test-problems are analyzed based on the objective function, traveled distance by parts and material flow, Cell Capacity Utilization (CCU), and System Capacity Utilization (SCU). Analysis of results illustrated the priority of CBVCMSs compared to the equivalent CMSs. Through one to one comparison of the CCUs, 8 out of 12 virtual cells belonging to four CBVCMSs were found to have a CCU in total 63.84 % higher than the equivalent classical cells. Considering the averages or the summations of the CCUs, all test problems (4 out of 4), have values in total 5.39 % greater than the classical CMSs. Moreover, by considering SCU as the comparative criterion, CBVCMSs outperformed the equivalent CMSs in all test-problems by 106.08% improvement in the whole of the system. Since the objective function of the model generated over SDLs is in average

18.42% smaller than the functional layouts, for all systems, SDLs give better arrangements in the formation of CBVCMSs compared with FLs. Moreover, comparison of the minimum material flows revealed that in 9 out of 10 comparisons, the developed systems generated over the SDLs gave in average 31.81% smaller values. In addition, by considering the developed system in DRC settings, in all test problems, the dissimilarity of parts assigned to a cell and load unbalances among cells decreased in average 12.41% and 41.48% respectively compared to the same system without DRC settings.

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

PEMBANGUNAN SISTEM PEMBUATAN SELULAR MAYA BERASASKAN KAPASITI DALAM KEKANGAN DWI-SUMBER TERHADAP TATARAJAH SEMI-AGIHAN

Oleh

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Sistem Pembuatan Selular Maya (VCMSs) merupakan satu konsep pembuatan yang fleksibel telah direka untuk meningkatkan prestasi sistem pembuatan selular klasik (CMSs) dan persekitaran pembuatan lot kerja dengan mewujudkan kumpulan sumber maya yang sementara untuk perancangan pengeluaran dan sistem kawalan. Konsep asasnya ialah bagi salah satu daripada aplikasi utama Kumpulan Teknologi (GT), berdasarkan kepada kumpulan yang berorientasikan pengeluaran, ia sangat berguna semasa permintaan yang tinggi dan kepelbagaian, selaras dengan pertambahan berbagai jenis mesin yang diperlukan untuk pemprosesan. Kelebihan pendekatan ini ialah dapat memperbaiki kecekapan dalam penggunaan mesin, memudahkan kawalan pengeluaran, dan sistem pembuatan yang berkualiti tinggi.

Penyelidikan ini membangunkan satu sistem baru yang dinamakan VCMSs Berasaskan Kapasiti (CBVCMSs), yang menganggap keupayaan mesin berbagai guna, kemahiran pekerja, dan proses perancangan yang menggunakan pendekatan berasaskan kapasiti dengan menentukan elemen sumber (REs). Pembentukan

CBVCMSs dilakukan melalui formula baru yang dikenali sebagai Pengaturcaraan Campuran Integer Bukan Linear (MINLP) iaitu model matematik bersepadu. Pada masa yang sama, pendekatan Pengaturcaraan Gol (GP) dengan beberapa objektif dan semua komponen sistem yang dibentuk pada masa yang sama walaupun terdapat beberapa kekangan. Selain itu, model yang telah digunakan dirumus berdasarkan isu Kekangan Dwi-Sumber (DRC), contohnya: pemprosesan beberapa bahagian ditangguhkan sama ada pekerja, mesin, atau kedua-duanya jika tidak diperolehi. Pekerja perlu fleksibel kerana dalam tetapan DRC bilangan mesin melebihi bilangan pekerja. Dalam kajian ini, pekerja dianggap mempunyai tahap yang berbeza kerana menjalani pelbagai latihan (pelbagai tahap) dan kecekapan (heterogen). Prestasi CBVCMSs yang telah dibentuk bertambah baik dengan menggunakan susun atur novel yang dikenali sebagai Tatarajah Semi-Agihan (SDLs) menggunakan Algoritma Genetik (GA). Untuk membentuk SDL, secara teknikalnya beberapa REs, yang berurutan diantara satu sama lain, ditakrifkan sebagai satu kumpulan. Melalui tugasan kelebihan berat diantara satu kumpulan REs dan diminimumkan secara menjumlahkan perbezaan beratnya, REs ini cuba untuk mengurangkan kos aliran bahan.

Disebabkan terdapat masalah pembentukan sel dalam CMSs NP-keras, ini akan meningkat untuk pembangunan CBVCMSs dalam perancangan model MINLP terutamanya bagi latar DRC, kaedah tepat harus digantikan dengan kaedah metaheuristik untuk mencari penyelesaian optimum yang global. Dalam penyelidikan ini, Pelbagai-Objektif Carian-Tabu (MOTS) dikaji untuk menyelesaikan model matematik multi-objektif yang dicadangkan dan untuk mencapai penyelesaian optimum yang global atau hampir-global dalam masa yang bersesuaian. Bagi

pengesahan model, tiga contoh berangka dalam bentuk dua puluh ujian-pemasalahan yang dianggap perlu dan untuk menjelaskan kesahihan model satu kajian kes sebenar dilakukan.

Keputusan yang diperolehi daripada berlainan ujian-pemasalahan dianalisis berdasarkan fungsi objektif, jarak perjalanan bahagian-kerja dan pengelolaan bahan, Penggunaan kapasiti sel (CCU), dan Penggunaan Sistem Kapasiti (SCU). Analisis keputusan menggambarkan keutamaan-CBVCMSs berbanding dengan CMSs setara. Melalui perbandingan satu dengan satu bagi CCUs, 8 daripada 12 sel maya yang dimiliki oleh empat CBVCMSs telah ditemui mempunyai CCU berjumlah 63.84% lebih tinggi daripada sel klasik yang sepadan. Memandangkan purata jumlah CCUs itu, semua masalah ujian (4 daripada 4), mempunyai nilai 5.31% lebih besar daripada CMSs klasik. Selain itu, dengan mengambil kira SCU sebagai kriteria perbandingan, CBVCMSs mengungguli CMSs setara dalam semua ujian-permasalahan kepada 106.08% bagi keseluruhan sistem. Oleh kerana fungsi objektif model yang dijana melalui SDLs yang purata 18.42% lebih kecil daripada FLs, untuk semua sistem, SDLs memberikan perkiraan yang lebih baik, membentuk CBVCMSs berbanding dengan FLs. Ini bermakna dengan menggunakan model metamatik terhadap pengaturan mesin yang berlainan, ini menjadikan SDLs membentuk CBVCMSs yang lebih dekat kepada matlamatnya. Selain itu, perbandingan yang minimum pengelolaan bahan mendedahkan bahawa 9 daripada 10 perbezaan, pembentukan sistem dijana melalui SDLs memberikan nilai 31.81% lebih kecil. Ini menunjukkan potensi sistem itu untuk mencari jarak perjalanan lebih singkat untuk bahagian-kerja. Di samping itu, dengan mengambilkira sistem yang dibentuk dalam latar DRC, dalam semua ujian-pemasalahan, perbezaan bahagian karja yang ditugaskan kepada

sel dan beban tidak seimbang diantara sel menurun kepada purata 12.41% dan 41.48% masing-masing berbanding dengan sistem yang sama tanpa latar DRC.

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