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Genetic Algorithms to Resolve Facility Layout Problem of an Industry in Bangladesh

Subrata Talapatra[*1], Tarapada Bhowmick[1] , Kazi Arif-Uz-Zaman[1]
[1]Department of Industrial Engineering and Management, Khulna University of Engineering & Technology
Khulna-9203, Bangladesh
E-mail:sub_ksy@yahoo.com

Abstract

The facilities layout is also called plant layout for a manufacturing plant. Plant layout design is one of the strategic fields that determine the long run efficiency of operation. The layout consists of all equipments and machineries within the building structure. The handling system consists of the mechanisms needed to satisfy the required facility interactions. Traditional approaches to the plant layout problem have assumed that the volume of flow between pairs of departments is deterministic. But it has been seen that production plans are subject to revisions due to changes in demand, product mix, new technology, etc. A project is conducted to optimize the layout design of the production line at the shop floor of a company named Bangladesh Cable Shilpha Ltd., Khulna, aiming at overcoming the current problems attributed to the inefficient layout. A Genetic Algorithm layout technique is used to generate a near optimal layout based on formal methods that are rarely used in practice.

Keywords: *Facility layout, flexible manufacturing, stochastic programming.*

1. Introduction

Plant layout problems can occur in a large number of ways and can have significant effects on the overall effectiveness of the production system. Effective facilities planning can reduce material handling cost by at least 10 to 30%. The size of the investment in new facilities each year makes the field of facilities planning important. The objectives of the Plant Layout Strategy are to meet the requirement of minimizing the investment in equipment and material handling cost, product design and volume, process equipment and capacity: minimize overall production time; maintain flexibility of arrangement and operation; minimize variation in types of material handling equipment; facilitate the manufacturing process, quality of work life: provide for employee convenience, safety and comfort; facilitate the organizational structure and building and site constraints: utilize existing space most effectively. Layouts can be classified as seven types: fixed position layout; process oriented layout, also called job shop; group layout; office layout; retail/service layout; warehouse layout; product-oriented layout. It is highly desirable that the optimum plant layout need to be designed. Unfortunately, the magnitude of the problem is so great that true system optimization is beyond current capabilities. The approach normally taken in solving the plant layout problem is to try to find a satisfactory solution. Previously, facilities layout problems were solved primarily by using iconic models. Then analytical approaches were developed. A number of different procedures have been developed to aid the facilities planner in designing layouts. These procedures can be classified into two main categories: construction type and improvement type. Construction type layout methods basically involve developing a new layout from scratch. Improvement procedures generate layout alternatives based on an existing layout. Based on the above two procedures, many algorithmic approaches have been developed. Some of them are Systematic Layout Planning (SLP) procedure, steepest descent search method by pair wise exchange, graph-based construction method, programming, network, Tabu search, simulated annealing and genetic algorithm. Based on these approaches, many computer-aided layout routines have been developed.

A number of design goals can be modeled as layout objectives. In addition, a set of constraints often has to be satisfied to ensure the applicability of the layouts. Efficient calculations of objectives and constraints are necessary to solve the layout problems in reasonable time since the analysis of objectives and constraints can be computationally expensive and a large number of evaluations may be required to achieve convergence. The search space of the layout problem is non-linear and multi- model, making it vital to identify a suitable algorithm to navigate the space and find good quality solutions.

The layout goals are usually formulated as objective functions. The objectives may reflect the cost, quality, performance and service requirements. Various constraints may be necessary to specify special relationships between components. The specifications of components, objectives, constraints, and topological connections define a layout problem and an optimization search algorithm takes the problem formulation and identifies promising solution by evaluating design alternatives and evolving design states. Analysis of objectives and constraints vary from problem to problem. However, the optimization search technique and geometric representation and the resulting interference evaluation are problem independent and are, thus, the focus for a generic layout tool [1].
The primary objective of the design problem is to minimize the costs associated with production and materials movement over the lifetime of the facility. Such problems occur in many organizations, including manufacturing cell layout, hospital layout, semiconductor manufacturing and service center layout. For US manufacturers, between 20% and 50% of total operating expenses are spent on material handling and an appropriate facilities design can reduce these costs by at least 10%-30% [2,3].

Altering facility designs due to incorrect decisions, forecasts or assumptions usually involves considerable cost, time and disruption of activities. On the other hand, good design decisions can reap economic and operational benefits for a long -time period. Therefore, the critical aspects are designs that translate readily into physical reality and designs that are "robust" to departures from assumptions.

