AN IMPROVED ANT SYSTEM ALGORITHM FOR UNEQUAL AREA FACILITY LAYOUT PROBLEMS

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A thesis submitted in fulfillment of the
requirements for the award of the degree of
Master of Engineering (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

OCTOBER 2009

To my God, Allah *'azza wa jalla*

Then to my beloved parents, wife and daughter

ACKNOWLEDGEMENTS

In preparing this thesis, I was in contact with many people, researchers, and academicians. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Dr. Wong Kuan Yew, for his encouragement, guidance, critics and friendship. I am also indebted to Universiti Teknologi Malaysia (UTM) for funding my Master study.

My fellow friends from the Indonesian Student Association (PPI) should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

To date, a formal Ant Colony Optimization (ACO) based metaheuristic has not been applied for solving Unequal Area Facility Layout Problems (UA-FLPs). This study proposes an Ant System (AS) algorithm for solving UA-FLPs using the Flexible Bay Structure (FBS) representation. In addition, this study proposes an improvement to the FBS representation when solving problems which have empty spaces. The proposed algorithm uses several types of local search to improve its search performance. It was extensively tested using 20 well-known problem instances taken from the literature. The proposed algorithm is effective and can produce all of the best FBS solutions (or even better) except for 2 problem instances. In addition, it can improve the best-known solution for 7 problem instances. The improvement gained by the proposed algorithm is up to 21.36% compared to previous research. Evidently, the proposed algorithm is also proven to be effective when solving large problem sets with 20, 25, and 30 departments. Furthermore, this study has implemented a Fuzzy Logic Controller (FLC) to automate the tuning of the AS algorithm. The experiments involved tuning four parameters individually, i.e. number of ants, pheromone information parameter, heuristic information parameter, and evaporation rate, as well as tuning all of them at once. The results showed that FLC could be used to replace manual parameter tuning which is time consuming. The results also showed that instead of using static parameter values, FLC has the potential to help the AS algorithm to achieve better objective function values.

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ABSTRAK

Sehingga kini, metaheuristik *Ant Colony Optimization* (ACO) belum lagi digunakan untuk menyelesaikan *Unequal Area Facility Layout Problems* (UA-FLPs). Matlamat projek ini adalah untuk membangunkan satu algoritma *Ant System* (AS) untuk menyelesaikan UA-FLPs dengan menggunakan model *Flexible Bay Structure* (FBS). Selain itu, kajian ini juga membuat pembaikan kepada model FBS apabila menyelesaikan UA-FLPs yang mengandungi ruang kosong. Algoritma yang dibina tersebut menggunakan beberapa jenis pencarian tempatan (*local search*) untuk meningkatkan prestasi pencariannya. Ianya diuji secara luas menggunakan 20 masalah terkenal yang diambil daripada literatur. Algoritma tersebut adalah berkesan dan boleh menghasilkan semua solusi FBS terbaik (bahkan lebih baik) kecuali untuk 2 set masalah. Selain itu, algoritma tersebut juga boleh memperbaiki solusi terbaik untuk 7 set masalah. Pembaikan yang diperolehi mencapai 21.36% bila dibandingkan dengan kajian-kajian yang lepas. Jelasnya, algoritma ini juga berkesan untuk menyelesaikan masalah bersaiz besar yang mempunyai 20, 25, dan 30 jabatan. Tambahan lagi, projek ini telah menerapkan *Fuzzy Logic Controller* (FLC) untuk menala secara otomatik nilai parameter-parameter di dalam algoritma AS. Eksperimen dengan FLC membabitkan penalaan empat parameter secara berasingan, iaitu *number of ants*, *pheromone information parameter*, *heuristic information parameter*, dan *evaporation rate*, dan penalaan semua empat parameter secara sekaligus. Hasilnya menunjukkan bahawa FLC boleh digunakan untuk menggantikan penalaan parameter secara manual. Hasilnya juga menunjukkan bahawa FLC berpotensi untuk membantu algoritma AS untuk mencapai fungsi objektif yang lebih baik daripada menggunakan nilai parameter yang statik.

