MODELLING LARGE SEQUENTIAL UNEQUAL FACILITY LAYOUT PROBLEM WITH IMPROVED SIMULATED ANNEALING SOLUTION

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Arutperunjothi

"Be pure in thoughts, words and actions."

Dedicated to my beloved mum, dad,

sister, brother, family members and friends.

To lovable God.

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ABSTRACT

The Facility Layout Problem (FLP) is an arrangement of the facilities in the floor layout. In the past research, unequal-sized FLP (UFLP) are given less attention compare to equal-sized FLP and only one type of functional tools for small problem has been explored. Thus, the research introduced a new mathematical model of Sequential Unequal Facility Layout Problem (SUFLP) that can solve large problem for different types of functional tools. In this work, the functional tools consist of machines with different function, support tools and work-in-process which are arranged sequentially in a block instead of grid structure which is commonly used in the literature. The SUFLP is solved by minimizing the total weighted sum of distances traveled from one drop-off point of a block to pick-up point of the next block and the perimeter utilization in the layout. An improved simulated annealing (SA) with the concept of tabu in the search of neighbourhood solution was applied to find the best placement of functional tools in the layout. The work proposes modified temperature setting schemes and temperature reduction rules with various initial temperatures and stopping criteria. Based on the computational experiments, the iteration based theoretically optimum using composite scheme with initial temperature of 10000 and stopping criteria of 10 consecutive non improving solutions gives the best layout design that minimizes the objective function under consideration. In order to reduce the time consumed for decision making in facility layout design, a software is in need. However, until now, only few effective and user-friendly computer aided tools have been proposed for this purpose. Moreover, the software can only cater for one type of functional tool only. Motivated by this, a software that uses SA as the solution techniques and can deal with more than one type of functional tools was developed.

ABSTRAK

Masalah Susunatur Fasiliti (FLP) ialah pengaturan kemudahan dalam susunatur lantai. Dalam kajian yang lalu, Masalah Susunatur Fasiliti Berbeza Saiz (UFLP) diberi perhatian yang kurang berbanding dengan FLP sama saiz dan hanya satu jenis perkakas untuk masalah kecil telah diterokai. Oleh itu, penyelidikan ini memperkenalkan model matematik yang baru iaitu "*Sequential Unequal Facility Layout Problem"* (SUFLP) yang boleh menyelesaikan masalah besar untuk perkakas yang berlainan jenis. Dalam karya ini, perkakas terdiri daripada mesin dengan fungsi yang berbeza, perkakas sokongan dan kerja dalam proses disusun mengikut urutan berjujukan di dalam blok dan bukan struktur grid yang biasa digunakan dalam kesusasteraan. SUFLP diselesaikan dengan meminimumkan jumlah jarak perjalanan berpemberat yang diukur dari titik jatuh satu blok kepada titik pungut bagi blok seterusnya dan penggunaan perimeter dalam susunatur. Suatu "*simulated annealing"* (SA) yang diperbaiki dengan konsep pantang digunakan untuk mencari penempatan terbaik pekakas dalam susunatur. Penyelidikan ini akan memperbaiki skim tetapan suhu dan kaedah pengurangan suhu dengan pelbagai suhu awal dan kriteria pemberhentian. Berdasarkan eksperimen berkomputer, teori optimum berasaskan lelaran menggunakan skim komposit dengan suhu awal 10000 dan kriteria pemberhentian 10 penyelesaian tanpa pembaikan berturut-turut memberikan reka bentuk susunatur yang terbaik dengan fungsi objektif yang minimum. Dalam usaha mengurangkan masa untuk membuat keputusan dalam reka bentuk susunatur fasiliti, perisian diperlukan. Walau bagaimanapun, sehingga kini, hanya beberapa perisian yang berkesan dan mesra pengguna telah dicadangkan bagi tujuan ini. Selain itu, perisian ini hanya boleh menampung satu jenis perkakas sahaja. Didorong oleh ini, perisian yang menggunakan SA sebagai teknik penyelesaian dan boleh berususan dengan lebih daripada satu jenis perkakas telah dibangunkan.

