FLP Optimization Problem using Multi-point Swapped Crossover

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Abstract

One important choice in manufacturing and service systems is the Facility Layout Problem (FLP). The proper architecture of the equipment is essential for achieving optimal use. Having the best facility configuration is crucial for lowering product costs and enhancing the efficiency of the manufacturing process. In order to reduce the cost of material handling, this research suggests a genetic approach for resolving the equal area facility layout problem. To answer the problem of facility layout, numerous optimizations and heuristic algorithms have been presented and published in the literature. The effectiveness of the suggested approach is assessed and contrasted with other methods. The proposed method's main benefit over competing strategies is that GA's coding is straightforward and it produces the majority of the optimal value compared to other approaches.

Keywords
Facility Layout Problem, Multi-point, Swapped crossover, Optimization, Genetic Algorithm

1. Introduction

The layout of facilities or departments is a facility layout problem (FLP) on manufacturing and service sectors are experiencing all throughout in their process operation. In order to minimize a specific objective function, it can be expressed as the ideal assignment of a facilities to b locations. Facility layout planning is an essential step in the production process and has a significant impact on the company's profitability. The majority of the total operational cost is made up of total material handling expenses, which are calculated by adding up unit material flow, unit material handling expense, and the rectilinear distance between the centroids of locations between pieces of equipment.

According to Tompkins and White (1996) material handling costs account for 20% to 50% of overall operating costs, total production costs range from 10% to 80%, and a well-designed facility can save material handling costs by 10% to 30%. Therefore, a small reduction in material handling costs can help to reduce overall operating costs.

To encourage safe and effective operations, reduce travel time, lower the cost of material handling, and avoid obstacles in material and facility mobility, a suitable facility layout is crucial. Years had passed, and a great deal of research had been done to address the facility layout issue. Drira et al. (2007) offered a summary of solutions to facility layout issues. Different ways are utilized to overcome these difficulties depending on the workshop's characteristics, the issue being addressed, and other variables. Aleisha and Lin (2005) drew attention to the fact that simulation techniques are routinely used to evaluate the effectiveness of the layout.

Facility layout problems often involve multiple, competing objectives, such as minimizing costs, maximizing efficiency, and reducing environmental impact. Balancing these objectives requires advanced optimization algorithms and decision-making tools. This paper use genetic algorithm with different approach of crossover strategy. The performance of Genetic Algorithm heavily depends on the selection of parameter values such as population size, crossover and mutation probabilities, and selection strategies. Finding the optimal values for these parameters is a significant challenge for researchers.

Approaches to solving facility layout issues

Several heuristics approaches have been provided in the literature to tackle the facility layout problem. To answer the problem of facility layout, metaheuristic methods such as Tabu Search, Simulated Annealing, Ant Colony, and Genetic Algorithm are applied (FLP). Chiang and Kouvelis (1996) developed a tabu search method that uses a neighborhood-based approach meanwhile, a simulated annealing algorithm was created by Chwif et al.(1998) to overcome the aspect ratio problem in facility layout. They made use of random moves on the planar site and paired exchanges between facilities. McKendall et al. (2006) employed two simulated annealing methods as an alternative for a dynamic facility layout problem. They applied the pairwise exchange approach and a "look-ahead and look-back strategy" that improves simulated annealing. In a sequence-dependent single row machine layout problem, Solimanpur et al. (2005) created an ant colony algorithm. In order to solve constrained and unconstrained dynamic layout issues, Baykasoglu and Gindy (2001) adopted the ant colony technique. Several approach in solving facility layout problem has been presented in the literature (Roslin et al 2009); (Zhou et al. 2020; (Mohamadi et al.2019; (Kromer et al. 2020) ; (Matai and Singh 2021); (Siregal et al. 2020); (Molla et al. 2020).

