A FIREFLY ALGORITHM APPROACH FOR MULTI-ROW FACILITY LAYOUT PROBLEM

Akash P Lukose[1], Abyson Scaria[1],Babu George[1]

[1]Department of Mechanical Engineering, St. Joseph's College of Engineering and Technology, Palai, Kerala, India

Abstract: The facility layout problem is an optimization problem that makes efficient layouts. Layout design has a prime importance on the performance of manufacturing systems. The facility layout problem (FLP) helps to reduce the material handling costs by a well organized positioning of facilities. The facility layout problems are generally regarded as NP-Hard problems. The different methodologies for solving FLP's can be exact algorithms, heuristics and meta-heuristics. The exact algorithms are generally used when the number of facilities in the layout is up to 16. For large sized FLP's, heuristics were developed to attain near optimal solution in reasonable computation times. In the recent literatures, there is a great focus on biology-inspired meta-heuristic algorithms to find most suitable solutions for FLP's. Firefly Algorithm is a recently developed Meta-heuristic, which represents some of the traits of the firefly behaviour. This paper focuses on the application of firefly algorithm to multi-row facility layout problem with the goal of reducing total material handling cost. A parameter analysis was done and some general FLP's were solved using the algorithm. A comparative study between Genetic Algorithm and Firefly Algorithm was also performed.

Keywords: Facility layout problem (FLP), NP-Hard, Firefly Algorithm, Genetic Algorithm, Parameter Analysis.

1. Introduction

A facility is an entity that facilitates the performance of any job. Facility can be a manufacturing cell, a work center, a department or a ware house. Facility layout is an arrangement of facilities required for the production of goods or delivery of the services. By considering the various interactions between facilities and material handling system, the facility layout problem helps to make efficient layouts. The facility layout problem (FLP) helps to reduce the material handling costs by determining the most suitable arrangement of facilities within the given space; subject to various constraints such as site plan, the building, service requirements, the departmental area and the decision maker.

Layout problems are usually found in manufacturing systems which is related to the positioning of various facilities in a plant. The arrangement of facilities has specific impact on the net efficiency of operations, reduce manufacturing cost, decrease lead times, and increase productivity. Facility Layout Problem is considered to be significantly complex problem and the most studied problem in facilities planning [1]. The facility layout problem was a typical NP-hard problem, so it is difficult to arrive at the optimal solution using exact methods. This calls for the usage of approximation algorithms for obtaining satisfactory solution.

Global optimization problems were effectively solved by using the swarm intelligence, which was a nature inspired metaheuristic approach. The Firefly algorithm (FA) which is used in this work

IOP Conf. Series: Materials Science and Engineering **396** (2018) 012072 doi:10.1088/1757-899X/396/1/012072

focus on the flashing pattern of tropical fireflies. This paper focuses on the application of firefly algorithm to multi-row facility layout problem with the goal of reducing total material handling cost.

2. Literature Review

The various objectives taken by the researchers for the facility layout problems include reduction of material handling and curtailment of material handling cost, minimization of material flow and reducing the total distance travel for material and improving the total closeness between facilities. The single row facility layout problem is extensively investigated in the literature with different objectives. But the multi-row facility layout problem is rarely addressed by the researchers.

Liu et al. [2] considered the facility layout problem by using certain logistic flows and stochastic product demand techniques. The rotations were allowed, but the shape of the department was same. Apart from traditional material handling costs, some of the criteria such as the shape ratio factor, the operational performance rating and the Work In Process (WIP) value was considered in this paper. Jannat et al. [3] deals with optimization of multi-objective facility layout problems. The objectives considered include reducing the material handling cost and maximizing the closeness rating score. Chang et al. [4] suggested a mathematical model by considering the production volume and alternative routing to attain the cell formation and cell layout concurrently. A hybrid tabu search algorithm was used to solve it due to the combinatorial nature of this model.