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LIST OF SYMBOLS

ACO	-	Ant Colony Optimization
Ave	-	Average
CO	-	Combinatorial Optimization
FLP	-	Facility Layout Problem
EFLP	-	Equal-sized FLP
UFLP	-	Unequal-sized FLP
SA	-	Simulated Annealing
TS	-	Tabu Search
GA	-	Genetic Algorithm
QAP	-	Quadratic Assignment Problem
SSA	-	Segmented Simulated Annealing
SBL	-	Shape-based Block Layout
IP	-	Integer Programming
LIP	-	Linear Integer Programming
MIP	-	Mixed Integer Programming
NP	-	**N**on-polynomial
P/D	-	Pick-up and Drop-off
SFLP	-	Static Facility Layout Problem
DFLP	-	Dynamic Facility Layout Problem
non-QAP	-	non-Quadratic Assignment Problem
M	-	Machinery locations
WIP	-	Work-in-process
Exp	-	Exponential
MDI	-	Multiple Document Interface
FCL	-	Framework Base Class Library
CLR	-	Common Language Runtime
TRR	-	Temperature reduction rule

TSS	-	Temperature setting scheme
SC	-	Stopping criteria
VRL	-	Vertical Referrence Line
HRL	-	Horizontal Referrence Line
SS	-	Simple Scheme
CyS	-	Cycle Scheme
CES	-	Cyclic Exponential Scheme
CoS	-	Composite Scheme
GRR	-	Geometric Reduction Rule
αVA	-	Cooling factor based Van Laarhoven and Aarts
*k*VA	-	Iteration based Van Laarhoven and Aarts
*k*TO	-	Iteration based Theoretically Optimum
*α*TO	-	Cooling Factor based Theoretically Optimum
*p*TO	-	Parameter-less Theoretically Optimum
secs	-	Seconds
Dev	-	Deviation
W	-	Floor width
L	-	Floor length
N	-	Number of blocks
O_r	-	Orientation of functional tool $r \in P$
L_x	-	Length of the horizontal side of total floor
L_y	-	Length of the vertical side of the total floor
$U_{x(i)}$	-	Length of the horizontal side of block $i \in N$
$U_{y(i)}$	-	Length of the vertical side of block $i \in N$
τ_r	-	Width of the functional tool $r \in P$
υ_r	-	Length of the functional tool $r \in P$ (where, $\tau_r \leq \upsilon_r$)
ω_1	-	Normalized weight for distance measure
ω_2	-	Normalized weight for perimeter measure
H	-	Large value, $H >> L_x L_y$
m_r	-	Distance between centroid of functional tool $r \in P$ and VRL
n_r	-	Distance between centroid of functional tool $r \in P$ and HRL

e_r	-	Length of the horizontal side of functional tool $r \in P$
g_r	-	Length of the vertical side of functional tool $r \in P$
px_i	-	Distance between the pick-up point of block $i \in N$ and VRL
dx_i	-	Distance between the drop-off point of block $i \in N$ and VRL
py_i	-	Distance between the pick-up point of block $i \in N$ and HRL
dy_i	-	Distance between the drop-off point of block $i \in N$ and HRL
γe_{rs}	-	Distance between functional tool *r* and *s* are to be separated horizontally
γg_{rs}	-	Distance between functional tool *r* and *s* are to be separated vertically
P	-	Number of total tools
Sup^i	-	Number of support tools (*Sup*) for each block $i \in N$
Mac^i	-	Number of machines (*Mac*) for each block $i \in N$
$Argmt^i_{Sup}$	-	Arrangement of support tools for each block $i \in N$
$Argmt^i_{Mac}$	-	Arrangement of machines for each block $i \in N$
$Argmt^i_{WIP}$	-	Arrangement of work-in-process (*WIP*) for each block $i \in N$
$Col^i_{\Pr edefined}$	-	Predefined number of columns for each block $i \in N$
Row^i	-	Number of rows for each block $i \in N$
λ_{ij}	-	Binary variable
π	-	Initial permutation
k	-	Iteration
α	-	Cooling factor
x_0	-	Initial solution
x	-	Current solution
x'	-	Neighbourhood solution
$F(x_o)$	-	Cost of initial solution
$N(x),\ Z(x')$	-	Objective value of neighbourhood solution
$Z(x_0)$	-	Objective value of initial solution
$Z(x)$	-	Objective value of current solution

$Z(x^*), Z^*$	-	Best objective value out of $k \in K$ iterations
Z	-	Objective value
Z_b^*	-	Best objective value for each $b \in B$ run
Z_{Ave}	-	Average solution (objective values)
Z_{best}	-	Overall best solution (objective value)
Z^{ψ}	-	Best objective value out of B runs
T_{Ave}	-	Average computational time in seconds
$P(\delta)$	-	Probability of acceptance
T_0	-	Initial temperature
T_f	-	Final Temperature
T_k	-	Temperature update coefficient
T_s	-	Tabu list size
U_k	-	Absolute value of neighbourhood solution minus current solution
Z_k	-	Current objective value
Z_{k-1}	-	Previous objective value
C	-	Depth of the deepest local minimum
U	-	Upper bound
B	-	Number of runs
$C_{\max}$	-	Estimation of the maximum value of the cost function
c	-	Boltzmann's constant
δ	-	Change in total distance or real number
θ	-	Random number between 0 and 1
γ	-	Small real number
p	-	Integer value

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Facility Layout Problem (FLP) is an arrangement of the facilities in the floor layout which significantly impact the manufacturing costs, production times and productivity level. Facilities layout and design includes optimally locating equipment, materials, people, infrastructure and data collection points to minimize costs, movement, handling, and travel distance of the material and labor while increasing overall productivity (Scholz *et al.*, 2008). In general terms, FLP smooth the way to access facilities for better production or delivery of services in any job performance. Thus, a good facilities arrangement in layout can reduce up to 50% of the total operating expenses and improves the overall operations efficiency (Drira *et al.*, 2007).