Genetic algorithm strategies

In contrast, the Genetic Algorithm (GA) is utilized to resolve the issue of facility layout in facilities with equal and unequal area. Tong-tong et al. (2011) created an evolutionary algorithm with a penalty function to reduce "transportation distance" in the workshop layout for uneven area facilities. An enhanced adaptive evolutionary algorithm was put up by Yi et al. (2013) for solving workshop layout. According to the sigmoid function curve, the likelihood of crossover and mutation adapts in accordance with the fitness value. For unequal area facilities research presented by Tavakkoli-Moghaddam and Panahi (2007); Salas-Morera et al. (2011); Salas-Morera et al. (2011) and Aiello et al. (2012) proposed evolutionary algorithm and provided a multi-objective model to address facility layout problem in an equal facilities area. Moreover, Chan and Tansri's (1996) examined various genetic crossover operators to address the facility layout issue for facilities of equal area. They contrasted the cycle crossover, the order crossover, and the partially mapped crossover (PMX, OX, and PC) (CX). The outcome demonstrates that the PMX operator produced first-rate outcomes. A genetic algorithm was presented by Mihajlovic et al. (2006) to reduce material handling costs in an industrial layout problem. For the purpose of designing production systems, Mak et al. (1998) created a genetic algorithm. To solve the facility layout problem based on slice structure encoding, In addition, in order to reduce the cost of material handling, Kulkarni and Shanker (2007) solved quadratic assignment issues using a genetic algorithm. An improved GA strategy of Misola and Navarro (2013) was employed,verified and compared using problems in the literature and evaluate the probability mutation and crossover Navarro and Navarro (2016). Extensive research in the development and application of genetic algorithm to solve facility layout problem has been presented in the literature (Asl and Wong (2015); Phanden et al. (2018); Lin and Yingjie (2019); Zhao et al. (2020); and Wang and Campbell (2020).

The genetic algorithm has been utilized extensively in both binary and continuous variable optimization and is well-liked for resolving facility layout issues. Because it attempts to mirror biological evolution in order to identify better answers, it is a well-liked technique for avoiding local optima in improving search algorithms. Genetic algorithms combine evolution and computation. It uses software metrics developed in response to genetics and evolution. It is designed to quickly look for better answers to complicated computer problems.

In this study, the facility layout problem was solved using GA with new crossover methodology which is a multi-point swapped crossover. Minimizing the overall cost of material handling is the goal. The objective values are converted to their relative fitness before the selection operator, which sets the suggested method apart from previous efforts. Most of the solutions in the literature that is now available that employ evolutionary algorithm approaches to solve facility layout problems have codification issues. Swap mutation and multi-point swapped crossover were implemented to simplify the GA's coding.

2. Problem Formulation

The cost of material handling in manufacturing processes can be reduced by finding a solution to the facility layout issue. To determine the total material handling cost for a potential system layout, certain parameters such as the volume of the material flow or production among equipment, the unit material handling cost in per unit distance between equipment, and the rectilinear distance between equipment should be identified. The total material handling cost of the system is the objective function TC for the facility and it shows the extent of the organization of the facilities shown below.

$$\min TC = \sum_{i=1}^{n}\sum_{j=1}^{n} F_{ij} C_{ij} D_{ij} \tag{1}$$

Where F*ij* is the quantity of material flow between equipment *i* and *j*, C*ij* is the unit cost of material handling between equipment *i* and *j* sites, D*ij* is the rectilinear distance between the centroids of those locations, and *TC* is the overall cost of material handling for the system.

3. Methodology

The GA's starting operator, which is produced at random, creates the first population. An individual is represented as a single-level string. The length of the chromosomal string is equal to the position number of the facility. Fig. 1 illustrates the encoding of the first parent.

