BOTTLENECK ADJACENT MATCHING HEURISTICS FOR SCHEDULING A RE-ENTRANT FLOW SHOP WITH DOMINANT MACHINE PROBLEM

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In the name of

ALLAH,

Most Gracious,

Most Merciful.

To my beloved parents Sh Ahmad bin Omar Bareduan and Maznah binti Ali Al-Qasam.

Also my loving wife Sharifah Hamidah binti Syed Hassan Al-Jahsyi.

And cheering children Nazhif, Haniff, Nadhirah,

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ABSTRACT

The re-entrant flow shop environment has become prominent in the manufacturing industries and has recently attracted researchers attention. Typical examples of re-entrant flow shops are the printed circuit board manufacturing and furniture painting processes where components or processed parts enter some specific machines more than once. Similar with other manufacturing environment, identifying appropriate scheduling methodologies to ensure high output rate is very much desirable. The problem explored and investigated in this research is a special type of scheduling problem found in a re-entrant flow shop where two of its processes have high tendency of exhibiting bottleneck characteristics. The scheduling problem resembles a four machine permutation re-entrant flow shop with the routing of M1,M2,M3,M4,M3,M4 where M1 and M4 have high tendency of being the dominant machines. The main objective of this research is to take advantage of the bottleneck characteristics at the re-entrant flow shop and use it to develop heuristics that can be used to solve its scheduling problems. There are four major concentrations in this research. First, basic mathematical properties or conditions that explain the behaviour of the bottleneck processes were developed to give an insight and clearer understanding of the re-entrant flow shop with dominant machines. Second, four new and effective scheduling procedures which were called BAM1 (Bottleneck Adjacent Matching 1), BAM2, BAM3 and BAM4 heuristics were developed. Third, bottleneck approach was utilised in the study and the analysis using Visual Basic macro programming indicated that this method produced good results. Fourth, the Bottleneck Scheduling Performance (BSP) indexes introduced in the BAM heuristics procedure could be used to ascertain that some specific generated job arrangements are the optimum schedule. As a general conclusion, this research has achieved the objectives to develop bottleneck-based makespan algorithms and heuristics applicable for re-entrant flow shop environment. The experimental results demonstrated that the BAM heuristics generated good performances within specific $P1$ (first process) bottleneck dominance level and when the number of jobs increases. Within the medium to large-sized problems, BAM2 is the best at weak $P1$ dominance level whereas BAM4 is the best at strong $P1$ dominance level.

ABSTRAK

Aliran masuk semula merupakan persekitaran yang biasa ditemui di industri pengeluaran dan ianya telah menarik perhatian ramai penyelidik. Contoh tipikal bagi persekitaran ini ialah proses pembuatan papan litar tercetak dan pengecatan perabut di mana komponen produk melalui mesin tertentu lebih dari sekali. Seperti persekitaran pembuatan yang lain, mengenalpasti kaedah penjadualan yang dapat memaksimumkan pengeluaran sangat diperlukan. Masalah yang diterokai dan diselidiki dalam kajian ini merupakan masalah penjadualan yang khusus bagi sebuah aliran masuk semula di mana dua daripada prosesnya berpotensi tinggi memiliki ciri-ciri kejejalan. Masalah penjadualan ini digambarkan sebagai satu aliran masuk semula yang dilengkapi dengan empat mesin. Perjalanan prosesnya pula melalui M1,M2,M3,M4,M3,M4 di mana M1 dan M4 memiliki ciri-ciri kejejalan. Objektif kajian ini adalah untuk menggunakan ciri-ciri kejejalan tersebut bagi membangunkan beberapa heuristik yang boleh digunakan untuk menyelesaikan masalah penjadualan aliran masuk semula. Terdapat empat penekanan utama dalam kajian ini. Pertama, ciri-ciri matematik asas untuk menerangkan sifat-sifat kejejalan proses telah dibangunkan bagi memperolehi kefahaman yang mendalam tentang aliran masuk semula ini. Kedua, empat heuristik baru yang dinamakan BAM1 (*Bottleneck Adjacent Matching 1*), BAM2, BAM3 dan BAM4 telah dibangunkan. Ketiga, pendekatan menggunakan ciri-ciri kejejalan telah digunakan dalam kajian ini dan keputusan analisis menggunakan pengaturcaraan makro Visual Basic menunjukkan kaedah ini sangat berkesan. Keempat, indeks prestasi penjadualan kejejalan (*Bottleneck Scheduling Performance (BSP) indexes*) yang diperkenalkan dalam heuristik BAM boleh digunakan untuk mengesahkan bahawa suatu susunan jadual yang dihasilkan merupakan penyelesaian yang optimum. Sebagai kesimpulan umum, kajian ini telah berjaya mencapai objektif untuk membangunkan algoritma tempoh siap keseluruhan kerja berasaskan konsep kekejalan beserta heuristik yang sesuai digunakan untuk aliran masuk semula. Keputusan eksperimen menunjukkan heuristik BAM menghasilkan prestasi yang baik pada paras kejejalan $P1$ (proses pertama) tertentu dan apabila bilangan kerja meningkat. Pada paras kejejalan $P1$ rendah, BAM2 merupakan heuristik yang terbaik manakala pada paras kejejalan $P1$ tinggi, BAM4 menghasilkan keputusan yang terbaik.