1.2 Background of the Study

In general, FLPs are known to be complex and *NP*-hard problem (non-polynomial) (Balakrishnan *et al.*, 2003a). In order to elucidate this problem, various optimization approaches for small problems and heuristic approaches for the larger problems have been proposed. But, many of approaches are not optimally solved for more than 20 unequal-sized of facilities (Wang *et al.*, 2005).

After an inactive period, a layout problem has now gained new interest and more attention in recent years. The new challenges for the FLP have evolved since the companies started to aware on the importance of productivity improvements. This is because the facility layout determines the basic structure of the production system which has a considerable impact on the attainable efficiency (Bock and Hoberg, 2007).

Besides, the product or service design in the manufacturing or service system will respond to changes quickly in a well design layout. In the context of a manufacturing environment, the option for a good layout system is extremely important to rationalize the involved activities. So, it is equally important to the implementation of the manufacturing system and to its daily operation. This occurs frequently in a flexible manufacturing system due to the high cost of the acquisition of facilities and the operational of material handling carries (Alvarenga *et al.*, 2000).

FLP is also one of the well-studied problems in the field of combinatorial optimization (Meller *et al.*, 2007). For FLP, various formulations have been developed. More particularly it has been modeled either as quadratic assignment problem (QAP), quadratic set covering problem (QSP), linear integer programming (LIP) problem, mixed integer programming (MIP) problem or graph theoretic problem (Kusiak and Heragu, 1987; Alvarenga *et al.*, 2000 and Balakrishnan *et al.*, 2003a).

In the past, FLP has been mostly modeled as a QAP, graph oriented approach or MIP problems. The main drawback of QAP and QSP is that they suffer from fundamental limitations which are the potential locations identification (Xie and Sahinidis, 2008) and the unequal-sized FLP cannot be considered sufficiently. Meanwhile, the disadvantage in using graph oriented approach is that the facility dimensions are not considered during optimization. It only been used after the layout is constructed according to the optimal graph (Osman, 2006 and Scholz *et al.*, 2008). Furthermore, up to now MIP models of FLP used to be solved optimally for only less than ten facilities in a reasonable computational time (Sherali *et al.*, 2003; Castillo and Westerlund, 2005 and Castillo *et al.*, 2005).

In the broadest sense, QAP has been traditionally used to model the equal-sized FLP (Mavridou and Pardalos, 1997 and Drira *et al*., 2007), including urban planning, control panel layout, and wiring design (Meller and Gau, 1996). However, more than 20 departments in a facility layout are unlikely to be solved optimally using QAP model (Balakrishnan *et al*., 2003a).

In real application, departments accomodate unequal-sized and based on the past studies, the QAP formulation is less attractive for the unequal-sized FLP (UFLP) compared to the equal-sized FLP (Logendran and Kriausakul, 2006). This is because of the criterion choice used in finding the best layout from various solutions are not easy for UFLP. Since formulating the UFLP as a QAP has one major disadvantage where one must specify the possible locations for all facilities which is discretizing the problem (Auriel and Golany, 1996). Thus, it is better to formulate the UFLP without specifying the location especially for unequal size.

Meanwhile, Armour and Buffa (1963) proposed the UFLP using the pair wise exchanged approach to solve it. After their work, UFLP was started to attempt by few other authors. These include a nonlinear optimization method by Van Camp *et al*. (1991), simulated annealing approach by Tam (1992b), clustering approach by Hon-iden (1996) and genetic algorithmic approach by Tate and Smith (1995a and 1995b), Banerjee *et al*. (1997), and also by Gau and Meller (1999).

Nowadays, researchers seek for various approximate methods including various local search and metaheuristics approaches to find optimal solutions for these problems in a reasonable computational time (Balakrishnan *et al*., 2003a and Ramkumar *et al.*, 2008a). Researches have applied recent search techniques such as simulated annealing (SA), tabu search (TS), genetic algorithm (GA), and ant colony optimization (ACO) which have proved to be effective.

As a final remark, the commercial software tools available on the market to globally assist in the design of manufacturing are currently limited. The commercial software tools such as CRAFT, CORELAP, ALDEP, PLANET, WINSABA and

AutoCAD using Systematic Layout Planning can only cater for square or rectangular cell shape and the usage is limited to a type of reference cell (or facility) only. Therefore, there is a need to make the resolution approaches more generic, so that the layout procedures can be embed in software tools supporting the design of manufacturing systems (Drira *et al.*, 2007).

