IMPROVED COVARIANCE MATRIX EVOLUTION STRATEGY ALGORITHM FOR STOCHASTIC DYNAMIC UNEQUAL AREA FACILITY LAYOUTS IN AN OPEN AREA

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2015

DEDICATION

To my Parents and my wife

ACKNOWLEDGEMENTS

Firstly, I wish to express my heartfelt gratefulness to the Almighty Allah (S.W.T) for the blessing and strength, which He has given me during the completion of this research.

My sincerest gratitude goes to my main supervisor Associate Prof. Dr. Kuan Yew Wong for his continuous support for my PhD study and research, for his motivation, advice, patience, enthusiasm and immense knowledge from the beginning to the completion of the present research. Without his continued support and interest, this thesis would not have been completed.

I am also indebted to Universiti Teknologi Malaysia (UTM) for financial support. Librarians and staff at UTM also deserve special thanks for their useful assistance and help throughout this research. Unfortunately, it is not possible to list all of them in this limited space.

I would also like to express my deepest gratitude to my parents for their support and encouragement during my life and this research. Without their continued support and interest, I will not be at this point. I also wish to express my appreciation to my mother-in-law and father-in-law for their support and encouragement. At the end, I would like to especially thank my devoted wife, Somayyeh, whose love and patience supported me during our life in Malaysia.

ABSTRACT

Facility layout problems deal with layout of facilities, machines, cells, or departments in a shop floor. This research has formulated unequal area stochastic dynamic facility layout problems in an open or wall-less area in order to minimize the upper bound of the sum of the material handling costs, and the sum of the shifting costs in the whole time planning horizon. In addition, the areas and shapes of departments are fixed during the iteration of an algorithm and throughout the time horizon. In unequal area stochastic dynamic facility layout problems, there are several periods for the material flow among departments or product demand such that the material flow among departments or product demand is not stable in each period. In other words, the product demand is stochastic with a known expected value and standard deviation in each period. In this research, a new mixed integer nonlinear programming mathematical model was proposed for solving this type of problems. Particularly, they are non-deterministic polynomial-time hard and very complex, and exact methods could not solve them within a reasonable computational time. Therefore, meta-heuristic algorithms and evolution strategies are needed to solve them. In this research, a modified covariance matrix adaptation evolution strategy algorithm was developed and the results were compared with two improved meta-heuristic algorithms (improved particle swarm optimization and modified genetic algorithm). These two meta-heuristic algorithms were developed and used to justify the efficiency of the proposed evolution strategy algorithm. The proposed algorithms applied four methods, which are (1) department swapping method, (2) local search method 1, (3) period swapping method, and (4) local search method 2, to prevent local optima and improve the quality of solutions for the problems. The proposed algorithms and the proposed mathematical model were validated using manual and graphical inspection methods, respectively. The trial and error method was applied to set the respective parametric values of the proposed algorithms in order to achieve better layouts. A real case and a theoretical problem were introduced to test the proposed algorithms. The results showed that the proposed covariance matrix adaptation evolution strategy has found better solutions in contrast to the proposed particle swarm optimization and genetic algorithm.

