Using genetic algorithms on service facilities layouts design

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Abstract

Traditionally, the objective of a service facility layout problem is to minimize the material handling cost and optimize the physical spaces that support a productive activity of the service system. Service delivering interface has direct impact to the efficiency and effectiveness of service system in light of customer's contact. Layout problem of service facilities has received little attention in the literature. Due to complexity and combination of the facility layout problems, the genetic algorithm is put forward that codifies a chromosome and uses a direct representation to assign the departments to the different branch areas, enables good solutions to be justified in real instances of the problem in tourist service centre. The solution is shown on a decision plan representing the graphic layout of the departments within the service facility. This application is highly flexible that the decision maker can accordingly define the departments' number to be accommodated, facility sizes, segment sizes, and algorithm parameters to be added or simplified.

Keywords: Layout design; Service facility; Genetic algorithm; Tourist service centre

1 Introduction

When designing a service facility, one of many important issues is the need to minimize material handling costs and optimize the physical spaces that support a productive activity of the service system. A good facility layout can reduce these costs by at least 10%-30% and 8% of the U.S. gross national product has been spent on new facilities every year since 1955 and modifications of existing facilities are not included [1]. To find the optimization of the design of facility layout is important in both manufacturing and service industries [2]. Closely related methods can be used when designing of airports, public service platforms and similar installation where efficient flow of customers, working stuff, supporting materials and information is of great importance.

The Facility Layout Problem is based on the optimal allocation of all the departments that are involved in a productive process in order to achieve the economy of resources such as space and time. A facility or department is a physical entity that facilitates the development of any productive process. The minimum parameters required to solve the problem are: number of departments, size of the office, size of the departments to be located, flow matrix between the departments of the branch and the unit transportation cost matrix. Absolute costs are not necessary in order to compare the layout alternatives, so all the unit costs are assumed to be equal (even all equal to unity) in practice [3]. A flow matrix can be changed for a perception matrix where the desirable proximity between departments is represented. As a

solution of the problem, the optimal position of each department in the branch is obtained.

In recent years, a lot of suboptimal approaches have been developed to solve Facility Layout Problems (FLPS). Given that this problem falls into the class of NP-complete problems, suboptimal methods are used to solve it. Previous works had used techniques like Tabu Search [4], Simulated Annealing [5] and Genetic Algorithms [6]. The application of Tabu Search to the Facility Layout Problem has a strong relation with the Quadratic Assignment Problem (QAP). The results suggest that a good Tabu list sizes increase with dimension of the problem and the best known solutions were obtained using less CPU time than previously reported in the literature for the standard problems tested. An adaptation of Simulated Annealing procedure based on the model to solve the problem, where good layouts to small and medium problems are obtained and conclusions about the metheuristic performance for big problems are established [5]. Gas outperforms other heuristic methods. GAs start by producing initial population and stop by reaching sub-optimization via genetic operators such as reproduction, crossover and mutation [7]. Each individual in a population acts once and in parallel to avoid failing onto a local optimal domain. The possibilities for reaching a global optimization are increased. Genetic algorithm is one the most frequently techniques inside the literature as method to solve combinatorial optimization problems and are considered to be an effective and robust approach. When solving the FLPS using Gas, each individual the population represents one facility layout.

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The fitness of each facility1ayout is found, and as always, the best individuals get to pass the chromosomes on to the next generation. David M. Tate etc. [8] describes a GA approach to QAP that finds solutions competitive with those of the best previously-known heuristics, and argue that genetic algorithms provide a particularly robust method for QAP and its more complex problems. In addition, Islier etc. presents a model based on GA to facility layout using a load factor, a shape factor and a deviation factor to build the objective function [3]. This model has been widely used. For a Facility Layout Problem variation, that is the multi-channel manufacturing system design, Ozcelik and Islier propose a model based on GA to get better solutions for a problem found in the literature and found solution for a real life problem [9]. The technique chosen for this study was Genetic Algorithms with an improvement and construction approach.

This paper describes the adaptation of GA to the Facility Layout Problem. In Section 2 some generalizations about genetic algorithms are presented. The problem description and the model proposed are described in Section 3. The description of the proposed GA strategies, the chromosome design and the implementation are showed in Section 4. A genetic algorithm for the facility layout of a virgin office is proposed in Section 5. An experimental design to evaluate the algorithm efficiency is described in Section 6. The computational results and a comparison between actual and obtained layouts for each instance are presented in Section 7. Finally, conclusions are given in Section 8.