1.3 Statement of the Problem

Based on the literature review, UFLP are given less attention compare to equal-sized FLP. This is because of the criterion choice used in finding the best layout from various solutions are not easy for unequal-sized FLP especially for large problem size. Most of the past research deals with one type of facility such as machine or department in the layout design. Besides, more than 20 unequal size departments in a facility layout are unlikely to be solved optimally. Thus, the intent of the research is to introduce a new mathematical model for UFLP that can solved large problem size which deals with more than one type of facility in the layout design.

For the solution method, simulated annealing (SA) works well and produce good results compare to genetic algorithm and tabu search based on the literature review. Since the UFLP is complicated and deals with large problem size, a simple SA do not works well for this type of problem. Thus, an improved SA with the concept of tabu list size is adopted in order to solve the large problem size of UFLP. The success of the SA is determined by the choice of the temperature setting schemes, temperature reduction rules, initial temperature and stopping criteria. These factors are capable in improving the performance of an SA algorithm in order to produce a good solution procedure for UFLP.

In order to reduce the time consumed for decision making in facility layout design, a software is in need. However, until now, only few effective and user-friendly computer aided tools have been proposed for this purpose. Moreover, the software can only cater for one type of functional tool only. Motivated by this, a software that uses SA as the solution techniques and can deal with more than one type of functional tools has to be developed.

1.4 Objectives of the Study

There are a few objectives that expect to achieve at the end of this research. They are:

1. To formulate mathematical model for the unequal-sized FLP (UFLP) with constraints of preventing blocks from overlapping, blocks located within the boundaries of the layout and allocate space between blocks.
2. To improve Simulated Annealing (SA) algorithm for solving large problem size of UFLP based on implementing new temperature setting schemes, constructing a novel temperature reduction rules and the parameter settings for initial temperature and stopping criteria.
3. To develop a software as an interface to ease and aid the visualization of the problem, algorithm and solution using Microsoft Visual C# Language.

1.5 Significance of the Study

In this research, there are a few significance of the study as follows:

1. The constructed model will better visualize real-life UFLP.
2. Efficient parameter settings for initial temperature, temperature setting schemes, temperature reduction rules and stopping criteria for the proposed SA algorithm.
3. The developed software can be implemented to solve real-life UFLP.

1.6 Scope of the Study

This research is bounded by the following field of reference:

1. Particularly focuses on UFLP with sequential functional tools arrangement.
2. The layout of a manufacturing facility is studied, and its distance traveled between functional tools and perimeter utilization with normalize weight factors are used to measure the layout efficiency.
3. The distance traveled between functional tools are measured using pick-up and drop-off (P/D) points based on rectilinear distance.
4. Assumption are made that the flow between blocks does not change with their arrangement and remains the same after a complete facility layout is generated by the algorithm (fixed flow), reserve empty space in the layout, there is space between functional tools and blocks and the tools are placed in a sequential manner.
5. SA algorithm is chosen as the solution method to solve the UFLP.
6. The performance of the algorithms is measured based on the solution quality.
7. The parameters of the proposed algorithm that will be investigated are initial temperature, temperature reduction rules, temperature setting schemes and stopping criteria.
8. The algorithm and software will be developed using Microsoft Visual C# Language.

1.7 Outline of the Thesis

This thesis is divided into seven major chapters. Chapter 1 consists of the research framework for this research. It contains the introduction, background of study, problem statement, objectives of the study, significance of the study, scope of the study and the thesis organization for the whole research.

This is followed by Chapter 2, which elaborates the literature review of the facility layout problem (FLP), basic type of layout, classification and formulation of various FLP. Related works on FLP are also presented in this chapter. This chapter also explores and provides a review on the solution methods for solving the UFLP namely non-heuristic methods, heuristic methods, metaheuristic methods and hybrid heuristics.

Chapter 3 describes the research methodology adopted. This includes all the steps involved in conducting this research. Then, chapter 4 presents the problem descriptions, mathematical model, solution method, program construction and software development for UFLP in this research.

Chapter 5 briefs the improved temperature setting schemes with the initial parameters settings that are implemented in the SA algorithm for the UFLP in this research. Experiments results were presented to find the best solution using the proposed temperature setting schemes in this research.

Meanwhile, Chapter 6 reviews the new temperature reduction rules used in SA algorithm. It also contains the experiments results to test the accuracy of the algorithms and the quality of the solutions for the proposed temperature reduction rules using different temperature setting schemes. Based on the experiments that were conducted, this chapter analyzes the overall results based on the discussion.

Finally, Chapter 7 outlined the conclusions, contributions and recommendations for future research.

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