The project manager or planner usually performs the task of preparing the layout based on his/her own knowledge and expertise. Apparently, this could result in layouts that differ significantly from one person to another. To put this task into more perspective, researchers have introduced different approaches to systematically plan the layout of production sites [4,5].

Facility layout planning can generally be classified according to two main aspects: (1) method of facility assignment and (2) layout planning technique.

Mathematical techniques usually involve the identification of one or more goals that the sought layout should strive to achieve. A widely used goal is the minimization of transportation costs on site. These goals are commonly interpreted to what mathematicians term "objective functions". This objective function is then optimized under problem-specific constraints to produce the desired layout. Systems utilizing knowledge-based techniques, in contrast, provide rules that assist planners in layout planning rather than perform the process based purely on a specified optimization goal(s).

Usually the selected fitness function is the minimum total costs of handling of work pieces. In general, those costs are the sum of the transport costs (these are proportional to the intensity of the flow and distances) and other costs.

An effective facility layout design reduces manufacturing lead-time, and increases the throughput, hence increases overall productivity and efficiency of the plant. The major types of arrangements in manufacturing systems are the process, the flow line or single line, the multi-line, the semi-circular and the loop layout. The selection of a specific layout defines the way in which parts move from one machine to another machine. The selection of the machine layout is affected by a number of factors, namely the number of machines, available space, similarity of operation sequences and the material handling system used. There are many types of material handling equipment that include automated guided vehicles, conveyer systems, robots, and others. The selection of the material handling equipment is important in the design of a modern manufacturing facility [6].

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. This problem belongs to the non-polynomial hard (NP-hard) class. The problem complexity increases exponentially with the number of possible machine locations.

2. Algorithms for workstation layout

In plant layout problem, many researchers describe the problem as one of optimizing product flow, from the raw material stage through to the final product. This is achieved by minimizing the total material handling costs. Solving the problem it is required to know the distances between departments (usually taken from their centroids), the number of trips between departments, and the cost per unit.

The layout space is defined as the mathematical representation of the space of configurations mapped against the cost per configuration. Deterministic algorithms are unable to navigate such a space for globally near-optimal solutions, and stochastic algorithms are usually required for solutions of good quality.

For instance, a flexible manufacturing system (FMS) consisting of N machines will comprise a solution space with the size N. The problem is theoretically solvable by testing all possibilities (i.e., random searching of the solution space). For arranging the devices in the FMS the number of possible solutions is equal to the number of permutations of N elements.

Various models and solution approaches have been proposed during past three decades. Heuristic techniques were introduced to seek near-optimal solutions at reasonable computational time for large scaled problems covering several known methods such as improvement, construction and hybrid methods, and graph-theory methods [10]. However, the area of researches is still always interesting for many researchers, since today the problems are solved by new methods and with the possibility of application of much greater computation capacity of modern computers.

A variety of optimization algorithms have been applied to the layout problem. Some of the approaches may be efficient for specific types of problems, but often place restrictions on component geometry, allowable degrees-of-freedom, and the objective function formulation. Others are applicable to a wider variety of problems but may require prohibitively long computing time to solve even simplistic problems. Layout algorithms can be classified into different categories according to search strategies used for design space exploration. The target of all methods is the minimum transport costs, but they differ in exactingness, particularly in the length of the procedure. However, it cannot be decided with certainty which basic method and/or method of improvement of the layout is the best.

3. Mathematical model

The facility layout problem 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 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.

The total cost function is defined as:

$$C = \sum_{i=1}^{M} \sum_{j=1}^{M} G_{ij} C_{ij} L_{ij} \quad (1)$$

Where,

Gij =amount of material flow among machines i and j (i,j=1,2, .,M)

Cij =unit material handling cost between locations of machines i and j (i,j=1,2, ,M)

Lij =rectilinear distance between locations of machines i, and j.

C =total cost of material handling system.

The evaluation function considered in this paper is the minimization of material handling cost, and criterion most researchers prefer to apply in solving layout problems. However, the proposed approach may be applied to other functions as well.

To solve the problem it is necessary to know the matrix of the transport quantities between the individual devices N in a time period. Also the variable transport costs, depending on the transport means used, must be known. For example: connection between two devices can be performed by another transport device. The costs of transport between two devices can be determined if their mutual distance Lij is known. During execution of the GA the value Lij changes with respect to the mutual position of devices and with respect to position in the arrangement.

Fitness function thus depends on the distance Lij between the devices. The distance between serving points is multiplied by coefficients Gij and Cij, which measure the amount of material flow and the handling cost between devices, their constants are defined by input matrix, as shown in Table 1 and Table 2. The value of the cost function is thus the sum of all values obtained for all the pairs of devices. The aim of optimization process is to minimize this value. Fitness is based on the principle that the cost of moving goes up with the distance.

