# SPIRAL FACILITY LAYOUT GENERATION AND IMPROVEMENT ALGORITHM

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## Abstract:

This study is concerned with construction and improvement of a facility layout heuristic called Spiral Facility Layout Generation and Improvement Algorithm (SFLA). The algorithm starts with positioning departments from center point and continues like a hologram from center to outside. The aim of any facility layout algorithm is to better allocate the departments within facility. SFLA is compared with the existing space filling curve methods, MCRAFT and MULTIPLE, that are available in the literature. To form an initial spiral curve, a block system is used, like the bands for MCRAFT. The width and length of the blocks are given by user and departments are formed according to these values and placed around the spiral curve.

The initial layout can be selected either randomly or with a method which is called enhanced initial layout. Enhanced initial layout find the highest related department and put it into center and then add the other departments according to their relationships with the previous one.

20 departments data by Armour and Buffa(1963) have been used to test the performance of the SFLA. For bandwidth 4, SFLA gave better results than both MULTIPLE and MCRAFT. For the same flow data, 200 initial sequences selected randomly. Then initial layouts generated from these random sequences. Using pair wise exchange improvement methods both MCRAFT and SFLA layouts are improved. For bandwidth 4, SFLA often yielded better results than MCRAFT. Significance of the results is statistically tested.

**Keywords**: Facility Layout, Facility Design, Facility Layout Construction Algorithm, Facility Layout Improvement Algorithms, Facility Layout Evaluation

## 1. Introduction

Facility Layout Problem (FLP) is considered to be significantly complex problem and the most studied problem in facilities planning. The FLP is “concerned with determining the most efficient arrangement of interacting departments within a designated section of a building subject to constraints imposed by the site plan, the building, the departmental area, service requirements, and the decision maker” [1]. The problem is an NP-hard problem and the optimal solution is nearly impossible to obtain. Several methodologies such as Quadratic Assignment Problem and Mixed Integer Programming models have been developed since the problem had been defined.

The heuristic procedures are generated since the optimum was lacking. One of the most known heuristic procedures is CRAFT which is generated by Armour and Buffa in early sixties [2]. The CRAFT algorithm is a kind of QAP that uses discrete type representation and aimed to minimize the distance between interacted departments. Inspired by CRAFT, many heuristics have been developed following decades. In this paper, a model that is also based on the idea of CRAFT has been generated by applying a spiral route. The spiral route begins from the center of the plant area and the departments are assigned by following this center to outer route. The aim is to gather the most frequently used departments at the center and thus minimizing the distance between them. Section 2 briefly cowers the literature in facilities planning. In section 3, the algorithm is described and in section 4, example problems and results can be found.

## 2. Literature Review

Basically, two approaches have been used to seek the optimal solutions for Facility Layout Problem. These are; the quadratic assignment problem approach and the graph-theoretic approach [3]. The graph-theoretic approach problems are obtained to maximize the adjacency of departments as objective function. Most known examples are MATCH [4] and SPIRAL [5]. The QAP approach problems are obtained to minimize the (rectilinear distance X flow X unit cost) between departments. There are many examples of this approach. One of the well-known examples is the CRAFT. The other examples are ALDEP [6], SHAPE [7], MCRAFT [8] and MULTIPLE [1]. At this research we focus on the CRAFT and MCRAFT heuristics in order to compare the performance of MCRAFT with the algorithm that we have generated, SFLA.

CRAFT is the abbreviation of Computerized Relative Allocation of Facilities Technique and it is presented by Armour and Buffa (1963). It’s an improvement type layout. The initial layout is given and, the algorithm computes the distance between the centers of each facility and determines the cost of the initial layout. The product of the flow and the distance between facilities gives the cost of initial layout. CRAFT begins with an initial layout and performs two-way and three-way exchanges. At each iteration, the exchange that leads to the largest cost reduction is selected. The next iteration starts with the new layout and it continues until no further improvement can be done by the pairwise exchange. The facility pairs for the pairwise exchange are considered only if they have the same area or they are adjacent. This is the limitation of CRAFT algorithm. The solution is highly dependent on the initial layout. For better results, the algorithm needs to start with a better initial. The user may identify the initial layout so, several initial layouts can be tried and the best result can be chosen.

MCRAFT is the extended version of CRAFT. It is presented by Hosni, Whitehouse and Atkins [8]. MCRAFT divides the plant area into bands and assign the bands to one or more facilities. Also the MCRAFT eliminates the pairwise exchange limitations - the adjacency and the area equality- that CRAFT faces. By using MCRAFT, all the pairs can be tried with the pairwise exchange algorithm. This situation makes a very big contribution to find the optimum solution.

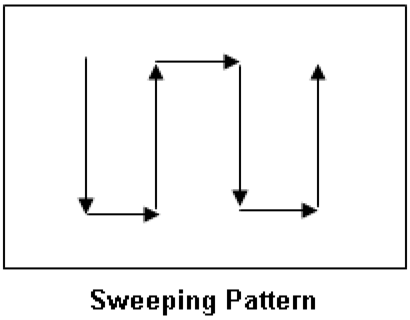
Other than MCRAFT, MULTIPLE is an extended version of CRAFT. Hilbert curves are used to represent the plant layout. These contiguous and connected curve visits all the grids on the layout and the exchange of the departments' positions can be performed easily [1].