ABSTRAK

Masalah susun atur kemudahan adalah berkaitan dengan susun atur kemudahan, mesin, sel atau jabatan di lantai pengeluaran. Kajian ini telah memformulasikan masalah susun atur kemudahan stokastik dinamik ketidaksamaan saiz di kawasan terbuka atau tidak berdinding untuk meminimumkan sempadan atas bagi jumlah kos pengendalian bahan, dan jumlah kos peralihan dalam keseluruhan tempoh masa perancangan. Di samping itu, saiz dan bentuk jabatan adalah tetap semasa lelaran algoritma dan sepanjang tempoh masa. Dalam masalah susun atur kemudahan stokastik dinamik ketidaksamaan saiz, terdapat beberapa tempoh masa untuk aliran bahan antara jabatan atau permintaan produk di mana aliran bahan antara jabatan atau permintaan produk adalah tidak stabil pada setiap tempoh masa. Dalam kata lain, permintaan produk adalah stokastik dengan nilai jangkaan dan sisihan piawai yang diketahui dalam setiap tempoh masa. Dalam kajian ini, satu model matematik baru pengaturcaraan integer campuran tak linear telah dicadangkan untuk menyelesaikan jenis masalah ini. Khususnya, masalah ini adalah masa polinomial keras tidak ketentuan dan sangat kompleks, dan kaedah tepat tidak dapat menyelesaikan masalah ini dalam tempoh masa yang munasabah. Jadi, algoritma meta-heuristik dan strategi evolusi diperlukan untuk menyelesaikannya. Dalam kajian ini, satu algoritma strategi evolusi adaptasi matrik kovarians yang diubahsuai telah dibangunkan dan hasilnya telah dibandingkan dengan dua algoritma meta-heuristik yang diperbaiki (iaitu pengoptimuman partikel berkumpulan dan algoritma genetik yang diperbaiki). Dua algoritma meta-heuristik ini dibangunkan dan digunakan untuk menjustifikasikan kecekapan algoritma strategi evolusi. Algoritma-algoritma yang dicadangkan menggunakan empat kaedah iaitu (1) kaedah penukaran jabatan (2) kaedah pencarian setempat 1 (3) kaedah penukaran tempoh dan (4) kaedah pencarian setempat 2, untuk mengelakkan penyelesaian optima setempat dan memperbaiki kualiti penyelesaian bagi masalah ini. Algoritma-algoritma yang dicadangkan telah disahkan menggunakan kaedah manual manakala model matematik telah disahkan menggunakan kaedah penyemakan graf. Kaedah cuba-cuba telah digunapakai untuk menentukan nilai parameter bagi algoritma yang dicadangkan demi mencapai susun atur yang lebih baik. Satu kes sebenar dan masalah teoritikal telah diperkenalkan untuk menguji algoritma-algoritma yang dicadangkan. Hasil kajian menunjukkan bahawa strategi evolusi adaptasi matrik kovarians menghasilkan penyelesaian yang lebih baik jika dibandingkan dengan pengoptimuman partikel berkumpulan dan algoritma genetik.

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LIST OF ABBREVIATIONS

FLPs	-	Facility layout problems
SFLPs	-	Static facility layout problems
STFLPs	-	Stochastic facility layout problems
DFLPs	-	Dynamic facility layout problems
STDFLPs	-	Stochastic dynamic facility layout problems
UA SFLPs	-	Unequal area static facility layout problems
EA SFLPs	-	Equal area static facility layout problems
UA STFLPs	-	Unequal area stochastic facility layout problems
EA STFLPs	-	Equal area stochastic facility layout problems
UA DFLPs	-	Unequal area dynamic facility layout problems
EA DFLPs	-	Equal area dynamic facility layout problems
UA STDFLPs	-	Unequal area stochastic dynamic facility layout problems
EA STDFLPs	-	Equal area stochastic dynamic facility layout problems
CMA ES	-	Covariance matrix adaptation evolution strategy
PSO	-	Particle swarm optimization
GA	-	Genetic algorithm
NP-hard	-	Non-deterministic polynomial-time hard
STDFLP-RE	-	The real case
STDFLP-ONE	-	The theoretical problem instance

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 An Overview

The foundation of this research is explained in this chapter. The background of this research is provided in section 1.2 and it is concerning static facility layout problems (FLPs), dynamic FLPs, stochastic FLPs, and stochastic dynamic FLPs. The problem is clearly stated in section 1.3 and the next section (section 1.4) is allocated to the objectives of the research. Questions and scope of the research are identified in sections 1.5 and 1.6, respectively. Sections 1.7 and 1.8 state the significance and contributions of this research, respectively. Finally, the structure of this thesis is mentioned in section 1.9.

1.2 Background of the Research

Facility layout is a strategy that has been widely utilized in many countries in order to decrease the total operating cost. According to Tompkins et al. (2010), facility design will be one of the most momentous areas in the manufacturing environment in the future. The main aim of FLPs is to find the best position or layout for facilities, departments, cells, and machines in a given area in order to reduce the total operating cost within manufacturing environments.

Particularly, FLPs cope with finding the locations of facilities, machines, or departments in a shop floor in order to minimize the sum of the material handling costs among them. In static FLPs (SFLPs), the product demands are stable and cannot change for a long duration. It means the material flow among facilities, departments, cells, or machines is fixed throughout the entire planning horizon. SFLPs where the shapes and areas of all facilities or departments are same were introduced by Koopmans and Beckmann (1957) for the first time. Armour and Buffa (1963) further developed this type of problems and formulated SFLPs where the shapes and areas of all departments or facilities could be different. They assumed that the shapes of facilities or departments could change during the iteration of an algorithm whereas their areas could not change.

