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# Optimal Solution for Multi-Objective Facility Layout Problem Using Genetic Algorithm

**S. Jannat, A.A. Khaled and Sanjoy Kumar Paul**
**Department of Industrial and Production Engineering**
**Bangladesh University of Engineering and Technology**
**Dhaka -1000, Bangladesh**

## Abstract

This paper addresses optimization of multi-objective facility layout problem. Facility layout plays a key role for companies, and it is an inseparable part of the manufacturing system design process. Traditionally there are two approaches to the facility layout problem. One is the quantitative approach aiming at minimizing the total material handling cost and another is qualitative approach aiming at maximizing closeness rating score. In this paper both approaches have been taken into consideration separately. Again, the research also solved the problem combining these two approaches at the objective function level. Genetic algorithm (GA) is developed for the multi-objective facility layout problem and found out the optimal facility location for a particular problem considering the two objectives, *i.e.* minimization of the material handling cost and maximization of the closeness rating score. In GA, primarily an initial population is created and by the crossover operator and mutation process new offspring is generated and if the offspring meet the stopping criteria the result was selected for the process. From this approach, a non dominated solution set is found (Pareto optimal) approximately for the multi objective facility layout problem.

## Keywords
Facility layout problem, Genetic algorithm, Pareto optimal solution.

## 1. Introduction
The facility layout problem is one of the most fundamental quadratic assignment problems in Operations Research [1]. The problem has been widely studied by many researchers in Operations Research and management science, and known to be NP complete (NP, nondeterministic polynomial) [2] . A facility layout problem (FLP) is about arranging the physical departments or machines within a facility to help the facility work in a productive way. A poor layout can lead to accumulation of work-in process inventory, overloading of material handling system, inefficient setups and longer queues [3]. Therefore, solution of an FLP is a strategic study to be conducted. Traditionally, there are two approaches for the facility layout problem. The first one is the quantitative approach aiming at minimizing the total material handling cost between departments or machines based on a distance function. The second one is the qualitative approach aiming at maximizing closeness rating scores between departments or machines based on a closeness function. The most important example for this approach can be systematic layout planning- SLP procedure, suggested by Muther [4]. A Pareto-optimal solution is developed in this study for a facility layout problem. A solution called Pareto-optimal if it is not possible to decrease the value of one objective without increasing the value of the other. The difficulty that arises with this approach is the rise of a set of Pareto-optimal solutions, instead of a single optimum solution. The focus of Pareto-optimization is to find a set of compromised solutions that represent a good approximation to the Pareto-optimality. A genetic algorithm is proposed to find the non-dominated solution set approximately for the multi-objective facility layout problem.

## 2. Facility Layout Problem
A typical facility layout problem considers optimizing the location of n facilities. Many real life problems have more than one objective. These problems are named as multi-objective optimization problems. Multi-objective problems were converted into a single objective by weighting the objectives and an optimizing solution was sought. In this study, firstly qualitative and quantitative objectives are handled as different objective functions and non-dominated approximate Pareto optimal solution set is

constructed through a search procedure [5]. After that by weighting the objectives, a single objective function is also constructed and then studied the impact of result. Here Pareto optimal set (POS) is used in place of approximate Pareto optimal solution set. In this study, process type facility layout problem is considered when multi-products with different production volume and different process routings need to be manufactured. The selection of a specific layout defines the way in which parts move from one machine to another machine [6].

| | | |
|---|---|---|
| 9 | 1 | 5 |
| 3 | 4 | 6 |
| 8 | 7 | 2 |

(a)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 1 | 5 | 6 | 4 | 3 | 2 | 7 | 8 |

(b)

Figure 1: (a) Process shop layout (b) Chromosome of process shop layout

The problem in machine layout design is to assign machines to locations within a given layout arrangement such that a given performance measure is optimized. The measure used here is the minimization of material handling cost and maximization of total closeness rating score. This problem belongs to the non-polynomial hard (NP-hard) class. The problem complexity increases exponentially with the number of possible machine locations.

