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# A non dominated ranking Multi Objective Genetic Algorithm and electre method for unequal area facility layout problems

Giuseppe Aiello, Giada La Scalia *, Mario Enea

*Dipartimento di Ingegneria Chimica, Gestionale, Informatica, Meccanica, University of Palermo, Italy*

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ABSTRACT

The unequal area facility layout problem (UA-FLP) comprises a class of extremely difficult and widely applicable optimization problems arising in diverse areas and meeting the requirements for real-world applications. Genetic Algorithms (GAs) have recently proven their effectiveness in finding (sub) optimal solutions to many NP-hard problems such as UA-FLP. A main issue in such approach is related to the genetic encoding and to the evolutionary mechanism implemented, which must allow the efficient exploration of a wide solution space, preserving the feasibility of the solutions and ensuring the convergence towards the optimum. In addition, in realistic situations where several design issues must be taken into account, the layout problem falls in the broader framework of multi-objective optimization problems. To date, there are only a few multi-objective FLP approaches, and most of them employ over-simplified optimization techniques which eventually influence the quality of the solutions obtained and the performance of the optimization procedure. In this paper, this difficulty is overcome by approaching the problem in two subsequent steps: in the first step, the Pareto-optimal solutions are determined by employing Multi Objective Genetic Algorithm (MOGA) implementing four separate fitness functions within a Pareto evolutionary procedure, following the general structure of Non-dominated Ranking Genetic Algorithm (NRGA) and the subsequent selection of the optimal solution is carried out by means of the multi-criteria decision-making procedure Electre. This procedure allows the decision maker to express his preferences on the basis of the knowledge of candidate solution set. Quantitative and qualitative objectives are considered referring to the slicing-tree layout representation scheme. The numerical results obtained outperform previous referenced approaches, thus confirming the effectiveness of the procedure proposed.

## 1. Introduction

The facility layout problem (FLP) is the determination of the most efficient physical arrangement of a number of interacting facilities on the factory floor of a manufacturing system in order to meet one or more objectives. Facilities usually represent the largest and most expensive assets of the organization and are of crucial importance to the organization (Nordin, Zainuddin, Salim, & Ponnusamy, 2009). Tompkins et al. (1996) estimate that between 20% and 50% of operating cost can be attributed to facility planning and material handling., and such costs can be reduced considerably by an effective layout design. Several heuristic approaches have been proposed in the literature in the recent years to find (sub-) optimal solutions to the FLP, including simulated annealing algorithms, tabu search methods, neural networks and genetic algorithms (GAs). According to Sirinaovakul and Thajchayapong (1994), a frequent drawback of such algorithms is that they do not explore enough possibilities while generating their solutions thus being extremely sensitive to the initial solution. Heragu and Alfa (1992) sited these algorithms as local optimization algorithms which, once hit an unattractive region, had no way of backing out and exploring other regions. Glover and Greenberg (1989) noted that reliable heuristic algorithms are not sensitive to their initial solutions and that an exhaustive search of the solution space can be achieved by parallel processing. This should avoid the search procedure to be trapped into inferior solution regions. A GA is a stochastic search technique based on the concept of the survival of the best, emulating the mechanisms of the Darwinian evolution, thus achieving a sub-optimal solution via recursive operations of crossover and mutation (Holland, 1975; Michalewicz, 1992). Most of the studies conducted in FLPs have focused on a single objective, either quantitative or qualitative goodness of the layout (Tuzkaya & Ertay, 2004). In contrast, practical FLPs involve several conflicting objectives. Therefore, both quantitative and qualitative objectives must be considered simultaneously before arriving at any conclusion. A layout that is optimal with respect to a given criterion might be a poor candidate when another criterion is paramount.

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* Corresponding author.
*E-mail addresses:* giada.lascalia@unipa.it, lascalia@dtpm.unipa.it (G. La Scalia).

