AN ANT COLONY OPTIMIZATION-BASED ALGORITHM FOR MINIMIZING THE MAKESPAN OF A JOB SHOP PROBLEM

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To

My Caring family,

My Supportive abah (Abdul Mahad @ Abdul Hamid bin Abdullah),

My lovely emak (Zainon bt Babjee),

My Dearest (Muhamad Mohzan b Hj. Jaafar)

Lecturers and friends.

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ABSTRACT

Combinatorial optimization is a branch of optimization in applied mathematics and computer science, related to operations research, algorithm theory and computational complexity theory that sit at the intersection of several fields, including artificial intelligence, mathematics and software engineering. The quest for a solution to NP-hard problem has brought many researchers into developing approximation method, an algorithm which attempts to find solutions to hard optimization problems but gives no guarantee that the solution is the best possible solution. In this research Ant Colony Optimization (ACO) heuristics algorithm is proposed to solve Job Shop Scheduling Problem (JSP). An appropriate ACO algorithm based on the job shop problem is developed and implemented on a case study of JSP with the aims of improving the performance of the algorithm in term of computational effort and time. It is about minimizing the total completion time, such as the makespan of a selected *n*-jobs and *m*-machines problem. Results from the case study have shown that the proposed ACO algorithm has a competitive advantage over the best given solution.

ABSTRAK

Pengoptimuman berkombinatorik adalah salah satu cabang pengoptimuman di dalam aplikasi matematik dan sains pengkomputeran, ianya berkaitan dengan kajian operasi, teori algoritma dan teori pengkomputeran kompleks yang terletak pada penggabungan beberapa bidang; termasuklah pengaturcaraan pintar, matematik dan perisian kejuruteraan. Penekaan ini ialah satu penyelidikan kepada masalah NP-rumit dan telah membawa ramai penyelidik kepada pembentukan kaedah penghampiran iaitu suatu algoritma yang mana direka untuk mencari penyelesaian kepada jawapan masalah optima rumit, akan tetapi ianya tidak memberi jaminan bahawa satu penyelesaian itu adalah jawapan yang paling tepat. Dalam kajian pengoptimuman koloni semut ini, kaedah heuristik telah dicadangkan untuk menyelesaikan masalah aliran kerja. Satu Algoritma Koloni Semut berdasarkan masalah perkilangan untuk masalah aliran kerja, dengan tujuan memperbaiki satu prestasi algoritma dalam skop kesungguhan pengkomputeran dan masa. Ini adalah untuk meminimumkan jumlah masa penyudahan, iaitu jangka buatan untuk masalah n kerja dan m mesin yang terpilih. Keputusan daripada masalah sebenar ada menunjukkan tentang algoritma koloni semut adalah di antara saingan sihat yang memberikan jawapan yang paling baik.

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LIST OF ABBREVIATIONS

ACO	–	Ant Colony Optimization
JSP	–	Job Shop Problem
Np-hard	–	Non-deterministic Polynomial Time Hard
TSP	–	Traveling Salesman Problem
	–	

LIST OF SYMBOLS

C_{max}	–	Makespan / total completion time
m	–	Total of machine
n	–	Total of job
i	–	node i
j	–	node j
M_m	–	m Machine
J_n	–	n Job
J_j	–	Jobs at node j
O_{ij}	–	Operation at node i and node j
P_{ij}	–	Processing Time
s	–	Source Node
t	–	Sink Node
λ	–	Wavelength
α	–	Real positive parameters
β	–	Real positive parameters
ρ	–	Evaporation rate
γ	–	Decision variable, generates a sequence
$\|O\|$	–	Operations
η_{ij}	–	Heuristic value associates with the common C_{ij}
τ_{ij}	–	Pheromone value at node i and j
d_{ij}	–	Heuristic distance between node i and j
G	–	A representative of a graph
S_{ij}^{e}	–	Empty Solution

S_g	–	Good solution
L_k	–	Tour length of the k-th ant
	–	

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter presents the introduction to this thesis. It begins with the description of the overall background followed by a brief history of Scheduling, Job Shop Problem (JSP) and Ant Colony Optimization(ACO). Research objectives, scope of the study and discussion on the research contribution are also given. This research are comparing the results for the same case study taken from [1] and solves the job shop problem by using the different methods.

Job Shop problem is a combinatorial problem classified as an NP-hard problem [2]. It has been widely studied for the last two decades and this problem can be found in many of the real life problems. Many heuristic approaches have been introduced to solve this problem.

Ant Colony Optimization is one of the heuristic methods. It emulates the behaviour of ants colony in their search for food where they search for the shortest distance due to the strength of the pheromone trail. This method was first introduced by Dorigo on 1992 and there is a range of application for optimization problems. In this study the exploration on the architecture of ACO in solving JSP has been done.