Location	1	2	3	4	5	6	7	8	9	10	11	12
Facility	10	4	5	2	9	7	3	11	6	12	1	8
Parent	10	4	5	2	9	7	3	11	6	12	1	8

Figure 1. Chromosome coding

The objective function, which is the total cost of material handling, is called after the initial population is formed, and the generated population is passed as an input. The objective function is then determined for each person. This paper's fitness function is provided by Chipperfield et al. (2020).

$$Fitness(x_i) = 2 - MAX + 2(MAX - 1)\frac{x_i - 1}{Nind - 1} \tag{2}$$

Where MAX is the selection pressure or bias in favor of the fittest individual, Nind is the total number of individuals, and x_i is the position of individual *i* n the ordered population.The roulette wheel selection was made based on the total cost of material handling, this selection process is utilized to probabilistically choose individuals according to its total material handling cost.This study's crossover is a swapped crossover based on Kulkarni et al. (2007). Instead of using two parents like in previous crossover approaches to develop the only workable solution, this method acts as a single parent. Only one parent's initial chromosome string is altered, and their chromosome strings are switched at the crossover places. P stands for parent, and O for offspring. Fig. 2 demonstrates the use of the multi point swapped crossover:

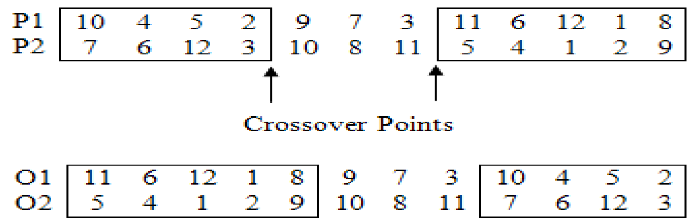

Figure 2. Swapped Crossover

The objective value will be determined after the offspring have undergone mutation. This study coupled elitism with fitness-based reinsertion. The maximum number of generations determines the termination.

4. Results and Discussion

Two numerical examples from the literature are used to demonstrate the efficacy of the suggested strategy. The MATLAB platform was used to code the complete simulation.A benchmark numerical example is used to evaluate the suggested method in comparison. Tables 1 and 2 indicate the amount of material flow and the unit material handling cost between pieces of equipment, respectively. The arrangement of the plant is a 3x3 grid. For ease of use, Table 3 tabulates the rectilinear distance between equipment positions for the 3x3 grid.

Case Example 1

Table 1. Material flow between equipment

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

Table 2 Unit material handling cost

From/To	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

19 sets of trials were run in their research to find the ideal ratio of P for population and G for generation. It is assumed that the crossover and mutation probabilities are 0.7 and 0.8 for each simulation individually. The ideal facility layouts that were produced, as shown in Table 4, resulted in total material handling costs of 4818, which were comparable to those reported in the literature.

Table 3. Rectilinear distance between equipment

From/To	1	2	3	4	5	6	7	8	9
1	0	1	2	1	2	3	2	3	4
2	1	0	1	2	1	2	3	2	3
3	2	1	0	3	2	1	4	3	2
4	1	2	3	0	1	2	1	2	3
5	2	1	2	1	0	1	2	1	2
6	3	2	1	2	1	0	3	2	1
7	2	3	4	1	2	3	0	1	2
8	3	2	3	2	1	2	1	0	1
9	4	3	2	3	2	1	2	1	0

Table 4. Optimal solutions

Optimal Solutions	Facility								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	4	3	7	8	9	1	5	2	6
2	5	2	6	8	9	1	4	3	7
3	6	2	5	1	9	8	7	3	4
4	7	3	4	1	9	8	6	2	5
5	7	1	6	3	9	2	4	8	5
6	4	8	5	3	9	2	7	1	6
7	5	8	4	2	9	3	6	1	7
8	6	1	7	2	9	3	5	8	4

The results are shown in Table 5 and shows the best total material handling cost along with Best and the number of trials desired to achieve optimal solutions.