## 3. Problem Statement

The facility layout problem addressed here is the assignment of M machines to N locations in a manufacturing plant. During the manufacturing process, material flows from one machine to the next machine until all the processes are completed. The objective of solving the facility layout problem is therefore to minimize the total material handling cost and maximize the total closeness rating score of the system. To determine the material handling cost for one of the possible layout plans, the production volumes, production routings, and the cost table that qualifies the distance between a pair of machines/locations should be known. In certain types of layout problems, numerical flow of items between departments either is impractical to obtain or does not reveal the qualitative factors that may be crucial to the placement decision [7]. For this situation the venerable technique that is known as systematic layout planning (SLP) is used. To determine the total closeness rating score a relationship chart showing the degree of importance of having each department located adjacent to every other department is required.

The objectives can be represented as follows:

i. Minimize the material handling cost

$$MHC = \sum_{i=1}^{M}\sum_{j=1}^{M} F_{ij} C_{ij} D_{ij} \tag{1}$$

$F_{ij}$, amount of material flow among machines i and j (i,j= 1,2,….,M).

$C_{ij}$, unit material handling cost between locations of machines i and j (i,j= 1,2,….,M).

$D_{ij}$, rectilinear distance between locations of machines i and j

$MHC$, total cost of material handling system

ii. Maximize the total closeness rating score

$$CRS = \sum_{i=1}^{M}\sum_{j=1}^{M} R_{ij} \tag{2}$$

$R_{ij}$ Closeness score between locations of machines i and j

iii. Minimize total cost considering the above two factors

$$Z = \alpha_1 MHC + \frac{1}{\alpha_2 CRS} \tag{3}$$

$\alpha_1$ and $\alpha_2$ are the weights used to unify the two objectives

The constraint considered in this model is as follows:

(1) The precedence constraints which ensure that the processing sequence of process flow operation to be predefined.

The problem is to find optimum allocation of M machines on N locations considering the constraints and objectives.

## 4. Problem Solving Process

Genetic algorithm (GA) has been applied to select the best valued fitness function. Solving with GA requires several parameters such as encoding type, length of the chromosome, selection method, reproduction operations, termination conditions etc. Using GA as a solving procedure a result is obtained. The problem solving approach is shown in Figure 2.

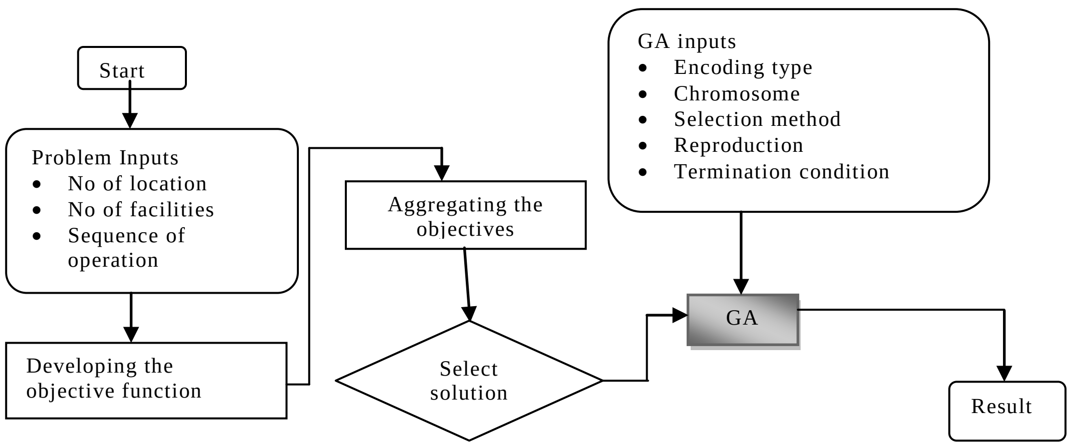


Figure 2: Problem solving approach

### 4.1 Solving with Genetic Algorithm

#### 4.1.1 Algorithm structure

Step 1: Create *N* no. of chromosomes (Facility location) to create an initial population pool. A typical chromosome is shown in figure 3. The initial population number is taken as computer input for the program. Check the chromosome strings whether they are valid or not.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 6 | 9 | 8 | 3 | 2 | 4 | 7 |

Figure 3: A typical chromosome for 3 rows and 3 columns

Step 2: Evaluate the Fitness function or the objective function

Step 3: Calculate the probability $p_i$ and cumulative probability $q_i$ for $i$ chromosomes. $[i = 20]$

Step 4: Select the chromosomes with some selection mechanism. Roulette wheel mechanism is used.