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In general, minimization of the total material handling (MH) cost is often used as the optimization criterion in FLPs. The closeness rating, hazardous movement, safety, and the like are also important criteria in FLPs. In fact, these qualitative factors have significant influence on the final layout and should give consideration. Consequently, the FLP falls into the category of multi-objective optimization problem (MOOP). Multi-objective optimization is a technique to treat several objectives simultaneously without converting them into one. The objective of MOOPs is to find a set of Pareto-optimal solutions, which are the superior solutions when considering all the objectives. In MOOPs, the absolute optimal solution is absent and the designer must select a solution that offers the most profitable trade-off between the objectives as an alternative. Thus, instead of offering a single solution, it is more realistic and appropriate to generate a number of "good" layouts that meet several criteria laid down by the facility designer and let decision makers choose between them based on the current requirement. Presumably, the most comprehensive way to take all these features into consideration in the selection process is to personally involve the decision maker(s) in the selection process, which is the procedure adopted in the Interactive Genetic Algorithms (Brintup, Takagi, Tiwari, & Ramsden, 2006) which have been recently applied to FLP (Hernandez, Morera, & Azofra, 2011). Such procedure, however, may expose the decision maker to a time consuming activity, and may result unpractical in many contexts, where a structured and transparent decision making is required. In such cases a fully automated procedure is preferred to select at least a set of best solution candidates, thus allowing the decision maker to evaluate a limited number of alternatives. For such purpose the different objectives are frequently combined into a single one by means of some aggregation procedures such as in the weighted sum method. The drawbacks of these methodologies are well documented in the multi-objective decision theory, as well as the benefits of a "true" multi-objective exploration of the solution space, resulting from a Pareto based approach. Pareto approaches (Goldberg, 1989) involve the evolution of the Pareto front constituted by the fitness of a generic individual corresponding to each optimality criterion considered. It has been recognized the GAs belonging to this class generally outperform the non-Pareto Based approaches (Tamaki, Kita, & Kobayashi, 1996; Zitzler & Thiele 1999). The methodology here proposed refers to the class of Pareto-based and is developed according to the framework of non-dominated sorting GA (NSGA) proposed by Srinivas and Deb (1995). More specifically, in this paper we propose a novel Multi Objective Genetic Algorithm (MOGA) to solve the facility layout problem considering four separate objectives based on an advanced encoding structure in order to ensure an efficient exploration of the search space. The objectives considered are commonly employed in the literature (Aiello, La Scalia, & Enea, 2012; Harmonosky & Tothero, 1992; Meller & Gau, 1996; Srinivas & Deb 1995), namely the minimization of the total Material Handling Cost the distance and the closeness requirements among the departments, and the desired aspect ratio. Additionally, the presence of feasibility constraints, required to ensure the practicability of the solution determined, may significantly hamper the convergence of the algorithm, which consequently requires a solid and efficient structure. In particular, it is well known that the very basic and most crucial component of a GA is related to the solution representation (i.e. the chromosome encoding scheme), as it significantly affects the overall performance of the algorithm and the quality of the solutions obtained (Datta, Amaral, & Figueira, 2011). In order to be implemented in a genetic algorithm, a layout representation scheme must be encoded into a string form, suitable for being employed within the common genetic operators such as mutation and crossover. The simplifications introduced in the layout representation in order to cope with these requirements, and to ensure that a chromosome can be easily decoded to a unique layout scheme, generally restrict the flexibility of the representation, thus limiting the feasible search space. The two general mechanisms reported in the literature for constructing such layouts are the flexible bay structure (FBS) developed by Goetschalckx (1992), and the more recent slicing tree structure (Arapoglu, Norman, & Smith, 2001; Moghaddam & Shayan, 1998). The slicing structure results from dividing an initial rectangle either in horizontal or vertical direction completely from one side to the other (guillotine cut) and recursively going on with the newly generated rectangles (Scholz, Jaehn, & Junker 2010). The Multi Objective Genetic Algorithm (MOGA) here proposed is hence based on a slicing tree encoding in order to ensure an efficient convergence towards the Pareto frontier, outperforming the current referenced approaches. Finally, the best block layout is determined by employing the well known multi-criteria decision-making procedure Electre. The remainder of this paper is organized as follows. Section 2 describes the genetic algorithm implemented in this study for the facility layout problem and in particular the ranking procedure adopted. To show performance of the suggested algorithm, comparative experiments are done in Section 3. In Section 4 the best solution is determined by means the Electre method and Section 5 concludes the paper with a short summary of the results obtained.

## 2. Genetic Algorithm

A lot of optimal and heuristic algorithms for solving FLPs have been developed in the past few decades. The majority of these approaches adopt a problem formulation known as the quadratic assignment problem (QAP) that is particularly suitable for equal area facilities. The main drawback of these approaches is that geometric constraints, e.g. unequal sizes of facilities, are not taken into account. In such situations, random search algorithms are the only practicable alternative, although they may just lead to a near-optimal solution. In its classical formulation the UA-FLP involves the minimization of the total material handling cost, however the needs of the real world of dealing with several design criteria such as the space utilization, flexibility, employee satisfaction and safety emerged already in the early stages of research (Muther & Boston, 1973). Consequently, to be more realistic, some researchers have considered more than a single objective in their solution approach to the UA-FLP. The presence of multiple objectives in a single optimization problem, however, significantly affects the optimization procedure since, for example, it gives rise not only to a single optimal solution but to a set of optimal solutions (largely known as Pareto-optimal solutions). In the absence of any additional information, each one of these Pareto-optimal solutions cannot be said to outperform any other. Classical optimization methods (including the multi-criteria decision-making methods) suggest converting the multi-objective optimization problem to a single-objective optimization problem thus emphasizing one particular Pareto optimal solution. According to this concept several authors combine the different objectives into a single one for example by means of Analytic Hierarchy Process (AHP) methodology (Harmonosky & Tothero, 1992; Yang & Kuo, 2003) or using a linear combination of the different objectives (Chen & Sha, 2005). Lee, Roh, and Jeong (2005) propose a genetic algorithm (GA) for multi-floor design considering inner walls and passages, using the weighted method approach to minimize the departmental material handling cost and maximizing closeness rating. A similar approach is proposed by Ye and Zhou (2007), who developed a hybrid GA-Tabu search (TS) algorithm. Over the past two decades, more advanced researches have led to the formulation of multi-objective evolutionary algorithms (MOEAs) (Coello et al., 2007; Day, 2005; Deb, 2001), with the objective to find multiple Pareto-optimal