Chung et al. [5] analyze the double row layout problem (DRLP) that includes the positioning of departments or machines on the two sides of a central corridor. Various heuristics were proposed and they were compared with MIP solutions by CPLEX 10.2, in a series of experiments. Alvarenga et al. [6] analyzed the facility layout problems in the situation of manufacturing environment and two procedures based on simulated annealing (SA) and Tabu Search (TS) were presented. For single-row layout problems having numbers of facilities 4, 10 and 11, both of the algorithms produced the optimal solutions. For other problems, they produced better solutions than those given in the literature. The algorithms produced the same results as in the literature for all the multi-row layout problems solved, with the exception of the one with 30 facilities.

Shahin et al. [7] proposed an approach for improving and optimization of the facility layout design. It was an integrated approach of simulation, quality function deployment (QFD), fuzzy analytic hierarchy process (AHP) and multiple criteria decision making (MCDM). Quantitative measure was determined by computer simulation and for qualitative measure analytical hierarchy process (AHP) was used. QFD was implemented to find out weights of criteria and the significance of the alternatives regarding the quantitative and qualitative measures. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method was used for rating the alternatives and selecting the best alternative.

Ohmori et al. [8] addresses Particle swarm optimization (PSO) technique. The proposed method did not use encoding techniques and instead, it searched coordinates of each department so that it can represent any possible layout. The objective of this model was to develop the layout for reducing the total material handling costs between departments.

Miao and Xu [9] described a model by taking account of handling cost and handling time for the facility layout problem. A hybrid algorithm which was formed by the superposition of Tabu Search (TS) and genetic algorithm (GA) was suggested to solve the model.

3. Problem Description

The general facility layout design problem is involved with the positioning of various departments of given areas within given facility. Single row facility layout problem (SRFLP) is concerned with positioning a number of facilities on a line to reduce transportation costs among the facilities. Arranging a number of facilities on different rows to reduce transportation costs among the facilities defines the multiple row facility layout problems (MRFLP).

The material handling cost of a system can be minimized by efficient arrangement of facility layouts. To determine the material handling cost for a possible layout of the system, certain parameters have to be known, such as the handling cost of unit material for unit distance between equipment, the amount of material flow or production volumes among equipment and the rectilinear distance between equipment.

3.1. Assumptions

- '*n*' facilities with the same shape and size to '*n'* distinct predetermined locations.
- Rectilinear distances are considered.
- The facility assigned to each location is one only.
- Each facility is assigned to only one physical location.

3.2. Mathematical Model

Minimize $Z = \sum_{i=1}^{N} \sum_{j=1}^{N} A_{ij}.X_{ij}$

s.t.

$$\sum_{i=1}^{N} X_{ij}=1 \; ; \quad j = 1, 2, 3.......N$$
$$\sum_{j=1}^{N} X_{ij}= 1; \; i = 1, 2, 3........N$$
$$X_{ij} € (0,1) \; ; \quad i,j = 1,2,3........N$$

where

X_{ij} € {1 , 0}
=1 if facility i is assigned to location j,
=0 otherwise.

A_{ij} = The cost of locating facility i at location j
$= f_{ij}. d_{ij}$

f_{ij} = flow cost from facility i to j

d_{ij} = distance from location i to j

Each location is assigned only one facility and each facility is assigned to only one physical location, respectively.

4. Solution Methodologies

The different methodologies for solving FLP's can be exact algorithms, heuristics and meta-heuristics. The exact algorithms are generally used when the number of facilities in the layout is up to 16. For large sized FLP's, heuristics were developed to obtain near optimal solution in reasonable computation times.

4.1. Exact Algorithms

Exact algorithms involve existence of a feasible solution and then the optimal solution was determined with certainty once such exact algorithm is successfully terminated. The main disadvantage of these

IOP Conf. Series: Materials Science and Engineering **396** (2018) 012072 doi:10.1088/1757-899X/396/1/012072

exact algorithms is that they entail heavy computational requirements when applied even to small size problems.

