UNIVERSITI PUTRA MALAYSIA

PROCESS PLANNING OPTIMIZATION
IN RECONFIGURABLE MANUFACTURING SYSTEMS

FARAYI MUSHARAVATI

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PROCESS PLANNING OPTIMIZATION
IN
RECONFIGURABLE MANUFACTURING SYSTEMS

By

FARAYI MUSARAVATI

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia,
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DEDICATION

To

All My Friends

There is a time for all things: a time for shouting, a time for gentle speaking, a time for silence, a time for washing pots and a time for writing journal papers and books. It is hard to make a BEGINNING, and will become harder, but IT MUST BE DONE. So be vigilant and vigorous for that will cover a “multitude of sins”. And do not frown. And remember: “work banishes those three great evils: boredom, vice and poverty”
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of
the requirement for the degree of Doctor of Philosophy

PROCESS PLANNING OPTIMIZATION IN RECONFIGURABLE
MANUFACTURING SYSTEMS

By

FARAYI MUSHARAVATI

May 2008

Chairman:      Associate Professor Napsiah Ismail, PhD
Faculty:   Engineering

Trends and perspectives in dynamic environments point towards a need for optimal
operating levels in reconfigurable manufacturing activities. Central to the goal of
meeting this need is the issue of appropriate techniques for manufacturing process
planning optimization in reconfigurable manufacturing, i.e. (i) what decision making
models and (ii) what computational techniques, provide an optimal manufacturing
process planning solution in a multidimensional decision variables space? Conventional
optimization techniques are not robust, hence; they are not suitable for handling
multidimensional search spaces. On the other hand, process planning optimization for
reconfigurable manufacturing is not amenable to classical modeling approaches due to
the presence of complex system dynamics. Therefore, this study explores how to model
reconfigurable manufacturing activities in an optimization perspective and how to
develop and select appropriate non-conventional optimization techniques for
reconfigurable process planning.
In this study, a new approach to modeling Manufacturing Process Planning Optimization (MPPO) was developed by extending the concept of manufacturing optimization through a decoupled optimization method. The uniqueness of this approach lies in embedding an integrated scheduling function into a partially integrated process planning function in order to exploit the strategic potentials of flexibility and reconfigurability in manufacturing systems. Alternative MPPO models were constructed and variances associated with their utilization analyzed. Five (5) Alternative Algorithm Design Techniques (AADTs) were developed and investigated for suitability in providing process planning solutions suitable for reconfigurable manufacturing. The five (5) AADTs include; a variant of the simulated annealing algorithm that implements heuristic knowledge at critical decision points, two (2) cooperative search schemes based on a “loose hybridization” of the Boltzmann Machine algorithm with (i) simulated annealing, and (ii) genetic algorithm search techniques, and two (2) modified genetic algorithms.

The comparative performances of the developed AADTs when tasked to solve an instance of a MPPO problem were analyzed and evaluated. In particular, the relative performances of the novel variant of simulated annealing in comparison to: (a) (i) a simulated annealing search, and (ii) a genetic search in the Boltzmann Machine Architecture, and (b) (i) a modified genetic algorithm and (ii) a genetic algorithm with a customized threshold operator that implements an innovative extension of the diversity control mechanism to gene and genome levels; were pursued in this thesis.
Results show that all five (5) AADTs are capable of stable and asymptotic convergence to near optimal solutions in real time. Analysis indicates that the performances of the implemented variant of simulated annealing are comparable to those of other optimization techniques developed in this thesis. However, a computational study shows that, in comparison to the simulated annealing technique, significant improvements in optimization control performance and quality of computed solutions can be realized through implementing intelligent techniques. As evidenced by the relative performances of the implemented cooperative schemes, a genetic search is better than a simulated annealing search in the Boltzmann Machine Architecture. In addition, little performance gain can be realized through parallelism in the Boltzmann Machine Architecture. On the other hand, the superior performance of the genetic algorithm that implements an extended diversity control mechanism demonstrates that more competent genetic algorithms can be designed through customized operators.

Therefore, this study has revealed that extending manufacturing optimization concepts through a decoupled optimization method is an effective modeling approach that is capable of handling complex decision scenarios in reconfigurable manufacturing activities. The approach provides a powerful decision framework for process planning optimization activities of a multidimensional nature. Such an approach can be implemented more efficiently through intelligent techniques. Hence; intelligent techniques can be utilized in manufacturing process planning optimization strategies that aim to improve operating levels in reconfigurable manufacturing with the resultant benefits of improved performance levels.
Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGOPTIMUMAN PERANCANGAN PROSES DALAM SISTEM PEMBUATAN YANG DAPAT DIBENTUK KEMBALI