2 Genetic algorithms

Genetic Algorithms (GA) are random directed search techniques [10]. It was invented by John Holland, professor of the Michigan University, who published his article "Adaptation in Natural and Artificial Systems" in 1975. Genetic Algorithms (GAs) are the heuristic search and optimization techniques that imitate the natural selection and biological evolutionary process. They arose as an alternative form to the gradients methods, which could result little practical when searches in a n-dimensional space are made and multiple relative optimal are present [11]. They are inspired on the evolution and natural selection processes. GAs combine the notion of survival of the fittest, random and yet structured search, and parallel evaluation of nodes of search space [12]. A genetic algorithm consists of a string representation (chromosomes) of nodes in the search space, a fitness function to evaluate the search nodes, and a stochastic assignment to control the genetic operators. Thus, their operators, which are based on evolutionary methods, act on the individuals pertaining to each generation in order to find solutions that represent improvements in the objective function. The individuals (pertaining to the population) within an AG are feasible solutions of the

problem. The population is a subset of the space solution and its size depends on the treated problem. Each individual of the population is represented by a chromosome. This is a mixture of symbols known like genes. The basic representation methods of the individuals are binary and integer or real numbers vectors. The construction of a genetic algorithm for FLP can be separated into the following and yet related tasks:

- Coding of a facility layout.
- Determination of fitness functions.
- Designing of genetic operators.
- Implementation of GAs.

A challenging problem in applying the GA is the coding of solutions of the facility layout as chromosomes. Take care to ensure that the meaning of original problem is preserved under the coding scheme. Commonly used representations are non-binary chromosomes, which consist of non-binary genes and are often called enumerated representation. In spite of the difficulty in codifying the individuals, to design the search strategies in which the allocation of the specific parameters of the problem is fundamental and the management of the constraints of the problem through genetic algorithms, it is possible to obtain good distributions from a guided search on a small fraction of the solutions space [13].

3 Problem formulation

Theme problem consists in establishing the optimal layout for four offices of a real tourist service centre network, through a computational implementation using a metaheuristic technique, with the purpose of increasing the efficiency in the operation of the same ones. The metaheuristic selected was Genetic Algorithms. The offices considered in this study were chosen because they were representative of different branches types. The selection process was in charge of a team of people that is part of the commercial management of the tourist service centre. The first of the four offices of the financial organization considered in this study consists of two plants. That is the reason why in the development of this work, each one of these will be considered like an independent office. Hence, five offices will be handled, and these will be the instances of the problem. The measures of the office and the departments corresponding to each studied branch were obtained from the planes provided by the tourist service organization. From interviews made to the commercial and operative managers of the tourist service centre network, surveys were obtained in which the relative importance of proximity between the departments of each office was graded. This set of grades, that from now on we will call perception matrix, are analogous to the measurement of the flow. Given that, the greater the flow between a pair of departments, the greater will be importance of proximity between them, and then the qualification in the perception matrix will be proportional to the flow

between departments. The format used is a variation of the relation activities diagram proposed by Muther [14].

The model proposed by Islier does not applied to the problem treated in this project, since although it is wanted to minimize the work load; a unit costs matrix is not available. On the other hand, a fixed area for each department exists, since the dimensions of the facilities are established from the beginning of the layout design process, unlike the model by Islier where minimum and maximum wished areas of each department are established. Thus, the following model is proposed:

Given the problem's nature, the objective function is:

$$O.F. = \sum_i \sum_j [f(i,j) * d(Z(i), Z(j))], i, j \in [1, N].$$

Subject to:
The departments are not overlapped to each other.
The departments and office area is respected.
The flank to which each department belongs is respected.
A relative fixed position for some departments is conserved.
Where:

N is the number of departments.

$f(i,j)$ represents the flow between department i and department j.

$d(Z(i), Z(j))$ represents the distance between the rectangles' centroids, where department i and department j are located, according to the allocation defined by the chromosome.

This distance is measured using rectilinear metric, thus:

$$d_{ij} = |x_i - x_j| + |y_i - y_j|, i, j \in [1, N],$$

where:

d_{ij} is the distance between department i and j.

x_i is the horizontal coordinate of the centroid of department i.

y_i is the vertical coordinate of the centroid of department i.

x_j is the horizontal coordinate of the centroid of department j.

y_j is the vertical coordinate of the centroid of department j.