This study involves the modeling of JSP and solving problem using Ant Colony Optimization techniques. The study considers a general problem of JSP with multi machines, which has no limitation. The Algorithm of Ant System was used to solve this JSP.

1.2 Research background

Scheduling has been defined as ”the art of assigning resources to tasks in order to ensure the termination of these tasks in a reasonable amount of time” [3]. The purpose of job scheduling is to balance the entire system load while completing all the jobs at hand as soon as possible according to the environment status [4]. Job shop scheduling problems are hard to solve due to their complexities in theory and practice.

There are three common shop models for scheduling; namely Open Shops, Flow Shops, and Job Shops. An open shop is ”build to order” and no inventory is stocked.

Production schedules therefore are usually generated by using heuristics in practice. However, it is very difficult to evaluate the quality of these schedules, and the consistency of performance may also be an issue. Manufacturing operations may be divided into Product-focused and Process focused. Flow Shop is the Product-focused; since it has the deterministic processing times, static arrivals and also famed as easiest scheduling problem.

The assembling of telephones is one of the examples for Product-focused. A metal shop making parts for Proton (assembly line) and the General Hospital is a Process-focused and well-known as the Job Shop Problem (JSP). JSP has the stochastic processing times and dynamic arrivals. Hence, the Process-focused is the most difficult scheduling problem. This study is focusing on Job Shop. The results for any scheduling problem are known as an approximation scheme.

The key factor for manufacturing productivity is scheduling. Effective scheduling can improve on-time delivery, reduce inventory, cut lead times and improve the utilization of bottleneck resources. Because of the combinatorial nature of scheduling problems, it is often difficult to find optimal schedules, especially within a limited amount of computation time.

1.2.1 Job Shop Problem (JSP)

Job Shop Problem is a discrete problem of a combinatorial problem. It is generalized from the Travelling Salesman Problem (TSP). It has also been illustrated as a problem in computational complexity theory which is hard to solve in practice. Job Shop is an NP-hard problem. The general objective of scheduling is to decide in what rules, methods or order is used to perform jobs in the sequence so that certain desired criteria are met.

Job-shop scheduling is a complicated and widely studied production scheduling problem. In a job-shop, jobs must be processed on machines in a specified order. The Scheduling must have both optimal and flexible solutions to respond to fluctuations in the demand and operations of the plants while minimizing costs and times of operations.

Mathematical programming has been applied extensively to job shop scheduling problems. Problems have been formulated using integer programming, mixed-integer programming and dynamic programming. The job shop scheduling problem (JSP) has a finite set of jobs processed on a finite set of machines. Each job is characterized by a fixed order of operations; each of the jobs is to be processed on a specific machine and specified duration. Each machine can process at most one job at a time [5]. Once a job initiates processing on a given machine it must complete processing and uninterrupted. In this research, near-optimal solution methodologies for job shop scheduling are examined.

1.2.2 Ant Colony Optimization (ACO)

The ant colony optimization algorithm (ACO) was first introduced by Marco Dorigo in 1992 [2], a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. This approach was inspired by the behaviour of ants in finding paths from the colony to food (the source). Unfortunately, it is difficult to analyze ACO algorithms theoretically, the main reason being that they are based on sequences of random decisions (taken by a colony of artificial ants) that are usually not independent and whose probability distribution changes from iteration to iteration.

ACO has been applied successfully to a large number of difficult combinatorial optimization problems including travelling salesman problems, quadratic assignment problems and scheduling problems. ACO is an algorithm approach, inspired by the foraging behavior of real ants. ACO can also be applied to the solution of

Combinatorial Optimization Problem (COP), which will be discussed later. ACO is a population-based metaheuristic used to find approximate solutions to difficult optimization problems. The algorithm involves a set of 'agents' called artificial ants search for good solutions to a given optimization problem.

In this study, the proposed ACO is used by transforming the optimization problem into a problem of finding the best path on a weighted graph. Artificial ants (hereafter ants) incrementally build solutions by moving on the graph. The solution construction process is stochastic and is biased by a pheromone model, that is a set of parameters associated with graph components (either nodes or edges) whose values are modified at runtime by the ants.

The basic mechanism of ACO metaheuristic is that a colony of artificial ants cooperates in finding good solutions to combinatorial optimization problems. An important and interesting behaviour of ant colonies appears in their foraging behaviour. In particular, ants are capable of finding the shortest paths between food sources and their nest without using visual cues. While walking from food sources to the nest and vice versa, ants exploit on their ground a substance called pheromone. Ants can smell pheromone substance and when choosing their way they tend to choose in probability paths marked by strong pheromone concentrations.