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LIST OF SYMBOLS

A	-	the total area of the facility
c_{ij}	-	the cost per unit distance per unit material from department *i* to department *j*
C_{ik}	-	department *i* located in location candidate *k* (department *i* located in the *k*th element of the department sequence)
d_{ij}	-	the distance between departments *i* and *j*
$f(s)$	-	ant objective function
$F(s)$	-	quality function
f_{ij}	-	the number of material flow from departments *i* to department *j*
H	-	the height of the facility
h_i	-	the height of department *i*
l_i	-	length of department *i*
l_{min}	-	minimum length of department

m_i	-	sum of material flow from and to department i
n	-	the number of departments
$N(s)$	-	available departments which have not been used in the corresponding ant
$p(C_{ik})$	-	probability to locate department i to location candidate k
p_{inf}	-	the number of infeasible departments
S_{upd}	-	the set of ants that is used for updating the pheromone
V_{all}	-	the best overall objective function value found
V_{feas}	-	the best feasible objective function value found
w	-	weight for the corresponding ant solution s.
W	-	the width of the facility
w_i	-	the width of department i
x	-	the centroid of an area below fuzzy membership function μ_c.
x_k	-	x axis value for the center of location candidate k
x_o	-	the crisp value
y_k	-	y axis value for the center of location candidate k

α - pheromone information parameter

α_{max} - maximum aspect ratio

β - heuristic information parameter

λ_k - the parameter for location candidate k

μ_c - fuzzy membership function

ρ - evaporation rate

τ_{ik} - pheromone value associated with the solution to locate department i to location candidate k

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CHAPTER 1

INTRODUCTION

1.1 Overview

Determining the physical organization of a production system is defined as a Facility Layout Problem (FLP). The term production system does not only point to manufacturing, but it also concerns service and communication systems (Meller and Gau, 1996). The objective of an FLP is mainly to minimize the total material handling cost of the production system. It can also include or combine various objectives such as to maximize space utilization, maximize flexibility, and maximize employee satisfaction and safety (Muther, 1955). In general, FLPs can include various layouts such as manufacturing, hospital, office, and construction layouts.

One of the important FLPs is the Unequal Area Facility Layout Problem (UA-FLP) which was originally formulated by Armour and Buffa (1963). In UA-FLPs, there is a fixed rectangular facility with dimensions H and W, where H is the height and W is the width. A number of departments which do not need to have the same area requirement must be arranged according to the following criteria: (1) all departments must be located inside the facility, (2) all departments must not overlap with each other, and (3) the final dimensions of the departments must fulfill some maximum ratio constraints and/or minimum value restrictions (Meller and Gau, 1996). The goal of the problem is to partition the facility into departments so as to minimize the total material movement cost. This objective is based on the material handling principle that material handling cost increases proportionally with the distance which must be traveled by the materials.

A UA-FLP is a complete Nondeterministic Polynomial (NP) problem and thus, recent research using exact algorithms can only optimally solve up to 11 departments (Meller *et al.*, 2007). In recent years, researchers have proposed several metaheuristic approaches to obtain high quality solutions for large UA-FLPs (Meller and Gau, 1996; Singh and Sharma, 2005). Researchers have also proposed several UA-FLP representations such as Flexible Bay Structure (FBS), Slicing Tree Structure (STS), and Quadratic Assignment Problem (QAP) to reduce the complexity of UA-FLPs (Meller and Gau, 1996).

1.2 Background of Research

As a metaheuristic, the Ant Colony Optimization (ACO) family was introduced by M. Dorigo and his colleagues in the early 1990s (Dorigo *et al.*, 1996). The first ACO algorithm developed was Ant System (AS) and subsequently, many variants have been developed in order to improve the algorithm performance. Among other ACO variants are Elitist AS (EAS), Rank-based AS (RAS), MAX-MIN Ant System (MMAS), and Ant Colony System (ACS). ACO was initially tested for solving the Traveling Salesman Problem (TSP), and then it has been implemented to solve various kinds of optimization problems such as Facility Layout Problem (FLP), scheduling, vehicle routing, timetabling, data mining, bioinformatics problems, etc. (Blum, 2005a).

One area which has been successfully solved by ACO is FLP. It is a very hard optimization problem and can be applied in many application areas (Meller and Gau, 1996). These reasons have encouraged many researchers to study it. The use of ACO to solve FLPs is mainly based on two reasons (Stützle and Dorigo, 1999). Firstly, ACO is suitable to solve discrete optimization problems because its solution structure uses a discrete solution representation. Secondly, ACO can use heuristic information to exploit the problems. This heuristic information can help ACO to search and examine promising solution regions.

Unfortunately, the application of ACO in solving FLPs is mainly limited to Quadratic Assignment Problems (QAPs) as will be discussed later in the literature review section. Only little research has been done to solve other classes of FLPs. For this reason, this research aims to implement ACO for solving another class of FLP, i.e. UA-FLPs.