4 Genetic algorithms for the facility layout problem

The problem solution is represented in a chromosome that is divided in five parts. The first four ones represent the flanks of the office (West, North, East and South), the fifth one represents the departments which the client does

not have direct access and they are in the office back part. Each one of the first four parts of the chromosome contains the numbers of the departments in the order in which they are located. The ordering of departments within the plane is made in the sense of the movement of the clock's hands. The fifth part contains the numbers of the departments located in the back part of the office, in form of "columns", which go from left to right, and are filled from top to bottom. For greater clarity we present the following example:

The chromosome:

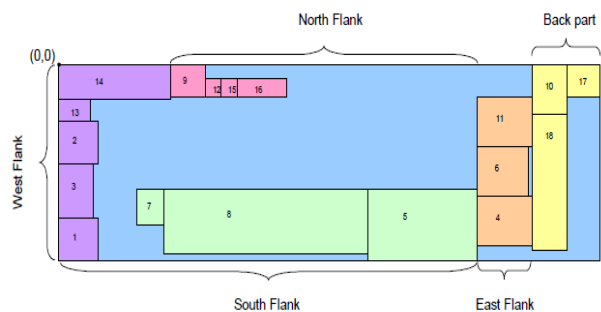| 1 | 3 | 2 | 13 | 14 | 9 | 12 | 15 | 16 | 11 | 6 | 4 | 5 | 8 | 7 | 10 | 18 | 17 |

Represents the layout in figure 1.

FIGURE 1 Layout corresponding to the representation
of the previous solution

In order to generate the initial population, to each one of the parts of the previous chromosome, a random number of interchanges between departments is made, as long as there is no constraint forbidding the interchange. From this process a new chromosome is generated that along with others generated of the same way, conforms the initial population.

The fitness evaluation of each individual consists in the sum of the product from the flow between departments and the rectilinear distance between the centroids of these. The selection strategy used was elitist where the best individual in cost terms of a generation goes intact to the following one.

The used strategy of crossing is uniform. After making the crossing between two chromosomes, the feasibility of the generated sons is verified, so that no department is absent within the chromosome. If the chromosome needs to be repaired in some of its parts, the first one repeated is replaced by the first absentee, in the departments that belong to that part.

The mutation operator works of the following way: Two random numbers between 1 and the number of departments that belong to the part of the chromosome that is being muted are obtained, and the positions corresponding to these numbers in that chromosome's part are interchanged. The mutation is made by each one of the five chromosome parts, and departments are interchanged between them only if these have not been assigned like fixed within the configuration previously defined by the user. Thus, it is guaranteed that the chromosomes continue being feasible after mutation.

Once the population for each generation is obtained, the algorithm evaluates the Objective Function for each one of the chromosomes. Because of this, it is necessary to find the coordinates of each department according to the ordering represented for each one of the chromosomes. New coordinates are found for all the departments of the chromosome. The departments assigned as fixed, conserve their position within the vector and although their coordinates could vary according to the new allocation, they conserve a fix relative position within the layout. The origin for the measurements is in the left superior corner of the office's plane.

The following pseudo code describes the way how the new coordinates are found. InX is a variable that keeps the position in X coordinate and InY has the same function for the Y coordinate. $InXnow$ is a variable that keeps the position in X coordinate for the back part of the office.

```
Algorithm to Find coordinates;
InY = Office height
InX = 0
For all departments ∈ West flank do
X coordinate = 0
Y coordinate = InY − Department height
InY = Y coordinate
Next
InY = greater departments height of the North flank
InX = greater departments wide of the west flank
For all departments ∈ North flank do
X coordinate = InX
Y coordinate = InY − Department height
InX = InX + Department wide
Next
a = greater departments wide of the East flank
b = Office wide − Back part wide
InX = b − a
InY = greater departments height of the North flank
For all departments ∈ East flank do
X coordinate = InX
Y coordinate = InY
InY = InY + Department height
Next
InY = Office height − greater departments height of the Costado Sur
For all departments ∈ Costado Sur do
InX = InX − Department wide
X coordinate = InX
Y coordinate = inY
Next
```

FIGURE 2 Pseudo code to find coordinates

5 Genetic algorithms for the facility layout of a start-up tourist service centre

In order to establish the facility layout of an office from zero, a metaheuristic model based on GA, similar to the previous one, is proposed. The construction, operators and output are equal to the explained ones in the previous algorithm, except in the generation of the initial population, which was generated randomly, considering the flanks to which each department belongs, according to the information entered previously by the user.