4.1.1. Problem Specific Algorithms

CRAFT is a helps to improve the facilities of the existing layout. The facility is improved by interchanging two or three departments and attains the optimal floor plan. The inputs for the procedure are: From-To Chart, Distances (determined for a given layout), Cost Matrix and an Initial layout. CRAFT uses a pair wise exchange algorithm, so it may not return the optimal result because the final solution is dependent on the initial layout of the plant.

CORELAP is an acronym for computerized relationship layout planning. A layout is generated by the CORELAP on the basis of total closeness rating (TCR) for each department.

ALDEP is an acronym for automated layout design program. ALDEP is quite similar to CORELAP, but in the case of ties it performs differently. It breaks ties randomly and the first department to enter is also chosen randomly.

4.1.2. Mathematical Techniques

Maximizing or minimizing a linear function subject to linear constraints defines the linear programming problem. The constraints constitute the equalities or inequalities. Constrained optimization is the practical application of linear programming. The objective function and the constraints used in the mathematical expression are linear.

A nonlinear program is similar to a linear program in that it contains an objective function, variable bounds and general constraints. The non linear program differs in the sense that it contains at least one nonlinear function, which can be the objective function or some or all of the constraints.

Dynamic programming is the process of breaking a complex problem into a sequence of simpler problems. The multistage optimization technique is the characteristic feature of it. It helps to form a general framework for solving many problem types.

4.2. Heuristic Algorithms

In order to obtain good (near optimal) solution in a reasonable computational time, heuristic algorithms were developed. A heuristic algorithm is defined by a set of steps for quickly identifying good quality solutions.

Construction algorithms are considered to be the simplest and oldest heuristic approaches. A construction algorithm consists of successive selection and placement of facilities until a complete layout is achieved. But these construction algorithms can be used to provide initial solutions for improvement algorithms.

The improvement methods start with the formation of feasible solution and try to improve it by interchanges of single assignments. The best solution which is produced by the exchange is retained and the process continues till a stopping criterion is reached or until the solution cannot be improved further. The quality of solutions is dependent on the initial layout and the location exchange procedure.

In hybrid algorithms, the solution of Quadratic Assignment Problem is determined by using a combination of two optimal or sub-optimal algorithms. Such combination of algorithms is essential in some cases to improve solution quality. This classification includes certain algorithms, which use the principal of improvement algorithms and construction algorithms.

4.3. Meta-Heuristic Algorithms

The development of meta-heuristic algorithms has high impact on the performance of improvement algorithm and it uses a general strategy like pair-wise exchange heuristic. Genetic Algorithm (GA) works on the theory of Darvin's theory of evolution and the survival of the fittest. By using natural selection and genetic operators, such as crossover, mutation and the selection, the Genetic algorithms guide the search through the solution space. The decision variables or input parameters of the problem are encoded in GA into solution strings of a finite length. Genetic algorithms usually work with the coding, on the other hand traditional optimization techniques work directly with the decision variables or input parameters. Instead of from a single point in the solution space, Genetic algorithms start to search from a population of encoded solutions. The initial population is created by random selection. Genetic Global optimum solutions are created by using genetic operators in GA based on the solutions in the current population. The commonly used genetic operators are selection, crossover and mutation. The evolution process proceeds until certain termination criteria are satisfied by replacing the old population by the newly generated individuals.

Simulated annealing (SA) is a general probabilistic local search algorithm, suggested by Kirkpatrick in 1983, to solve difficult optimization problems. SA is based on the analogy between the annealing of solids and the solving of combinatorial optimization problems. SA is a step-by-step method which could be considered as an improvement of the local optimization algorithm. This process accepts the better solutions. It also accepts worse solutions with a certain probability which is called the probability of accepting. The temperature determines the probability of acceptance. The probability of accepting a worse solution is large at a higher temperature. As the temperature decreases, the probability of accepting a worse solution also decreases as well.