The following description is a very brief summary about real ants and how they forage from real to artificial ants from Dorigo and Stutzle's book [2]:

"An ant colony represents a highly structured insect society that can accomplish complex tasks that in some cases far exceed the individual capabilities of a single ant. Ants coordinate their activities via indirect communication; for example, a foraging ant that has found food will deposit a chemical on the ground (pheromones) that increases the probability that other ants in the colony will follow its same path."

Many researchers use ACO to solve NP-hard problem such as travelling salesman problem [6], graph colouring [7], vehicle routing problem [8] and so on. This study applies the ACO algorithm to Job Shop Problem. Assumes each job is an ant and the algorithm sends the ants to search for resources.

The job problems, consists of scheduling given jobs with same order at all machines. The job can be processed at most on one machine; meanwhile one machine can process at most one job. The most common objectives and problem in this study, is the makespan. Hence, it is a decision making process with the goal of minimizing makespan. This research studies job shop scheduling with performance measure. This study focuses on representations and formulations of job shop with the makespan objective.

In production scheduling, the main problem is to minimize the makespan. The specific problem is assigning the operation:

- no one job in the job shop problem is pre-empted.
- the precedences given by the chain relations are respected.
- no two or more jobs are processed at the same time on the same machine.
- the maximum of the makespan, C_{max} of all operations is minimized.

This research is using the case study taken from [1] and compare the results by using a different method. The research in [1] had been done by taking the set of data from 'XYZ Company', and solve the JSP by using Shifting Bottleneck Heuristic Method, whereas to this research takes the set of data from [1] and solve the JSP by using a new ACO-based algorithm.

1.3 Problem Statement

The research aims to develop an algorithm based on ACO specially for minimizing the makespan of a JSP.

1.4 Objective of the Study

The objectives of this research are as follows:

(i) To explore Heuristic Method of Ant Colony Optimization for Job Shop Problem and its application in real-life phenomenon.

(ii) To develop an algorithm for solving JSP based on ACO.

(iii) To compare the efficiency of the new ACO-based algorithm with existing Shifting Bottleneck.

1.5 Scope of the Study

The objective of the research mostly focuses on minimizing the total completion time, such as the makespan. In this study, we will describe on how to minimize the makespan for the *n*-jobs and *m*-machines problem, which is classified as combinatorial optimization problem. Therefore, it is an NP-hard problem class and near optimum solution technique is preferred. Also considered on how to improve the performance of the modified algorithm; such as the quality of the results, the computational effort, the time to it takes to arrive at the solution. For the sake on improving this algorithm the best parameters values are chosen.

1.6 Significance of the Study

Scheduling has been widely studied on production and our real life problems. Since the key of manufacturer productivity is scheduling, it minimizes the cost and the times of operations. The industrial relocalize trying to maintain profit through the development of effective production schedules, better utilization of resources and overall, better planning. The significance of effective planning methods has increased and will likely continue to do so.

Moreover, the main idea of ACO is to use parameterized probabilistic model to construct solutions which is then used to update the model parameters values with the aim of increasing the probability of constructing high quality solutions by probabilistically making a number of local decisions.

In this research, a procedure to achieve the desired makespan with near optimal number of machines of each machine type was developed. The needs for efficient methods to obtain approximate solutions of high quality in a reasonable amount of time has also been justified. The problem in this study is to minimize the makespan while ensuring that not more than one job can be processed at the same time on the same machine and when a jobs starts, it must be completed and cannot be interrupted.

1.7 Thesis Organization

The thesis is divided into seven chapters. The first chapter introduces the research. This chapter gives explanation on the ACO and JSP, problem statement, objective of the study, scope of the study, significance of the study and research problem.

Chapter 2 is the Literature Review. It reviews the behaviour of real ants, while explaining the Classical Job Shop Problem. The literature also reviews the relevant research, research findings on ACO and motivations for extended research.

Chapter 3 introduces definition of Job Shop Problem genuinely. Next, the constraint of JSP is reviewed and some assumptions for JSP will be elaborated. This chapter also explained how to represent the problem into JSP, using the graph illustration.

Chapter 4 is the development of the algorithm. This chapter explains the ACO algorithm step by step. There are five main steps in the algorithm that is; initialize, Construct the Ant Solutions, Daemon Action, Pheromone Update and Terminating Condition.

Chapter 5 is where the implementation of ACO for JSP is discussed. The ideas of this research are also examined and considered. The system development for ACO software and the main point from the programming with Microsoft Visual Studio and C # language are explain.

Chapter 6 describes the case study and the procedures used to solve the problem. In this chapter the case study, framework and the layout from the DEN Metal Company are clarified. The mathematical calculation as also discussed.

Chapter 7 summarizes the thesis, determines and computes the results, then the conclusion is clarified. Some recommendations for future research related to the topics are also highlighted.

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