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LIST OF ABREVIATIONS

APA	-	Average performance advantage
API	-	Average percentage improvement
BAM	-	Bottleneck Adjacent Matching
BAM1	-	Bottleneck Adjacent Matching 1
BAM2	-	Bottleneck Adjacent Matching 2
BAM3	-	Bottleneck Adjacent Matching 3
BAM4	-	Bottleneck Adjacent Matching 4
BCF	-	Bottleneck correction factor
BMI	-	Bottleneck minimal idleness heuristic developed by Kalir and Sarin
BSP1	-	Bottleneck scheduling performance 1
BSP2	-	Bottleneck scheduling performance 2
BSP3	-	Bottleneck scheduling performance 3
BSP4	-	Bottleneck scheduling performance 4
CAD	-	Computer aided design
CDS	-	Heuristic developed by Campbell, Dudek and Smith
C_j	-	Completion time for each job
C_{max}	-	Makespan
CMC	-	Cyber manufacturing centre
CNC	-	Computer numerical control
ddm	-	Decreasing dominating machines
DL	-	Dominance level
DM	-	Decomposition method
$F_2//C_{max}$	-	2-machine flow shop, makespan objective

$F_3//C_{max}$	-	3-machine flow shop, makespan objective
FCFS	-	First-come-first-served
$F_m/prmu/C_{max}$	-	*m*-machine flow shop, permutation rule, makespan objective
GA	-	Genetic algorithm
idm	-	Increasing dominating machines
INA	-	Integrated Net Analyser software
k	-	The recurring loops
LB	-	Lower bound
LPT	-	Longest processing time first
m	-	Number of machines or stages
Max	-	Maximum
Min	-	Minimum
n	-	Number of jobs
NEH	-	Heuristic developed by Nawaz, Enscore and Ham
nmit	-	No machine idle time
NP-hard	-	Non-polynomial time algorithm
nwip	-	No-wait in process
$P(i,j)$	-	Processing time of the j^{th} job at i^{th} process
P1BCF	-	Process 1 bottleneck correction factor
PA	-	Performance advantage
PCB	-	Printed circuit board
PI	-	Percentage improvement
PN	-	Petri net
PO	-	Heuristic developed by Pour
RA	-	Random Access heuristic developed by Dannenbring
R_k	-	Non-scheduled jobs
SA	-	Simulated annealing
S_k	-	Partially arranged scheduled jobs
SME	-	Small and medium enterprise
SPT	-	Shortest processing time first
TS	-	Tabu search

TSP	-	Travelling salesman problem
UTHM	-	Universiti Tun Hussein Onn Malaysia
VP	-	Virtual processing time

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CHAPTER 1

INTRODUCTION

This chapter provides introduction and overview to the field of study which include sequencing and scheduling, cyber manufacturing system, re-entrant flow shop, problem description, research objectives, scope of the study, and significance of research.

1.1 Sequencing and Scheduling

Sequencing and scheduling play crucial roles in production planning and control. In the current competitive environment, effective scheduling has become a necessity for survival in the marketplace. Companies must ensure the meeting of delivery dateline committed to customers, as failure to do so may result in a significant loss of goodwill and vital businesses. At the same time, they also have to schedule the resources availability in the most effective manner. In production operations that involve many processes and resources, finding the optimal schedule involves complex and tedious steps. Very often, the schedules are normally obtained either by using simple heuristics (solution guidelines or rule of thumb that find feasible but not necessarily the optimum results) or through time consuming simulations.

Scheduling began to be considered seriously in manufacturing with the work of Henry Gantt during World War I (Pinedo, 2002). By using graphical techniques, he made a significant contribution to the field of scheduling which was considered as one of the oldest techniques available for operations scheduling (Turner *et al.*, 1993). Later, during the World War II the field of operations research established its advancement. It involves intensive mathematical approach to develop scientific model of operating system, incorporating measurement of factors such as chance and risk in order to predict and compare the outcomes of alternative decisions, strategies, or control. In 1954, S. M. Johnson introduced the algorithm for optimal scheduling of a two-stage flow shop environment which is famously known as Johnson's rule (Pinedo, 2002). This work was followed and expanded by other researchers in solving scheduling problems from various fields and complexity.

Beginning of 1980's, large scale manufacturing industries such as the petrochemical, steel, paper, and glass industries have ventured into formal scheduling techniques. In these industries, the principle production machineries and ancillary equipments are very costly, so maximising the utilisations are very much desired in order to have the most economical and efficient operations. Developing schedules that maximise throughput, in other words, minimise the schedule makespan (completion time of the last job), is consistent with the goal of reducing manufacturing cost (Lee, 2000).

Scheduling provides the anticipated start times of each job on each resource (Hopp and Spearman, 2008). In typical manufacturing industries, the resources are normally the machines and the jobs or tasks are the operations in the production processes (Pinedo, 2002). In general, scheduling is a decision making process with the goal of one or more objectives to ensure profitable operations. This research was devoted to the study of one particular manufacturing scheduling environment. The environment under study is the re-entrant flow shops with dominant machine characteristics. A dominant or bottleneck is an operation that has the lowest capacity of any operation in the process and thus limits a system's output (Krajewski and Ritzman, 2005). In particular, the manufacturing environment in this study is a part of the Cyber Manufacturing System available at Universiti Tun Hussein Malaysia (UTHM). Here, top performance and accurate scheduling is very critical in order to meet the ever demanding customer requirements.

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