Table 5. Optimal solutions

Exp.	GA Parameters		Proposed Method		Mihajlovic et al. (2007)		Trials	Adel El-Baz (2004)	Mak KL (1998)	Chan K and Tansri H (1994)
	P	***G***	**Trials**	**Best**	**Trials**	**Best**		**Best**	**Best**	**Best**
1	20	10	20	4818	4050	5119	200	5039	5233	4938
2	40	10	20	4818	8595	5150	400	4818	5040	5039
3	100	10	20	4818	180	4872	1000	4818	4818	4938
4	200	10	20	4818	405	4818	2000	4818	4818	4818
5	500	10	20	4818	270	4818	5000	4818	4818	4818
6	20	20	20	4818	360	4818	400	4872	5225	4938
7	40	20	20	4818	2160	4939	800	4818	4927	4992
8	100	20	20	4818	1125	4990	2000	4818	4818	4818
9	200	20	20	4818	765	4818	4000	4818	4818	4818
10	20	40	20	4818	1485	4818	800	4818	5225	4938
11	40	40	20	4818	3105	4818	1600	4818	4927	4992
12	100	40	20	4818	990	4818	4000	4818	4818	4818
13	200	40	20	4818	2160	4818	8000	4818	4818	4818
14	20	100	20	4818	3105	4818	2000	4818	5225	4938
15	40	100	20	4818	225	4818	4000	4818	4818	4927
16	100	100	20	4818	2160	4818	10000	4818	4818	4818
17	20	200	20	4818	3015	4818	4000	4818	4818	4938
18	40	200	20	4818	3240	4818	8000	4818	4818	4862
19	10	500	20	4818	3600	4818	5000	4818	4818	4818

The simulation's outcome demonstrates how much more effective the suggested strategy is than the four other approaches discussed in the literature. The findings demonstrate that the suggested approach generates each and every optimal solution after 20 trials of any P and G combination.

Case Example 2

Twelve machines from Xu et al., (2018),] are another illustration. Tables 6, 7, and 8 respectively display the amount of material flow, the unit material handling cost, and the rectilinear separation between equipment sites.

Table 6. Material flow between equipment

From/To	1	2	3	4	5	6	7	8	9	10	11	12
1	0	3	2	2	1	3	0	2	1	4	2	1
2	3	0	2	3	2	4	1	0	0	3	1	2
3	2	2	0	1	0	2	2	3	2	0	3	2
4	2	3	1	0	2	3	3	2	1	0	2	1
5	1	2	0	2	0	1	3	0	1	2	2	1
6	3	4	2	3	1	0	2	1	0	3	1	1
7	0	1	2	3	3	2	0	2	3	0	1	3
8	2	0	3	2	0	1	2	0	3	2	2	0
9	1	0	2	1	1	0	3	3	0	2	2	3
10	4	3	0	0	2	3	0	2	2	0	2	1
11	2	1	3	2	2	1	1	2	2	2	0	2
12	1	2	2	1	1	1	3	0	3	1	2	0

Table 7. Unit material handling cost

From/To	1	2	3	4	5	6	7	8	9	10	11	12
1	0	6	8	4	7	3	4	11	9	4	7	5
2	6	0	5	7	9	4	6	6	3	5	11	8
3	8	5	0	6	9	8	12	4	6	8	10	6
4	4	7	6	0	4	3	8	6	12	9	7	8
5	7	9	9	4	0	6	8	5	10	9	6	8
6	3	4	8	3	6	0	5	7	4	8	9	6
7	4	6	12	8	8	5	0	7	3	5	10	8
8	11	6	4	6	5	7	7	0	4	9	7	5
9	9	3	6	12	10	4	3	4	0	6	9	7
10	4	5	8	9	9	8	5	9	6	0	10	6
11	7	11	10	7	6	9	10	7	9	10	0	8
12	5	8	6	8	8	6	8	5	7	6	8	0

