Robotics and Computer-Integrated Manufacturing 25 (2009) 620–629

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

A new iterated fast local search heuristic for solving QAP formulation in facility layout design

A.S. Ramkumar [a], S.G. Ponnambalam [b,*], N. Jawahar [c]

[a] *Amrita School of Engineering, AVVP, India*
[b] *School of Engineering, Monash University, Sunway Campus, Malaysia*
[c] *Thiagarajar College of Engineering, Madurai, India*

ARTICLE INFO

Article history:
Received 23 November 2006
Received in revised form
26 February 2008
Accepted 31 March 2008

Keywords:
Facility layout design
Quadratic assignment problem
Heuristic
Search algorithm

ABSTRACT

In facility layout design, the problem of locating facilities with material flow between them was formulated as a quadratic assignment problem (QAP), so that the total cost to move the required material between the facilities is minimized, where the cost is defined by a quadratic function. In this paper, we propose a modification to iterated fast local search algorithm (IFLS) with a new recombination crossover operator and the modified IFLS is addressed as NIFLS. The ideas we incorporate in the NIFLS are iterated self-improvement with evolutionary based perturbation tool, which includes (i) recombination crossover as perturbation tool and (ii) self-improvement in mutation operation followed by a local search. Three schemes of NIFLS are proposed and the obtained solution qualities by the three schemes are compared. We test our algorithm on all the benchmark instances of QAPLIB, a well-known library of QAP instances. The performance of proposed recombination crossover with sliding mutation (RCSM) scheme of NIFLS is well superior to the other two schemes of NIFLS.

1. Introduction

The quadratic assignment formulation in facility layout design is a well-studied combinatorial optimization problem in manufacturing planning. Manufacturing companies spend a significant amount of time and money in designing or redesigning the facilities because the design of a facility layout has a tremendous effect on the operation of the system that it houses. A poor facility layout design will cost more and may result in poor system performance as well as customer satisfaction [1]. For the equal sized facility layout problem, the quadratic assignment problem (QAP) first proposed by Koopmans and Beckman [2] is used to model the problem. Since the QAP is notoriously difficult for exact solution methods even for smaller size problems, i.e. number of facilities less than or equal to 30, the development of a good heuristic procedures based on metaheuristics and evolutionary based search procedures are gaining importance among the researchers [3]. Evolutionary algorithms are typically stochastic processes and have been applied to many fields of combinatorial optimization. It has been shown that augmenting evolutionary algorithm with problem-specific heuristics can lead to highly effective approaches [4].

Evolutionary algorithms are search and optimization procedures that find their origin and inspiration in the biological world. Evolutionary algorithms are general term encompassing a number of related methodologies all of which are based on the natural evolution paradigm. Genetic algorithms, Evolution strategies and Evolutionary programming, are the historically prominent approaches emerging in recent years. An iterated fast local search algorithm (IFLS), a GA heuristic, is shown as promising one for QAP formulations [5]. In this paper, we propose a modification to IFLS with a new recombination crossover (RC) operator and the modified IFLS is addressed as NIFLS.

2. The quadratic assignment problem

The QAP is the problem of assigning n facilities to n locations, so that the cost of the assignment which is a function of the way facilities have been assigned to locations is minimized and it is first formulated in Ref. [2]. Since then it has been recognized as a model of many different real situations; applications have been described concerning planning of buildings in university campuses, arrangement of departments in hospitals, warehouse management and distribution strategies, minimization of the total wire length in electronic circuits, ordering of correlated data

* Corresponding author. Tel.: +60 3 55146203; fax: +60 3 55146207.
E-mail addresses: as_ramkumar@ettimadai.amrita.edu (A.S. Ramkumar), sgponnambalam@eng.monash.edu.my (S.G. Ponnambalam), jawahartce@tce.edu (N. Jawahar).

0736-5845/$ - see front matter
doi:10.1016/j.rcim.2008.03.022

in magnetic tapes and others [6]. Mathematically the QAP formulation in facility layout design is defined by two matrices of dimension $n \times n$: Let,

- $D = (d_{ij})$: the distance from location i to location j;
- $F = (f_{ij})$: the flow of materials from facility i to facility j.

Matrices D and F are integer-valued matrices. The cost of transferring materials between two facilities can be expressed as the product of the distance between the locations to which the facilities are assigned, i.e. expressed as a quadratic function of $f_{ij} \times d_{\pi(i)\pi(j)}$. To solve the QAP one must thus find a permutation Π of the indices (1, 2, …, n) which minimizes the total assignment cost:

$$\min_{\pi} \sum_{ij} f_{ij} d_{\pi(i)\pi(j)}. \tag{1}$$

In addition to the facility layout design, the QAP arises in many other applications, such as the allocation of plants to candidate locations, backboard wiring problem, design of control panels and typewriter keyboards, turbine balancing and ordering of inter-related data on a magnetic tape, etc. The details can be found in Refs. [7–9]. Since QAP is known to be NP hard, the research community has investigated it extensively. Exact algorithms for solving QAP include approaches based on (i) branch and bound [10,11], (ii) cutting planes [12], and (iii) dynamic programming [13]. Among these, the branch and bound algorithms are the most successful, but they are generally unable to solve problems of size larger than $n = 30$. Branch and bound techniques have evolved greatly over the past 40 years [14], starting with Gilmore [15] who solved a QAP of size $n = 8$, and Anstreicher [3] solved a QAP of size of 30 in 2000.