Step 5: Select the chromosomes as Parents which will undergo breeding for to create next generation.

Step 6: Take crossover rate $p_c$ and mutation rate $p_m$ as computer program input. Crossover rate indicates how many chromosomes will undergo the crossover operation. Mutation rate indicates how many of the bits will undergo through mutation. Crossover and Mutation operations are selected randomly.

Step 7: Select randomly the chromosomes for crossover. Apply single point crossover. No. of X-over points $N_{C_p}$ = L-1, where L = no of locations. If L = 6 then there are five points where crossover can take place.
Step 8: Select randomly the bits in chromosomes which will undergo the mutation process. The selected bits will be swapped with the adjacent bit (either earlier or later).
Step 9: A generation is complete and a new set of population (offspring) has been created.
Step 10: Evaluate the fitness function value for the new population and save the best value.
Step 11: Go to step 3 until Stopping conditions are met.
Predefined number of generations
No improvement in solution for last G generations. G is an input taken from the program. Typical value of G = 50.

## 5. Case Study

A hypothetical case is presented illustrating the Multi-objective facility layout problem. In this case a toy factory is considered where there are nine departments (shown in Table 1) that are to be arranged to minimize the interdepartmental material handling cost and maximizing the closeness rating score. For the optimum allocation of nine departments where all the departments space are equal the flow of materials and the cost involve to move the materials from one department to another department is given in a Table 2 and 3. These two tables are needed for calculating the material handling cost. Different reasons of closeness and numerical weights given to different closeness are shown in Tables 4 and 5. A relationship chart is shown in Table 6 that is required to calculate the closeness rating score.

Table 1: Departments name

| Department | Activity |
|---|---|
| 1 | Shipping and receiving |
| 2 | Plastic molding and stamping |
| 3 | Metal forming |
| 4 | Sewing department |
| 5 | Small toy assembly |
| 6 | Large toy assembly |
| 7 | Painting |
| 8 | Mechanism assembly |
| 9 | Packaging section |

Table 2: Flow between departments (number of moves)

| Dept. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 10 | 12 | 15 | 17 | 11 | 20 | 22 | 19 |
| **2** | 1 | 0 | 13 | 18 | 7 | 2 | 1 | 1 | 104 |
| **3** | 2 | 3 | 0 | 100 | 109 | 17 | 100 | 1 | 31 |
| **4** | 5 | 1 | 11 | 0 | 0 | 78 | 247 | 178 | 1 |
| **5** | 2 | 17 | 12 | 9 | 0 | 1 | 10 | 1 | 79 |
| **6** | 9 | 14 | 8 | 21 | 30 | 0 | 0 | 1 | 0 |
| **7** | 11 | 19 | 25 | 31 | 7 | 2 | 0 | 0 | 0 |
| **8** | 5 | 4 | 12 | 19 | 23 | 31 | 40 | 0 | 12 |
| **9** | 8 | 11 | 25 | 29 | 9 | 7 | 2 | 5 | 0 |

Table 3: Material handling cost between locations

| Dept. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 1 | 2 | 3 | 3 | 4 | 2 | 6 | 7 |
| **2** | 0 | 0 | 12 | 4 | 7 | 5 | 8 | 6 | 5 |
| **3** | 0 | 0 | 0 | 5 | 9 | 1 | 1 | 1 | 1 |
| **4** | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 4 | 6 |
| **5** | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| **6** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 6 |
| **7** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 1 |
| **8** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **9** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 4: Different reasons of closeness

| Code | Reason |
|---|---|
| 1 | Type of customer |
| 2 | Ease of supervision |
| 3 | Common personnel |
| 4 | Contact necessary |
| 5 | Share same space |
| 6 | Psychology |