Table 8 Rectilinear distance between equipment

From/To	1	2	3	4	5	6	7	8	9	10	11	12
1	0.0	1.0	1.8	1.5	1.2	1.4	2.0	1.3	1.6	1.5	2.0	1.0
2	1.0	0.0	2.0	1.6	1.0	1.8	1.4	1.0	1.8	1.2	1.0	2.0
3	1.8	2.0	0.0	1.2	1.6	1.4	2.0	1.4	1.4	2.0	1.2	1.0
4	1.5	1.6	1.2	0.0	1.5	1.0	1.4	1.6	1.0	1.6	1.4	1.5
5	1.2	1.0	1.6	1.5	0.0	1.2	2.0	1.8	1.0	2.0	1.7	1.0
6	1.4	1.8	1.4	1.0	1.2	0.0	1.4	1.0	1.5	1.2	1.4	1.9
7	2.0	1.4	2.0	1.4	2.0	1.4	0.0	2.0	1.2	1.4	1.0	1.6
8	1.3	1.0	1.4	1.6	1.8	1.0	2.0	0.0	2.0	1.3	1.4	1.2
9	1.6	1.8	1.4	1.0	1.0	1.5	1.2	2.0	0.0	1.4	1.6	1.3
10	1.5	1.2	2.0	1.6	2.0	1.2	1.4	1.3	1.4	0.0	2.0	1.5
11	2.0	1.0	1.2	1.4	1.7	1.4	1.0	1.4	1.6	2.0	0.0	1.6
12	1.0	2.0	1.0	1.5	1.0	1.9	1.6	1.2	1.3	1.5	1.6	0.0

In this illustration, both the population and the number of generations rise at the same time to evaluate the behavior of the best possible solution. GA's first starting point consists of 50 people and 50 generations. For all simulations, the crossover and mutation probabilities are set at 0.7 and 0.8, respectively. In 20 trials, the best answer is contrasted. Table 9 displays the objective value and associated facility locations for several experiments that used 50 participants and 50 generations. The facility locations are displayed in fig. and the best answer in this example comes from trial number 14, which is 2050.6. 4.

Table 9. Objective value and facilities location for 50 individuals and 50 generations

Trial	Objective Value	Facility											
		1	2	3	4	5	6	7	8	9	10	11	12
1	**2082.8**	5	7	1	8	12	2	11	6	9	4	3	10
2	**2078.6**	2	10	7	3	6	12	1	5	11	9	8	4
3	**2078.6**	12	7	9	1	4	2	10	3	8	6	5	11
4	**2112.4**	4	2	7	3	1	11	10	12	8	9	5	6
5	**2053.4**	6	3	5	7	2	4	9	1	12	8	11	10
6	**2089.8**	6	8	2	11	7	3	9	10	4	1	12	5
7	**2110.4**	3	10	12	2	6	11	5	8	4	1	9	7
8	**2080.4**	5	7	1	3	12	9	10	4	11	6	8	2
9	**2113.8**	6	5	4	11	10	3	12	7	1	9	2	8
10	**2075.8**	6	8	12	4	3	11	5	1	7	10	9	2
11	**2108.4**	12	2	8	9	3	11	6	1	4	5	10	7
12	**2088.4**	6	10	1	12	11	4	9	2	7	5	8	3
13	**2064.4**	8	10	3	7	9	4	2	1	12	5	6	11
14	**2050.6**	4	7	1	6	5	11	9	3	10	12	8	2
15	**2087.8**	11	9	2	6	12	10	4	1	7	8	5	3
16	**2107.8**	1	10	12	7	11	4	5	6	8	2	9	3
17	**2092.0**	5	11	9	12	4	1	6	8	2	10	3	7
18	**2067.0**	12	7	1	8	5	11	6	3	10	9	4	2
19	**2069.0**	12	5	8	11	2	3	10	7	1	9	6	4
20	**2089.4**	11	8	6	2	7	5	4	10	12	9	1	3

Location	1	2	3	4	5	6	7	8	9	10	11	12
Facility	4	7	1	6	5	11	9	3	10	12	8	2

Figure 3. Best facility locations for 50 individuals and 50 generations

Table 10 Objective value at different number of individuals and generations

Individual/Generation	50	100	150	200	250	300
50	2050.6	2040.2	2044.4	2046.6	2040.2	2043.4
100	2047.4	2045.2	2040.2	2041.8	2040.2	2041.8
150	2045.8	2041.8	2041.8	2043.4	2041.8	2041.8
200	2045.0	2040.2	2040.2	2044.4	2040.2	2040.2
250	2044.4	2043.4	2041.8	2040.2	2040.2	2040.2
300	2041.8	2040.2	2041.8	2040.2	2040.2	2040.2

The starting parameter of GA is gradually increased by 50 until it reaches 300 for both individuals and generations. Table 10 shows the optimal objective value at different individuals and generations.Figure 5 depicts the ideal facility placements based on Table 10's optimal answer, which is 2040.2. Figure 6 depicts the graphical behavior of the objective value as more people and generations are added. Compared to an increase in individuals, an increase in generation leads to an increased objective value.