SFLPs where the shapes and areas of different departments could be different, but both their shapes and areas were fixed during the iteration of an algorithm were developed by Imam and Mir (1989). SFLPs are not suitable in some industries because they assume the product demands are fixed and constant. In reality, managers of companies must be able to respond quickly to changes in product demand and product price. Hence, dynamic FLPs (DFLPs), stochastic FLPs (STFLPs), and stochastic dynamic FLPs (STDFLPs) have been studied in which the product demands are not fixed and could be varied. In DFLPs, there are several periods (periods could be weeks, months, seasons, or years) for the product demands. In this type of problems, the material flow among facilities or departments can be changed in different periods but is fixed in each period. It is clear that there are several layouts for a solution of a DFLP (one layout for each period).

Rosenblatt (1986) investigated DFLPs where the shapes and areas of all facilities or departments were same, for the first time. He applied an exact method in order to minimize the sum of the material handling costs among departments and the sum of the shifting costs of departments in consecutive periods. DFLPs where the shapes of different departments could be different were originally studied by Montreuil and Venkatadri (1991). They assumed that the shapes of departments could be changed during the iteration of an algorithm whereas their areas were fixed in all periods and could not change during the iteration of an algorithm and throughout the time horizon.

Dunker et al. (2005) developed DFLPs where the shapes of various departments could be different. They assumed that the shapes and areas of departments could not change during the iteration of an algorithm and were fixed throughout the time horizon, whereas the departments have free orientations (the length and width of departments could be exchanged).

In STFLPs, there is only one period such that the product demands are uncertain. There are two types of STFLPs, which can either have: 1) stochastic product demands with a known variance and expected value or 2) several scenarios for product demands with different probabilities such that their summation is equal to one. The second type of STFLPs where the shapes of all departments were same was formulated by Rosenblatt and Kropp (1992) for the first time. The first type of STFLPs where the shapes of different departments could be different was originally formulated by Kulturel-Konak et al. (2004). They assumed that the product demands were stochastic with a known expected value and standard deviation. In addition, the shape of each department could change during the iteration of an algorithm whereas the area of each department was fixed and could not change.

In STDFLPs, there are several periods for the product demands such that the product demands are not stable and are uncertain in each period. There are two types of STDFLPs based on literature review. The first is STDFLPs in which the product demands are stochastic with a known variance and expected value in each period. The second is STDFLPs in which there are several scenarios for the product demands with different probabilities in each period such that their summation is equal to one in each period. Kouvelis and Kiran (1991) investigated the second type of STDFLPs where the shapes of all departments were same. Yang and Peters (1998) formulated the second type of STDFLPs where the shapes of different machines could be different. They assumed that the shapes and areas of machines were fixed during the iteration of an algorithm but each machine has free orientations (the length and width of machines could be exchanged). The first type of STDFLPs where the shapes of all facilities were same was firstly formulated by Moslemipour and Lee (2012).

This research is going to focus on STDFLPs where the areas and shapes of different departments could be different in order to minimize the sum of the material handling costs among departments and the sum of the shifting costs of departments in consecutive periods. In addition, each product demand is normally distributed with a known expected value and standard deviation in each period. An efficient method will be developed to solve the problems in this area.

1.3 Problem Statement

Having done a vast literature review, the problem studied in this research can be discussed from several perspectives. Firstly, SFLPs are not suitable in today's competitive market because companies must be able to respond rapidly to changes in product demand, product price, production volume and product mix. Therefore, it is necessary to focus on STDFLPs.

Secondly, in the real world, it is not practical to change the locations of departments in consecutive periods for dynamic problems because departments have walls and their shifting is very costly. Hence, it is necessary to address the problems where the facilities do not have walls such as departments in an open or wall-less area. In dynamic problems, the sum of the shifting costs of departments in an open or wall-less area in consecutive periods is certainly lower because there is no wall for departments in an open area. Therefore, departments in an open or wall-less area will be arranged in each period in this research.

Thirdly, research in the field of STDFLPs is very scarce based on literature review. Moreover, studies on this type of problems where the shapes and areas of all facilities or departments are same are rarely practical in today's competitive global marketplace. In addition, any change in shapes and areas of facilities or departments during the iteration of an algorithm is costly and managers aim to cut down the total operating cost in all situations. Fourthly, most of the data for product demands are normally distributed for stochastic problems in the real world (Casella and Berger, 2002).

Therefore, it is important to study STDFLPs where the areas and shapes of different departments can be different in an open or wall-less area, and the shapes and areas of departments are fixed during the iteration of an algorithm. In addition, the product demands are normally distributed with a known expected value and standard deviation in each period and departments have free orientations (the length and width of departments can be exchanged). This type of problems has not been studied and formulated until now.