4. Genetic algorithms

4.1. Approach

Early researchers of the facilities layout problem believed that the best approach to solutions was through the development of the general quadratic assignment problem (QAP). By using the this, the facilities layout problem can be optimally solved by applying implicit enumeration approaches such as cutting plane, branch and bound approaches, or other operations research techniques. The exact solution is obtained from optimal methods in a reasonable time only when the problem size is small. It has been shown that the solution times for the QAP are likely to increase exponentially as a function of the number facilities to be located. GAs have received a great deal of attention in the recent literature due to the fact that they do not rely on analytical properties of the function to be optimized which make them well suited to a wide class of optimization problems. The starting point in GA presented in this work was an initial population of solutions (which was randomly generated). Process shop layout and its randomly generated chromosomes are shown on figure 1. This population undergoes a number of transformations designed to improve the solutions provided. Such transformations are made in the main loop of the algorithm, and have three basic stages: selection, reproduction, and replacement, as discussed below. Each of the selection-transformation cycles that the population undergoes constitutes a generation; hopefully, after a certain number of generations, the population will have evolved towards the optimum solution to the problem, or at least to a near-best solution.

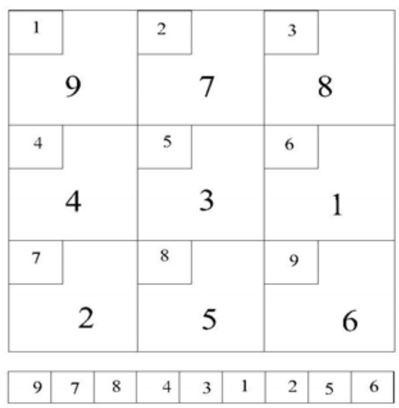

Fig. 1. Type of layout used in calculations and its chromosome representation

The selection stage consists of sampling the initial population, thereby obtaining a new population with the same number of individuals as the initial one. This stage aims at improving the quality of the population by favoring those individuals that are more adequate for a particular problem (the quality of an individual is gauged by calculating its fitness, using equation 1, which indicates how good a solution is).

The selection, mutation, and crossover operators were used to create the new generation of solutions. A fitness function evaluates the design and decides which will be the survivors into the next generation. Selection is accomplished by copying strings from the last generation into the new generation based on a fitness function value. Mutation is the process of randomly changing one bit of information in the string and it prevents GAs from stagnating during the solution process. Crossover is responsible for introducing most new solutions by selecting two parent strings at random and exchanging parts of the strings. The outline of the genetic search process used in this paper is summarized as follows:

1. To randomly generate an initial population of chromosomes with a population size ,P.
2. To evaluate each chromosome in the population according to the material handling cost equation.
3. To determine the average fitness for the whole population.
4. To use elitist strategy to fix the potential best number of chromosomes by deleting the worst number of each generation, and copying the best numbers into the succeeding generation. The total number of chromosome is kept constant for computational economy and efficiency. The average of whole chromosome acts as a guide to which chromosomes are eliminated and which of them ‘gets reproduced’ in the next generation. The process is applied to eliminate members with a fitness value $P(k)$ greater than 1.5 times the average of the chromosomes and copying the best number of chromosomes instead.
5. To apply the Monte Carlo selection technique to select parent chromosome from the current population. That is used for choosing randomly the parents for the crossover and mutation.
6. To apply the crossover and mutation operators to generate a new population based on the values of crossover and mutation probabilities (pc and pm, respectively). The rest of the population is brought from the previous population which has the best fitness value.

7. To check the pre-specified automatic stopping criterion. If the stopping criterion is reached, the search process stops. It will be needed to proceed the next generation, and to go to step 2. The flow chart of the GA optimization procedure is shown in Fig. 2.

4.2. String representation

The technique of GAs requires a string representation scheme (chromosomes). The entire manufacturing plant/department is divided into N grids and each grid represents a machine location. In this study, a form of direct representation for strings is used. Fig. 3 shows different examples of different types of production plant layout with their encoded chromosomes representation. This chromosome string representation indicates one of the possible machine layout plans of each production type. Examples of flow shop layout containing 9 machines/departments, production flow line contains 5 workstations, multi-line production system contains 6 machine locations, and a closed-loop layout type of 8 machines are presented in the figure.