3. Heuristics for QAPs

Heuristics or suboptimal algorithms are often used to estimate solutions for QAP instances. These procedures can produce good answers within reasonable time constraints. There are following categories of heuristics for the QAP: construction methods, limited enumeration methods, improvement methods, simulated annealing techniques, and genetic algorithms. Construction methods create suboptimal permutations by starting with a partial permutation which is initially empty. The permutation is expanded by repetitive assignments based on set selection criterion until the permutation is complete. The CRAFT (Computerized Relative Allocation of Facilities Technique), used for the layout of facilities was first introduced by Armour and Buffa [16]. Limited enumeration methods are motivated when one expects that an acceptable suboptimal solution can be found early during a brute force enumeration examination. Imposing either a time limit or an iteration limit could terminate such an enumeration method and these improvement methods are the most researched class of heuristic [8]. The popular methods are iterated local search and the tabu search. Both methods work by starting with an initial basic feasible solution and then attempting to improve it. The local search iteratively seeks a better solution in the neighborhood of the current solution, terminating when no better solution exists within that neighborhood [17]. The tabu search [18,19] works similarly to the local search; however, it is sometimes more favorable since it was designed to overcome the problem of a heuristic getting trapped at local optima. Simulated annealing method receives its name from the physical process that it imitates. This process, called annealing moves high-energy particles to lower energy states with the lowering of the temperature, thus cooling a material to a steady state. Initially, in the initial state of the heuristic, the algorithm is lenient and capable of moving to a worse solution. However, with each iteration, the algorithm becomes stricter requiring a better solution at each step [17]. For more details on these methods, see Refs. [20,21].

Genetic algorithms receive their name from an intuitive explanation of the manner in which they behave. This explanation is based on Darwin's theory of natural selection [8]. Genetic algorithms store a set of solutions and then work to replace these solutions with better ones based on some fitness criterion, usually the objective function value. Genetic algorithms are parallel and are helpful when applied in such an environment. Greedy Randomized Adaptive Search Procedure (GRASP) is a relatively new heuristic used to solve combinatorial optimization problems. At each iteration, a solution is computed by randomized search process and the final solution is taken as the one, which is the best after all GRASP iterations are performed. Li et al. [22] first applied the GRASP heuristic to 88 instances of QAP in 1994 and almost finding the best known solution in every case, and improved solutions for a few instances.

In recent times, attempts are made to solve QAP by heuristic approaches. It includes (i) construction methods [23,24], (ii) limited enumeration methods [6,25], (iii) GRASP [22], (iv) simulated annealing [26], (v) tabu search [27,28], (vi) genetic algorithms [29–31] and (vii) ant systems [32–34]. Talbi et al. [35] presented a parallel ant colony model to solve QAPs. The exploration of the search space is guided by the evolution of pheromones levels, while exploitation has been boosted by a tabu local heuristic. Solimanpur et al. [36] proposed an ant algorithm based inter-cell layout problem with material flow between the cells, modeled as a QAP. Singh and Sharma [37] reviewed the state-of-the-art papers on facility layout problem with quadratic assignment model and mixed integer programming models. A detailed analytical survey for the QAP is presented in Loiola et al. [38].

4. QAP instances

It is known from recent research on solving QAPs, the particular type of a QAP instances have a considerable influence on solution quality. According to Ref. [39] four classes of QAP have been defined. Class (i), Unstructured, randomly generated instances in which, the distance and flow matrix entries are generated randomly by uniform distribution. Class (ii), Grid-based distance matrix instances in which, the distance matrix stems from a $n_1 \times n_2$ grid and the distances are defined as the Manhattan distance between grid points. Class (iii), Real-life instances in which, the flow matrices have many zero entries and the remaining entries are clearly not uniformly distributed. Class (iv), Real-life like instances in which, the instances are generated in such a way that the matrix entries resemble the distributions found for real-life problems.

5. Proposed methodology

In this section, the features of NIFLS are described. NIFLS is a hybrid algorithm having population of size 2. The number of iterations used for termination criterion governs the complexity of the algorithm. Initial parents are generated randomly. A permutation of the machine size 'n' is mapped into chromosome with the alleles assuming different and non-repeating integer value is the $[1, n]$ interval. The objective function of the permutation π is $F(\pi)$ to minimize the cost function of the QAP, i.e. $\min Z = \min F(\pi)$. The flow chart of the proposed algorithm is shown in Fig. 1.