Tabu Search (TS) was suggested by Glover was an efficient method, which uses the local search techniques to obtain near optimal solution to combinatorial optimization problems. It uses a list of prohibited neighbour solutions known as the tabu list, the deterministic local search technique can able to escape local optima. Apart from escaping local optima, the tabu list can also used to avoid cycling by suppressing or penalizing moves which takes the solution in the next iteration, to previously visited points in the solution space and helps to reduce the computational time. A drawback of tabu search was that it cycles the same path in the previously visited solution unless a tabu neighbor exists. In other words, a loop is encountered when the search moves to previously visited solution that has not tabu for the past two iterations.

Kennedy and Eberhart proposed an evolutionary computation technique called Particle Swarm Optimization (PSO). It is commonly used evolutionary computation algorithm. It involves the initialization of a population having random solutions. Then it search for optimal solutions by updating generations. Potential solutions, called particles, are then ''flown'' through the problem space by following the current optimum particles. In particle swarm optimization concept at each step, the velocity of the particle is changed toward its 'pBest' and'gBest' locations.

An optimization algorithm is developed based on the intelligent foraging characteristic of honey bee swarm constitutes the Artificial Bee Colony (ABC) algorithm. The artificial bee colony contains three groups of bees. They are employed bees, onlookers and scouts .The employed bee searches for destination in which food is available. They collect the food and return to its origin. Then they perform waggle dance based on the quantity of food available at the destination. The onlooker bee watches the dance and follows the employed bee depending on the probability of the available food. So, more onlooker bees will follow the employed bee associated with the destination having more amount of food. When the food source becomes deserted the employed bee transforms to scout bee. Then it searches for the new food source. The optimization problems are solved by considering the foraging characteristic of honey bee. It divides population into two parts containing the employed bees and onlooker bees. An employed bee searches for the solution in the search space and the amount of food associated with the solution defines the value of objective function associated with the solution.

5. Firefly Algorithm

Firefly Algorithm is a recently developed Meta-heuristic, which represents some of the traits of the firefly behaviour. The flashing pattern of fireflies is used to develop this algorithm. Xin-She Yang developed the Firefly Algorithm (FA) at Cambridge University in 2007.

5.1. Behaviour of Fireflies

The intensity of light at a certain distance r from the light source follows the inverse square law. That is the intensity of the light I goes on decreasing as the distance r increases. Also, the air which absorbs the light becomes weaker with the increase in the distance. When these two factors are combined, majority of the fireflies are visible at a limited distance. This extends to a few hundred meters at night, which is sufficient for the communication of fireflies with each other.

5.2. Concept

Brightness and attractiveness are proportional to each other. Thus while considering any two flashing fireflies, the less bright one will move towards the one which is brighter. Both the brightness and attractiveness decreases as their distance increases. They will move randomly if there is no one brighter than other firefly. The objective function is determined by the brightness of a firefly.

5.3. Light Intensity and Attractiveness

In the firefly algorithm, there are two key aspects: the variation in the intensity of light and formulation of the attractiveness. We can assume that the brightness of a firefly is determined by its attractiveness which in turn is connected with the encoded objective function.

In the simple cases, such as for maximum optimization problems, the brightness I of a firefly for a particular location x could be chosen as I(x) is proportional to f(x). Even so, the attractiveness β is relative, it should be judged by the other fireflies. Thus, it will differ with the distance R_{ij} between firefly i and firefly j. Also light intensity decreases with the distance from its source. Hence light is absorbed by the media and we should allow to vary the attractiveness with the varying degree of absorption. For a stated medium with a fixed light absorption coefficient γ, the light intensity I vary with the distance r as:-

$$I = Io\, e^{-\gamma r2} \quad (1)$$

Since a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can define the attractiveness β of a firefly as:-

$$\beta = \beta o\, e^{-\gamma r2} \quad (2)$$

5.4. Implementation for Facility Layout Problem

For the implementation of firefly algorithm to the multi- row facility layout problem considering 1 firefly as 1 layout and randomly creating an initial population of n fireflies. The light intensity (I) is treated as the fitness function of the population. The light intensity level helps to determine the movements. Attractiveness is find out by using an unstable distance value. The iterative process is repeated for different fireflies until the maximum generation level is reached. The light intensity values are updated. Thus the fireflies are ranked and the current best is found until the stop condition occurs.