4.3. Selection operator

The selection operator is applied to select parent chromosomes from the population. A Monte Carlo selection technique is applied. A parent selection procedure operates as follows:

1. To calculate the fitness F_{sum} (Eq. (1)) of all population members.
2. To generate a random number (n) between 0 and F_{sum}.
3. To return the first population member whose fitness, when added to the fitness of the preceding population members, is greater than or equal to n

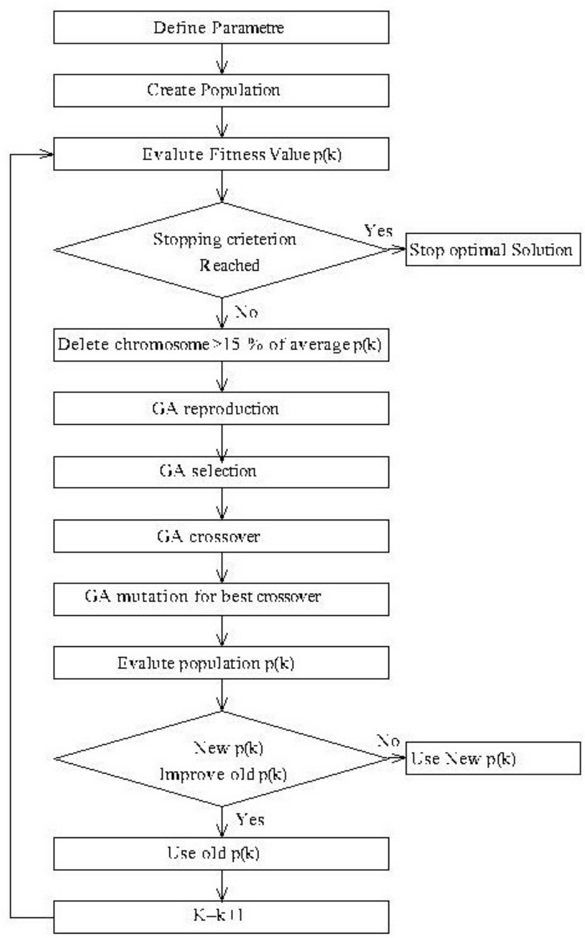

Fig. 2. Flow chart of GA optimization procedure.

4. To repeat Step 3 for the second population member and to check so that the new selected member is not the same as the first member.

4.4. Crossover operator

The probability of crossover pc is the probability of applying the crossover operator to these chromosomes. The remainder of chromosomes will produce offspring chromosomes, identical to their parents. Otherwise, the selected chromosomes to crossover will be crossed to produce two offspring chromosomes by using crossover operator. A new crossover operator is proposed as follows considering a pair of parent chromosomes (P1, P2) as shown below:

P1	1	3	6	8	4	2	5	7	9
P2	8	3	1	5	7	9	6	2	4

The way of crossover implemented has been chosen four central numbers of both parents i.e. (8,4,2,5) in P1 and (5,7,9,6) in P2, but not to exchange it from P1 to P2 and vice versa [13,14,6]. Their string is changed in original chromosome of one parent in the way they are lined in the other. To be precisely, numbers 8,4,2,5 in P1 should be lined as 2,5,8,4 in P1, and numbers 5,7,9,6 in P2 should be lined as 9,6,5,7 in P2. At this stage genes can not be found to exist in more than one position in the resultant chromosomes. The structures of the resultant chromosomes then become:

P1	1	3	6	2	5	8	4	7	9
P2	8	3	1	9	6	5	7	2	4

The mutation operator is used to rearrange the structure of a chromosome. The swap mutation was used, which is simply selecting two genes at random and swapping their contents. The probability of mutating a single gene is usually a small number.

Since it is difficult to assume the total optimum solution of the problem investigated, and it becomes more difficult if number of workstations (machines) increase, the program may be terminated when either the maximum number of generations is reached, or until the propounded limit is attained. The second procedure is applied. As propounded limit the value obtained for the material handling cost of optimal facility layouts presented in benchmark test was used. where the value of C = 4818. Only the results with value equal to this were placed in main database, and presented as optimums in figure 2.

In all experiments the same genetic parameters were used [13,14]. Those genetic parameters were: the probability of crossover pc = 0.6 and probability of mutation pm = 0.001. The percentage of replication of well-performed chromosomes in each generation was R = 5%.

4.5. Mutation operator

The mutation operator is used to rearrange the structure of a chromosome. The swap mutation is used, which is simply selecting two genes at random and swapping their contents. The probability of mutating a single gene is called the probability of mutation, pm, which is usually a small number. Mutation helps to increase the searching power. In order to explain the need of mutation, a case may be considered where reproduction or crossover may not produce a good solution to a problem. During the creation of a generation it is possible that the entire population of strings is missing a vital gene of information that is important for determining the correct or the most nearly optimum solution.