Location	1	2	3	4	5	6	7	8	9	10	11	12
Facility	6	4	5	11	2	3	9	7	1	8	12	10

Figure 4. Optimal facility location

Figure 5 indicates that an increase in generations results in a rise in the objective value, but it does not express the impact of an increase in individuals very clearly. The algorithm may be more sensitive to changes in the number of generations than the number of individuals, as this may suggest. However, because genetic algorithms are heuristic optimization approaches that might not always discover the global optimum, the ideal objective value achieved may not necessarily reflect the best feasible solution.

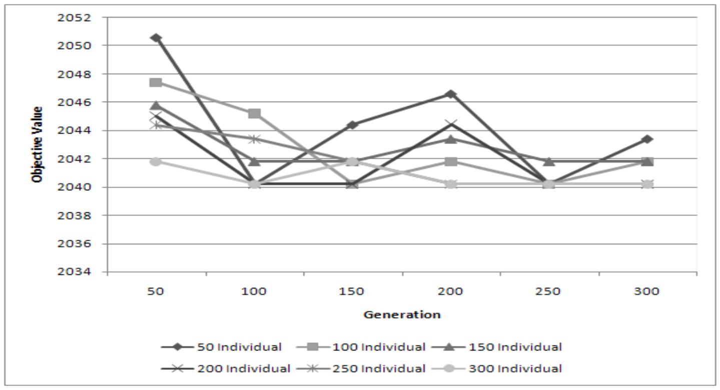

Figure 5. Graphical representation comparing the objective values at different individuals and generations

Conclusion and Future works

In this study, we created a method and modify the genetic algorithm process to reduce overall material handling expenses. Multipoint Swapped cross over was applied. In a comparison utilizing a benchmark numerical example, the proposed method is significantly more effective than the other methods in the literature. The solution demonstrates that an increase in generation has a positive impact on objective value more so than an increase in individual. Despite being simple, the coding is robust and produces good results.
Genetic Algorithm perform better compared to other solutions for several reasons. First, the performance of the GA might be significantly impacted by the standards of the initial population. Finding high-quality solutions is more likely if the initial population is good because it can serve as a better starting point for the search process, Second, the genetic operators used, such as swapped-crossover and mutation, can have an impact on how well the GA performs. The population's variety can be preserved and early convergence to less-than-ideal solutions can be avoided with the proper application of crossover and mutation operators. Third, the process utilized to choose individuals for the next generation may also have an effect on the standard of the solutions produced. Better outcomes may result from appropriate selection processes that give the fittest candidates priority. And Lastly, the fitness function's design, which is how the solutions are evaluated, is also very important. The goals of the facility layout problem should be accurately captured by a well-designed fitness function, which should also give an indication of how effectively each solution is working. Regarding the proposed technique of swapped crossover and mutation in the context of facility layout problem using genetic algorithms, The effectiveness of the swapped crossover and mutation technique may vary depending on the specific instance of the facility layout problem being solved. It may work well for some instances but not for others. The technique may not scale well to larger problem instances with a higher number of facilities or constraints. There is a risk of the algorithm converging prematurely to suboptimal solutions due to the limited exploration of the search space. The technique may require a large number of fitness function evaluations and can become computationally expensive for complex problems. The effectiveness of the swapped crossover and mutation technique may also depend on the selection of appropriate crossover and mutation operators, which can be challenging and require domain expertise. The methodology outlined in this research may be applied and tested in future work to a wide number of facilities and case studies from the real world applications considering multiple constraints and objectives.

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