Table 5: Numerical weight of different value

| Value | Closeness | Numerical weight |
|---|---|---|
| A | Absolutely necessary | 16 |
| E | Especially important | 8 |
| I | Important | 4 |
| O | Ordinary closeness OK | 2 |
| U | Unimportant | 0 |
| X | Undesirable | -80 |

### 5.1 Solving with GA

A computer program was developed with Microsoft® Visual C++ was used to solve the problem with different GA parameters. Three different generation numbers 1000, 5000 and 10000 were tested while various combinations of other parameters such as initial population (10, 30), crossover rate (0.25, 0.50) and mutation rate (0.001, 0.01 and 0.10) were also changed.

Table 6: Relationship chart

| Dept | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| **1** | U | A | E | I | O | E | I | O | A |
| **2** | A | U | A | I | E | O | X | U | E |
| **3** | E | A | U | E | U | E | O | E | I |
| **4** | I | I | E | U | A | U | O | E | A |
| **5** | O | E | U | A | U | O | I | I | O |
| **6** | E | O | E | U | O | U | U | A | I |
| **7** | I | X | O | O | I | U | U | U | X |
| **8** | O | U | E | E | I | A | U | U | X |
| **9** | A | E | I | A | O | I | X | X | U |

#### 5.1.1 Result analysis

Best result was obtained using the following parameters for the problem using GA.
Generation number: 10000
No of initial population 30
Crossover type: Single point crossover
Crossover rate: 0.50
Mutation rate: 0.10
Last G times best value did not changed 50
Computation time: 123406 mili second
Department sequence: 4.2.8.6.3.1.9.5.7
First objective function value (MHC) 605
Computation time: 69391 mili second
Department sequence: 5.4.9.1.2.3.6.8.7
Second objective function value (CRS) 92
Computation time: 116218 mili second
Department sequence: 4.2.8.6.3.9.1.5.7
Third objective function value (Z) 649.5

### 5.2 Convergence analysis

Genetic algorithms use a selection scheme to select individuals from the population to insert into a mating pool. Individuals from the mating pool are used by a recombination operator to generate new offspring, with the resulting offspring forming the basis of the next generation. A selection scheme in GAs is simply a process that favors the selection of better individuals in the population for the mating pool. The selection pressure is the degree to which the better individuals are favored and it drives the GA to improve the population fitness over succeeding generations. If the SP is too low, the convergence rate will be slow, and the GA will unnecessarily take longer time to find the optimal solution. If the selection pressure is too high, there is an increased chance of the GA prematurely converging to an incorrect solution. In addition to providing selection pressure, selection schemes should also preserve population diversity as this helps avoid premature convergence. Optimal solution using genetic algorithm is shown in table 7.

Table 7: Pareto Optimal Solution with GA

| Layout | Location | MHC | CRS |
|---|---|---|---|
| Pareto solution 1 | 5.7.9.2.6.4.3.1.8 | 940 | 70 |
| Pareto solution 2 | 5.7.9.6.4.2.8.3.1 | 864 | 62 |
| Pareto solution 3 | 4.2.8.6.3.1.9.5.7 | 605 | 92 |
| Pareto solution 4 | 5.7.9.6.2.4.8.3.1 | 793 | 63 |
| Pareto solution 5 | 6.1.9.7.3.4.2.5.8 | 418 | 108 |

## 6. Conclusions

A multi objective facility layout problem has been considered in this research. Two objectives have been considered, minimizing the material handling cost and maximizing the closeness rating score. Genetic algorithm is used to solve the problem. A special encoding is used for genetic algorithm where the chromosome itself represented the complete facility layout. This research work has customized a genetic algorithm for a process shop layout in a manufacturing environment. This algorithm can be applied to find the initial optimal facility location in a manufacturing environment. Though a number of researches have been carried out to solve facility layout problem none of them considered the two objectives at a time. In this thesis work the two objectives are considered at a time and get the solution and this solution called Pareto optimal solution. This developed algorithm can handle a large variety of problem sizes [8].

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