Oleh

FARAYI MUSHARAVATI

May 2008

Pengerusi: Associate Professor Napsiah Ismail, PhD
Fakulti: Kejuruteraan

Cenderung dan perspektif dalam persekitaran dinamik pada masa kini menghala kepada keperluan untuk mengoptimuman tahap proses aktiviti pembuatan yang dapat dibentuk kembali. Tujuan utama untuk memenuhi keperluan ini adalah merupakan teknik yang sesuai untuk pengoptimuman perancangan proses pembuatan, contohnya; (i) apa model pembuatan keputusan yang mana dan (ii) apa computational teknik, memberikan perencanaan proses pembuatan yang optimal pemecahan di tempat variabel keputusan multidimensi? Sambil pengalaman didapati teknik pengoptimuman lazim adalah tidak tepat dan, oleh karena itu, tidak cocok untuk penanganan tepat pencarian multidimensi, perencanaan proses optimization tidak setuju sampai pendekatan memperagakan yang klasik karena tenaga gerak sistem kompleks di pembuatan yang dapat dibentuk kembali. Oleh karena itu, kajian ini meneroka bagaimana untuk memodel semula aktiviti pembuatan yang dapat dibentuk kembali dalam perspektif pengoptimuman dan bagaimana untuk membina dan memilih teknik teknik cerdik untuk proses perencanaan yang dapat dibentuk kembali.
Didalam tesis ini, satu pendekatan baru untuk modeling pengoptimuman perancangan proses pembuatan (MPPO) telah direka dengan menambahkan konsep pengoptimuman pembuatan lewat memisahkan optimization metode. Keunikan pendekatan ini terdapat pada mematri fungsi menjadwalkan yang diintegrasikan ke dalam perencanaan proses yang diintegrasikan sebahagian fungsi untuk mengeksploitasi potensi strategis fleksibel dan reconfigurability dalam memproduksi sistem. Pelbagai model MPPO telah dibina dan variasi berkaitan dengan penggunaan dianalisa. Lima (5) pilihan algoritma teknik rekabentuk (AADTs) mengandungi; algoritma Simulated Annealing yang berbeza itu melaksanakan pengetahuan heuristik di ujung keputusan kritis, dua (2) rancangan siasat pencarian koperatif berdasarkan kepada longgar hybridization yang Boltzmann Machine algoritma dengan teknik pencarian algoritma simulated annealing dan genetik dan dua (2) algoritma genetik yang diubahsuai, telah dibangunkan dan diselidik untuk kesesuaian didalam memberikan perencanaan proses pemecahan.

Pertunjukan perbandingan untuk AADTs telah berkembang bila menugaskan untuk memecahkan kejadian masalah MPPO ialah menganalisa dan menilai. Di khusus, pertunjukan relatif variasi baru membuat Simulated Annealing menguatkan, di perbandingan ke: (a) (i) pencarian genetik dan (ii) pencarian simulated annealing, di Boltzmann Machine arsitektur, dan (b) (i) algoritma genetik yang terubah dan (ii) algoritma genetik yang terubah dengan operator yang dibuat menurut pesanan itu melaksanakan perpanjangan inovatif mekanisme kontrol keanekaragaman sampai tingkat gen dan genom; dikejar di tesis ini.

Kajian ini sudah mengungkapkan pembuatan memperpanjang itu optimization konsep lewat memisahkan optimization metode adalah pendekatan memperagakan yang efektif yang cakap mengurus aktivitas pembuatan yang dapat dibentuk kembali yang kompleks. Pendekatan seperti itu menyediakan kerangka keputusan sangat kuat untuk pebuatan perencanaan proses aktiviti sifat multidimensi. Oleh karena itu, teknik cerdas bisa digunakan dalam memproduksi perencanaan proses optimization strategi tujuan itu untuk memperbaiki menjalankan tingkat di pembuatan dapat dibentuk kembali dengan keuntungan diakibatkan tingkat pertunjukan yang diperbaiki.

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I certify that an Examination Committee met on the 23 May 2008 to conduct the final examination of Farayi Musharavati on his Doctor of Philosophy thesis entitled “Process Planning Optimization in Reconfigurable Manufacturing Systems” in accordance with the Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

Members of the Examination Committee were as follows:

Megat Mohamad Hamdan Megat Ahmad, Ph.D.
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Chairman)

Yusof Ismail, Ir. Md, Ph.D.
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Examiner)

Tang Sai Hong, Ph.D.
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Examiner)

Waguih ElMaraghy, Ph.D.
Professor
Faculty of Engineering
University of Windsor, Canada
(External examiner)

HASANAH MOHD GHAZALI, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 22 July 2008
This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Napsiah BT Ismail, PhD**  
Associate Professor  
Faculty of Engineering  
University Putra Malaysia  
(Chairman)

**Abdel Magid Salem Hamouda, PhD**  
Professor  
Faculty of Engineering  
Qatar University, Doha Qatar  
(Member)

**Abdul Rahman B Ramli, PhD**  
Associate Professor  
Faculty of Engineering  
University Putra Malaysia  
(Member)

___________________________

**AINI IDERIS, PhD**  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 14 August 2008
DECLARATION

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

Farayi Musharavati

Date: 10 June 2008
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# LIST OF ABBREVIATIONS