When using metaheuristic algorithms, one of the important factors is the balance between intensification and diversification in the search space. To provide this balance, determining the right values for metaheuristic parameters is one of the critical issues (Eiben *et al.*, 1999). To handle this matter, this research implements a Fuzzy Logic Controller (FLC) to automatically tune the ACO's parameters.

1.3 Problem Statement

UA-FLP as one of the well-known problems in facility planning has been studied for years. It is a very difficult problem because of the constraints contained. Conventional methods can only optimally solve UA-FLPs with up to 11 departments (Meller *et al.*, 2007). Meanwhile, the size of the problem still grows and the largest problem currently has 35 departments (Liu and Meller, 2007). Therefore, researchers have proposed several metaheuristic approaches to solve UA-FLPs especially for the large problems (Tate and Smith, 1995; Liu and Meller, 2007; Scholz *et al.*, 2009). Basically, metaheuristic approaches can only report the best-obtained solutions since they may not guarantee to obtain the optimum solutions. Therefore, there is an opportunity to use other metaheuristic approaches to improve the best-known solutions for UA-FLPs.

On the other hand, ACO has not been used for solving UA-FLPs although it is considered as one of the state of the art algorithms for solving FLPs, particularly QAPs. Therefore, it is advantageous to implement ACO for solving UA-FLPs in order to show that it can be used as an alternative to build a facility layout. Such an implementation may achieve better results compared to approaches proposed by previous studies. This will then encourage the use of ACO for solving UA-FLPs, with more confidence.

The selection of parameter values for ACO is essential to its performance. Past methods which have been used for parameter tuning in ACO have been reviewed but no one has used FLC to tune ACO's parameter values. On the other hand, FLC performed well when it was implemented to tune the parameter values of other metaheuristic algorithms. Therefore, the use of FLC to automatically tune the ACO's parameters is considered necessary because it may benefit ACO's performance. If the results are as good as those obtained from manual tuning, then FLC can be used to replace manual tuning which is time consuming.

1.4 Objective of Study

The objectives of this research are to:

i. Formulate an AS algorithm with FLC for solving UA-FLPs. Particularly, FLC is used to automatically tune the parameter values in AS.

ii. Evaluate the performance of the algorithm in solving UA-FLPs. The evaluation is based on comparing its performance, technically the best objective function values achieved with those obtained from previous studies.

1.5 Scope of Study

This study covers the design, development, and evaluation of the proposed algorithm for solving UA-FLPs. In addition, this research is restricted by the limitations listed below:

i. This study chooses the AS algorithm for the ACO implementation and it does not consider other ACO variants. AS is chosen because this research is an initial effort to use ACO for solving UA-FLPs and furthermore, AS is the most basic algorithm of ACO.

ii. In order to simplify UA-FLPs, this research uses the FBS model representation. The FBS model is selected because it has been thoroughly studied and thus, it provides a good basis for comparison.

iii. All the case problems are taken from previous studies which have been published in the literature. The smallest problem contains 7 departments whereas the largest one has 35 departments.

iv. This study is only interested in solving UA-FLPs which have a rectangular facility with fixed dimensions.

v. The total department areas must not exceed the facility area. In addition, this research will also solve UA-FLPs with empty spaces.

vi. All the departments are considered as rectangular and they have certain constraints that bound their dimensions with minimum and maximum values. In addition, this research does not take into account problems which have departments with fixed dimensions or locations.

vii. Rectilinear distance is used in material movement cost calculation.

1.6 Organization of Thesis

This thesis is structured as follows. Chapter 2 describes the literature review which lays down the fundamentals of UA-FLP and ACO. It provides a comprehensive review on the previous approaches used to solve UA-FLPs and clearly highlights that ACO has not been used for solving them. Chapter 3 discusses the methodology used in conducting this research. Chapter 4 introduces the formulation of the proposed AS algorithm for solving UA-FLPs. Meanwhile, chapter 5 presents the FLC formulation applied to the AS algorithm. In chapter 6, evaluation results obtained from the computational experiment are presented and discussed. Finally, chapter 7 gives several conclusions for the research and directions for future work.

1.7 Conclusions

In this chapter, the background of the research, its objectives and scopes have been described. The idea of using AS for solving UA-FLPs is a relatively novel concept. It is indicated that the use of FLC may improve the performance of AS by balancing its search intensification and diversification. This research is expected to produce an AS algorithm for solving UA-FLPs. This research is also expected to become a new paradigm for tuning the parameters in AS by using FLC. In the next chapter, a thorough review of the related literature will be provided.

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