6 Experimental designs

With the objective to establish the best combination of entrance parameters for the algorithm, for each one of the considered instances, three parameters, each one with three levels will be varied: Mutation rate (α): 0.01, 0.05 and 0.1, best offspring generated fraction (β): 0.3, 0.6 and

0.8, and best fathers fraction (γ): 0.2, 0.45 and 0.7, with a size of population of 100 and 1000 iterations. Throughout 30 replications, the minimum, average and maximum values for the objective function obtained are shown in table 1.

TABLE 1 Minimum, average and maximum values for the objective function obtained throughout 30 replications, for all the parameters combination

combination	α	0.01	0.01	0.01	0.05	0.05	0.05	0.1	0.1	0.1	0.01	0.05	0.1
	β	0.3	0.6	0.8	0.3	0.6	0.8	0.3	0.6	0.8	0.6	0.8	0.8
	γ	0.2	0.45	0.7	0.2	0.45	0.7	0.2	0.45	0.7	0.7	0.45	0.2
Instant 1	Minimum						4413.050						
	Mean						4413.050						
	Maximum						4413.050						
Instant 2	Minimum						617.100						
	Mean						617.100						
	Maximum						617.100						
Instant 3	Minimum						4207.250						
	Mean						4207.250						
	Maximum						4207.250						
Instant 4	Minimum						3700.375						
	Mean						3700.375						
	Maximum						3700.375						
Instant 5	Minimum						2702.125						
	Mean						2702.125						
	Maximum						2702.125						

By the experimental design showed previously, it is possible to affirm that the algorithm is robust, since in spite of the variations in the number of iterations, both the mean and the minimum value obtained present great stability in contrast to the variations of the parameters. At the same time, the maximum value that is obtained for a great number of experiments can vary according to the number of iterations. Thus, it is advisable to consider that a mutation rate superior to 0.05, will throw very good solutions to the studied problem.

7 Results

The facility layouts given by the algorithm are approaches on the optimal physical distribution of the same one, so that they are aids for the layout designer and at no moment they try to be an exact representation in the architectonic sense of the floor of the plant. In the following table, the number of departments, the objective functions values obtained for the present distributions and the best distributions found by means of the algorithm for each office are compared.

TABLE 2 Comparison between the present distribution and the best one found by the algorithm for each office, in terms of its F.O.

Office	Number of departments	Present Layout O.F.	Proposed Layout O.F.	Improvement percentage18
1	18	4,751,900	4,413,050	7.13%
2	8	622,400	617,100	0.85%
3	16	4,322,750	4,207,250	2.67%
4	16	3,765,275	3,700,375	1.72%
5	15	2,860,425	2,702,125	5.53%

From the previous table, it is clearly that in all the treated instances the objective function of the problem improved. From which it is deduced that the algorithm is able to design better distributions in spite of the limitations of space and number of feasible solutions that a small problem in terms of number of departments can represent.

8 Conclusions

As Tompkins states the services sector is often managed in a non-scientific way in spite of its size. The approach taken in this paper is the application of Operational Research concepts aimed to provide a more scientific solution to this particular problem [15]. The decision on the design of a more adapted layout is a multicriterial optimization problem. Because of this, it is recommendable to resort to experience, intuition and financial analysis techniques, according to the importance that the organization grants to each one.

A high generation's number is not an infallible method to always obtain the best well-known solution. Thus, in the search of good solutions for the studied problem, it is recommended to use a great number of generations, along with a mutation rate superior to 0.05.The algorithm developed is highly flexible, since starting from a present layout, fixed objects, prohibited zones, and contour office limitations can be considered, assuming to these two last ones as a fixed department within the plant. The distribution designs obtained by means of the genetic algorithm proposed satisfy in a better way the proximity necessity between the departments that must be next. According to the algorithm performance observed in each instance, it is possible to states that the algorithm is robust, since in spite of the variations in the number of iterations and entrance parameters, the average presents a remarkable stability, and in all cases the minimum known for each instance of the problem was obtained.

The scope of this paper should be extended to construct robust models that solve the facility layout problem in a tourist service centre considering other restrictions that were not considered in this work, such as Offices that have several floors, nonrectangular office plant, variable plant size, unknown plant size, prohibited zones within the hall destined for the clients, minimum and maximum areas for the departments and three-dimensional design. As alternative solution techniques, other metaheuristics like Simulated Annealing, Tabu Search, etc., and Hybrids methods integrated with Local Search strategies could be considered. The last one helps to increase exploration and to avoid solutions that correspond to local optimal. Additional to this, it turns out interesting to solve the problem with multiobjective approach, generating a family of solutions in the efficient border. Finally, further research could be done to extend the application of these methods to any other kind of service industry.

Acknowledgments

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