Finally, the problems stated earlier are very complex and non-deterministic polynomial-time hard (NP-hard); hence, exact methods cannot solve them within a reasonable computational time. In addition, Yildiz and Solanki (2012) reported that researchers must choose a powerful algorithm to find appropriate layouts for FLPs. This research is going to develop a modified covariance matrix adaptation evolution strategy algorithm to solve the problems as it is an emerging new technique which has not been applied in the field of FLPs.

1.4 Research Objectives

The objectives of this research are defined based on literature review, background of study, and statement of problem. The main objectives of this research are mentioned as follows:

1. To formulate a new mathematical model for STDFLPs with unequal area departments in an open or wall-less area.

2. To develop a modified covariance matrix adaptation evolution strategy algorithm to solve this type of problems.

1.5 Research Questions

Responding to these questions will help to formulate and solve STDFLPs with unequal area departments in an open or wall-less area.

1. Which model (linear programming, nonlinear programming, mixed integer linear programming, or mixed integer nonlinear programming) will be used to formulate the problems as mentioned earlier?

2. Which solution representation (continuous solution representation or discrete solution representation) is suitable to represent the solutions of the problems stated earlier?

3. Is an evolution strategy algorithm better than other meta-heuristics in solving this type of problems?

1.6 Scope of the Research

This research is bounded by the following scopes.

1. A modified covariance matrix adaptation evolution strategy algorithm will be developed to solve STDFLPs. This is because it is one of the strongest evolution strategy algorithms for solving combinatorial optimization problems. The results of this algorithm will be compared with two meta-heuristic algorithms (modified particle swarm optimization and genetic algorithm), which will also be developed in this research. This comparison is made to show the efficiency of the proposed evolution strategy algorithm.

2. MATLAB R2013a will be used in order to code the problem as mentioned earlier.

3. A case study in Iran and a theoretical problem instance will be considered for the collection of required data in the field of STDFLPs.

4. Rectilinear distance or city block distance will be used for calculating distance between two departments.

5. Planning horizon will be divided into several periods.

6. Rectangular shapes are used for departments.

7. The shape and area of each department are fixed during the iteration of an algorithm and throughout the time horizon.

8. The orientation of each department can change (the width and length of a department can exchange) during the iteration of an algorithm and throughout the time horizon.

9. An open given area without walls is assigned to locate the departments.

10. Each product demand is normally distributed with a known expected value and standard deviation in each period.

1.7 Significance of the Research

In accordance with Tompkins et al. (2010), FLPs are one of the significant areas in the field of manufacturing. In addition, they stated that roughly 8 percent of the gross national product has been spent on new facilities in the United States since 1955 and over $300 billions have been spent each year for layout and relayout. Krishnan et al. (2008) stated that between 20 to 50 percent of the total operating costs in manufacturing are allocated to material handling costs and these can be lessen by 10 to 30 percent with effective and efficient layouts. This research addresses STDFLPs with unequal area departments in an open or wall-less area which are very applicable in a volatile business environment.

Practically, by solving this type of problems, it helps managers of a company to have a more flexible and robust layout which can change in consecutive periods. This makes the company more adaptive and responsive in meeting fluctuating customer demands. Having on optimal layout in each period also helps to reduce the material handling cost which in turn will decrease the total operating cost. Moreover, work productivity and efficiency can be improved.

Theoretically, this research proposes a mathematical formulation for STDFLPs with unequal area departments in an open or wall-less area. This will be a new mathematical model as this type of problems has been neglected until now based on literature review. This research also develops and applies a modified evolution strategy algorithm as the solution technique. To date, it has not been used in the field of FLPs. It is envisaged that this technique will create better layouts in comparison with other meta-heuristic algorithms.

1.8 Structure of the Thesis

The thesis is divided into six chapters. Introduction of research as mentioned above is provided in this chapter (chapter 1), where the background, problem statement, objectives, questions, scopes, and significance of the research are explained. FLPs are briefly surveyed in the beginning of chapter 2. Then, the types of FLPs based on material flow are explained and reviewed. Next, the solution methods are investigated and finally, chapter 2 ends with analysis and conclusions. Chapter 3 is provided to show the methodology and phases of the research. The research design is divided into five phases and all phases are explained comprehensively in chapter 3.

The model for STDFLPs with the features mentioned above is formulated and the objective function is developed in chapter 4. Then, the proposed algorithms (modified covariance matrix adaptation evolution strategy, particle swarm optimization, and genetic algorithm) for solving the problems are explained. In addition, new swapping and local search methods are presented in chapter 4. Chapter 5 is designed to discuss the results of the current research. Finally, chapter 6 is provided for conclusions and recommendations for future studies.

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