4.6. Stopping criterion

The program is terminated when either the maximum number of generations is reached, or until the population converges.

5. Application of the GA to the layout problem of Bangladesh Cable Shilpha Limited (BCSL), Khulna.

The plant flow of materials between machines of Bangladesh Cable Shilpha Ltd (BCSL) and material handling cost between machines are presented in tables 1 and 2, respectively. The plant configuration layout is 3X3 grid using 9 machines; there are 362880 possible solutions in the solution space e.g. (9!). The stopping criterion for iteration has been obtained using value of fitness C from Eq. 1.

Table 1. Flow of materials between machines

From/To	1	2	3	4	5	6	7	8	9
1		100	3	0	6	35	190	14	12
2			6	8	109	78	1	1	104
3				0	0	17	100	1	31
4					100	1	247	178	1
5						1	10	1	79
6							0	1	0
7								0	0
8									12
9									

The experimental results are shown in Table 3 and expressed in terms of:

1. The material handling cost of the best solution among trials (Best)
2. The number of the trials needed to obtain one of the optimal solutions (#).

In general, an increase in the population solutions since the number of sampling solutions from the solution space is enlarged. The general cost performance for the four different approaches is studied with the sampling solution space used, Fig. 2 shows some of the resulting optimal machine layouts giving a material handling cost of value equal to 4818.

Results obtained by proposed approach are compared with the standard results [14,13,6] and found to have very less variation, and generation sizes can provide better number of iterations, as shown in the Figure 3. Minimum costs of handling is found to be 4818. The reason for such discrepancies of results presented in this paper and the results proposed by models selected for comparison from the literature, concerning number of iterations, is laying mainly in simplicity of the way of crossover implementing in this work comparing to the procedure explained in previous literature as described in section 4.

Table 2. Material handling cost between machines

From/To	1	2	3	4	5	6	7	8	9
1		1	2	3	3	4	2	6	7
2			12	4	7	5	8	6	5
3				5	9	1	1	1	1
4					1	1	1	4	6
5						1	1	1	1
6							1	4	6
7								7	1
8									1
9									

4	8	5
3	9	2
7	1	6

7	1	6
3	9	2
4	8	5

6	2	5
1	9	8
7	3	4

5	2	6
8	9	1
4	3	7

5	8	4
2	9	3
6	1	7

4	3	7
8	9	1
5	2	6

Fig. 3. Some of the optimal facility layouts for BCSL

Table 3. The experimental results for BCSL

Exp.	No.of trials	Proposed approach	No.of trials	M.Adel El-Baz	Mak et al.	PMX (Chan and Tansri)
	#	Best	#	Best	Best	Best
1	4050	5119	200	5039	5233	4939
2	8595	5150	400	4818	5040	5036
3	180	4872	1000	4818	4818	4938
4	405	4818	2000	4818	4818	4818
5	270	4818	5000	4818	4818	4818
Exp.	No.of trials	Proposed approach	No.of trials	M.Adel El-Baz	Mak et al.	PMX (Chan and Tansri)
	#	Best	#	Best	Best	Best
6	360	4818	400	4872	5225	4938
7	2160	4939	800	4818	4927	4992
8	1125	4990	2000	4818	4818	4818
9	765	4818	4000	4818	4818	4818
10	1485	4818	800	4818	5225	4938
11	3105	4818	1600	4818	4927	4992
12	990	4818	4000	4818	4818	4818
13	2160	4818	8000	4818	4818	4818
14	3105	4818	2000	4818	5225	4938
15	225	4818	4000	4818	4818	4927
16	2160	4818	10000	4818	4818	4818
17	3015	4818	4000	4818	4818	4938
18	3240	4818	8000	4818	4818	4862
19	3600	4818	5000	4818	4818	4818
Sum:	40995		63200			

6. Conclusion

The present paper proposes an approach using GAs to solve facility layout problems. This Algorithm may be used as a useful tool to find out an ideal workstations position of BCSL in short time as well as practical significance of saving financials needed for transportation costs in concrete production systems. The proposed GA approach for BCSL produces the optimal machine layout, which minimizes the total material handling cost. The effectiveness of the proposed approach has been examined by using three benchmark problems. The comparison indicates that the proposed approach is efficient and has a high chance of obtaining the best solution for the facility layout problem with less number of iterations. The solutions for the layout problem for BCSL have been calculated in reasonably short time on standard PC equipment. Only demerit of GA presented in this work, is that number of trials needed to obtain first optimum is to some extent larger, still overall number of iterations is much lesser (40995 < 63 200), with same number of experiments.

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