Considering eachfirefly asa single layout and the total number offireflies as thepopulation size respectively; 3 main functions are used to implement firefly algorithm to facility layout problem. Fitness function is used to calculate the fitness of firefly. Ranking function is used to rank the Fireflies according tothe fitnessvalues(sorting).Attractiveness function is to modify the current layout with the best layout. The FA algorithm is implemented on MATLAB (R2014a).

6. Computational Results

6.1. Parameter Analysis

Population size is the total number of fireflies. To find the best population size, a parameter analysis is required. A 3 rows 9 machines layout is considered for calculating the best population size.

Table 1. Parameter Analysis table

Sl. No.	Population Size	Average Best Score
1	10	627
2	20	617.40
3	30	612.80
4	40	617.60
5	50	614.20
6	60	608
7	70	609.80
8	80	610.40
9	90	610.20
10	100	611.40

The populationsize value varies from 10 to 100 fireflies and the results obtained for eachproblems are plotted. From these values,the best population size is determined using the curve fitting techniquein SPSS software. From this graph the best value for population size is estimated as 75 fireflies.

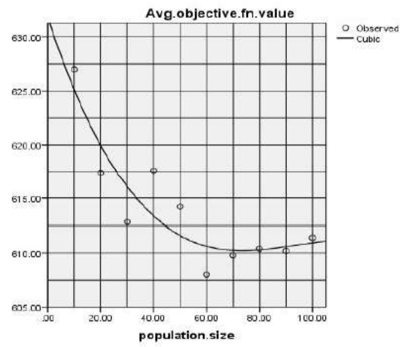

Figure 1. Parameter Analysis result using SPSS

6.2. Solution for general FLP's

The flow matrix and the cost matrix are randomly generated in the code, and the rectilinear distance is calculated. Using the newly developed FA code for FLP, different facility layout problems are solved.

Total material handling cost = Flow of material * Unit Cost * Distance (3)

The result for 4 rows 20 machines problem is obtained as:-

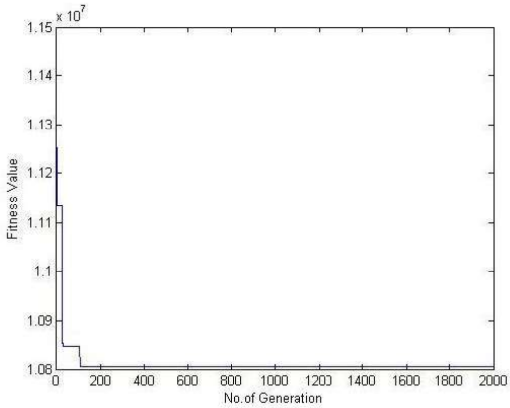

Figure 2. Final result of 4 rows 20 machines general problem

Total material handling cost = $1.081 * 10^7$.

Table 2: Final result for general problems

Sl. No	Number of Rows	Number of Machines	Population Size	Number of Generations	Best Score
1	4	20	75	2000	$1.081*10^7$
2	8	40	75	2000	$7.51*10^7$
3	12	60	75	2000	$2.371*10^8$
4	16	80	75	2000	$5.37*10^8$
5	20	100	75	2000	$9.98*10^8$

6.3. Comparative Study between GA and FA

Comparative study betweenfirefly algorithm and genetic algorithm is done. For this, a 3 rows 9 machines layout is considered and population size is taken as 10.The number of total generations is taken as 2000.