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<td>AADT</td>
<td>Alternative Algorithm Design Technique</td>
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<td>AADTs</td>
<td>Alternative Algorithm Design Techniques</td>
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<tr>
<td>AHP</td>
<td>Analytical Hierarchical Process</td>
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<tr>
<td>BM</td>
<td>Boltzmann Machine</td>
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<tr>
<td>BMGAS</td>
<td>Boltzmann Machine with Simulated Annealing Search</td>
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<tr>
<td>BMSAS</td>
<td>Boltzmann Machine with Genetic Algorithm Search</td>
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<tr>
<td>CCSs</td>
<td>Configurable Control Systems</td>
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<tr>
<td>CLPP</td>
<td>Closed Loop Process Planning</td>
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<td>CV</td>
<td>Coefficient of Variation</td>
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<td>DML</td>
<td>Dedicated Manufacturing Line</td>
</tr>
<tr>
<td>DMLs</td>
<td>Dedicated Manufacturing Lines</td>
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<tr>
<td>DPP</td>
<td>Distributed Process Planning</td>
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<td>FMS</td>
<td>Flexible Manufacturing System</td>
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<td>FMSs</td>
<td>Flexible Manufacturing Systems</td>
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<td>GA</td>
<td>Genetic Algorithm</td>
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<td>Genetic Algorithms</td>
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<td>GATO</td>
<td>Genetic Algorithm with a Threshold Operator</td>
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<td>GAWTO</td>
<td>Genetic Algorithm Without a Threshold Operator</td>
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<tr>
<td>GT</td>
<td>Group Technology</td>
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<tr>
<td>HC</td>
<td>Handling Costs</td>
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<tr>
<td>HCI</td>
<td>Handling Costs Index</td>
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<td>IAHP</td>
<td>Interval Analytical Hierarchical Process</td>
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<tr>
<td>MAE</td>
<td>Modular Actuator Element</td>
</tr>
<tr>
<td>MAEs</td>
<td>Modular Actuator Elements</td>
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<tr>
<td>MCDA</td>
<td>Multi-Criteria Decision Analysis</td>
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<tr>
<td>MGA</td>
<td>Modified Genetic Algorithm</td>
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<tr>
<td>MO</td>
<td>Manufacturing Optimization</td>
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<td>MPP</td>
<td>Manufacturing Process Planning</td>
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<tr>
<td>MPPO</td>
<td>Manufacturing Process Planning Optimization</td>
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<tr>
<td>MPPs</td>
<td>Manufacturing Process plans</td>
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<tr>
<td>MRP</td>
<td>Materials Requirements Planning</td>
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<tr>
<td>MTJs</td>
<td>Modular Tooling and Jigs</td>
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<tr>
<td>NLMPP</td>
<td>Non-Linear Manufacturing Process Planning</td>
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<tr>
<td>NLMPPs</td>
<td>Non-Linear Manufacturing Process Plans</td>
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<tr>
<td>NP, np</td>
<td>Number of Parts</td>
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<td>NPF, npf</td>
<td>Number of Part Families</td>
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<td>OMPI</td>
<td>Overall Manufacturing Performance Index</td>
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<td>OMPIs</td>
<td>Overall Manufacturing Performance Indices</td>
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<td>OPS</td>
<td>Operating Scenario</td>
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<td>OPSs</td>
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OPT  Optimized Production Technology  
PA   Part Array  
PCA  Production Cost Array  
PCC  Process Change Costs  
PCCI Process Change Costs Index  
PDS  Production Scenario  
PDSs Production Scenarios  
PM   Process Module  
PMC  Process Module Change  
PMCI Process Module Change Index  
PMP  Processing Machine Primitive  
PMPs Processing Machine Primitives  
PMRVs Processing Module Required Vectors  
PMSC Process Module Similarity Coefficient  
PMs  Processing Modules  
PS   Processing Stage  
PSC  Part Similarity Coefficient  
PST  Processing Types  
PVA  Production Volume Array  
QAP  Quadratic Assignment Problem  
RCC  Reconfiguration Change Costs  
RCCI Reconfiguration Change Costs Index  
RMS  Reconfigurable Manufacturing System  
RMSs Reconfigurable Manufacturing Systems  
RPP  Reconfigurable Process Planning  
RPPs Reconfigurable Process Plans  
SA   Simulated Annealing  
SCC  Set-up Change Costs  
SCCI Set-up Change Cost Index  
SGA  Simple Genetic Algorithm  
SM   Synchronous Manufacturing  
TAD  Tool Approach Distance  
TC   Tool Costs  
TCC  Tool Change Costs  
TCCI Tool Change Cost Index  
TCI  Tool Cost Index  
TSP  Traveling Salesman problem  
VCMS Virtual Cellular Manufacturing Systems  
VISM Visual Interactive Simulation Modeling  
WS   Work Station  
XS   Change in Production Scenario  
XSs Change in Production Scenarios