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

Figure 3. Flow matrix for the sample problem

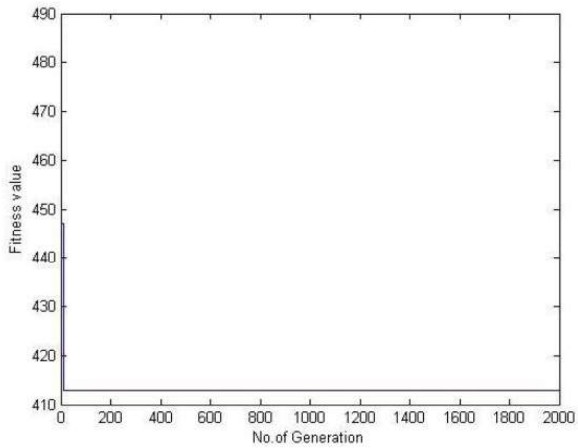

Figure 4. Final result of 3 rows 9 machines using FA

2	4	8
7	6	9
5	3	1

Figure 5. Best layout using FA

Total material handling cost using Firefly Algorithm = 413.

Total material handling cost using Genetic Algorithm is also obtained as 413. When both algorithms are computed for the same layout problem, both FA and GA give good result. So Firefly Algorithm is effective for solving layout problems.

7. Conclusion

The Facility Layout Problem provides the optimum arrangement of various facilities in the layout.The exact methods can be used to obtain an optimal layout when the number of departments is up to 16. In this work, we use a meta-heuristic approach to attain the optimal facility layout for larger problems. The Firefly algorithm used in this work is a latest meta-heuristic approach.Thecharacteristics of firefly behaviour were used to generate an algorithm for minimizing the objective of total material handling cost.A Multi-Row Facility Layout Problem is considered in the work.

A parameter analysis was done to determine the population size for Firefly Algorithm and was found to be 75. Different problems are solved using the Firefly Algorithm approach for upto 100 facilities in which the number of rows ranges from 4 to 20. A comparative study was also performed with Genetic Algorithm which establishes that Firefly Algorithm gives good results.

The closeness gap between the facilities is another crucial factor for facilitly layout problems which can be considered for future works. As another extension of the work, multiple objectives can be considered for the problem to enhance the system performance. The FLP problem with more number of machines, more number of rows and different number of machines in each row can also be considered as an extension of the work.

8. References

[1] Maricar G. Misola and Bryan B. Navarro "*Optimal Facility Layout Problem Solution Using Genetic Algorithm*", World Academy of Science, InternationalJournal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, Vol:7, No:8, 2013.
[2]F. Liu, M. Dong, F. Hou and F. Chen, "*Facility Layout Optimization with Stochastic Logistic Flows*", Service Operations and Logistics, and Informatics, SOLI, International Conference, pp. 534 – 539, 2006.
[3] S. Jannat, A. A. Khaled, and S. K. Paul, "*Optimal Solution for Multi-Objective Facility Layout Problem Using Genetic Algorithm*", Proceeding of The International Conference on Industrial Engineering and Operations Management, Dhaka, Bangladesh, 2010.
[4] C. C. Chang, T. H. Wu and S. H. Chung, "*A Novel Approach for Cell Formation and Cell Layout Design in Cellular Manufacturing System*", Management and Service Science, MASS,International Conference, pp. 20 -22, 2009.
[5] Jaewoo Chung and J.M.A. Tanchoco, *"The double row layout problem ",*School of Industrial Engineering ,International Journal of Production Research, Vol. 48, No. 3, 2010, 709–727.
[6] A.G.D. Alvarenga, F.J.N. Gomes And M. Mestria*, "Metaheuristic Methods for a Class of the Facility Layout Problem*", Journal of Intelligent Manufacturing-11, pp. 421-430, 2000.
[7] A. Shahin and M. Poormostafa,*"Facility Layout Simulation and Optimization: anIntegration of Advanced Quality and Decision Making Tools and Techniques",* Modern Applied Science, Vol. 5, No. 4, pp. 95-111, 2011.
[8] S. Ohmori, K. Yoshimoto and K. Ogawa, *"Solving Facility Layout Problem via ParticleSwarm Optimization",* Third International Joint Conference on Computational Science and Optimization, pp. 409 – 413, 2010.
[9] Z. Miao and K. Xu, "*Research of Multi-Rows Facility Layout Based on Hybrid Algorithm"*,International Conference on Information Management, Innovation Management and Industrial Engineering, pp. 553 – 556, 2009.