## 3. SFLA Algorithm

SFLA, is the abbreviation of Spiral Facility Layout Algorithm. This algorithm is inspired by the MCRAFT method. However, for filling the spaces, a spiral route is followed. The aim of using the spiral route is to centralize the flow and gather the most related departments at the center of the facility in order to reduce the distance between them and creating an easiness on material handling. The objective function is calculated according to distance based objective. The flow between facilities and the unit cost to carry the loads between facilities are required to calculate the objective function. The areas of the facilities are the third parameter that the algorithm requires to do the layout design.

### 3.1 Spiral Route

Discrete representation systems generally use layout patterns to swap the facility area. These patterns are contiguous curves that visit every grid in the facility area. There are several patterns are used in the literature such as the sweeping pattern, space filling curves etc [12]. They can be seen in Figure 3.1 and 3.2.



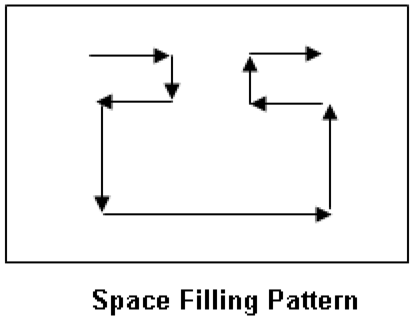




Figure 3.1: Sweeping Pattern

Figure 3.2: Space filling pattern

The spiral curve used by the algorithm SFLA starts at the center of the facility follows a spiral route till the end of the facility. The width of the spiral is adjusted according to the given band width and the length for the spiral curve. The shape of the spiral curve can be seen in Figure 3.3 below.

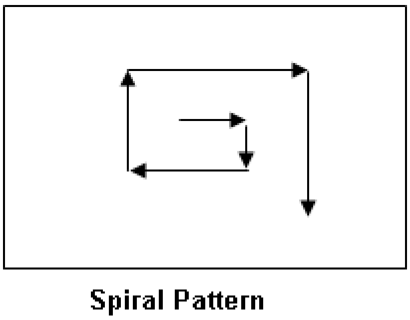



Figure 3.3: Spiral pattern

## 3.2 Block Sizes

The block sizes are calculated according to the given width and length of the facility. The calculation of the suggested block sizes are;

For the block width, the size is directly related with the total area over the number of departments and the width to length ratio of the total area.

$$BlockWidth = \sqrt{\frac{totalarea}{\left\| \sqrt{\#ofdepartments} \right\|^2}} * \frac{FacilityWidth}{FacilityLength} \tag{3.1}$$

For the block length, the size is directly related with the total area over the number of departments and the length to width ratio of the total area.

$$BlockLength = \sqrt{\frac{totalarea}{\left\| \sqrt{\#ofdepartments} \right\|^2}} * \frac{FacilityLength}{FacilityWidth} \tag{3.2}$$

This formulation has applied because it provides the required facility length/width ratio and allocates all the space formed by facility dimensions.

The user can give the band width and length. However, if inappropriate values are given, the spiral is formed according to these ratios and the dimensions of the plant area may vary from the one that is desired. At this point, tolerance limits are used. Tolerance limits give the range of adaptable sizes that can be transformed to the required sizes for the plant area.

For calculating the tolerance limit, required facility plant area width to length ratio is taken and this ratio is multiplied by (1 + (tolerance factor)) as upper limit and multiplied by (1 - (tolerance factor)) as lower limit. Then the designed plant area's length to width ratio is checked if it is in the tolerance limits.

| | | | | | |
|---|---|---|---|---|---|
| K | K | K | K | K | K |
| K | K | K | K | K | K |
| K | K | K | K | K | K |
| K | K | A | C | C | C |
| K | K | A | B | D | C |
| K | K | A | B | D | D |
| J | I | G | G | D | D |
| H | H | G | G | E | E |
| H | H | H | F | F | F |

Figure 3.4: Spiral Layout for 11 departments, block width 2, block length 3.

## 3.3 Algorithm

There are definitions and assumptions that we have to make about the algorithm.

### 3.3.1 The objective function

The objective function of the algorithm is calculated based on the distance based objective. It is calculated by multiplying the distance, flow and cost between facilities i and j as the formula can be seen in Equation 3.3. This objective function is based on the idea that the cost of material handling is increased with the distance that a load must travel [13].

$$\text{Min} \sum_{i} \sum_{j} (f_{ij} c_{ij}) d_{ij} \tag{3.3}$$

Where $f_{ij}$ is the flow between facilities i and j, $c_{ij}$ is the cost of moving between facilities i and j, $d_{ij}$ is the distance between facilities i and j. The rectilinear distance is used.

### 3.3.2 Pairwise Exchange Algorithm

SFLA performs two-way exchanges of departments. For each exchange SFLA calculates the largest reduction in cost and it performs this exchange with largest reduction in cost. The algorithm performs exchanges until there is no cost reduction can be done. Totally there are (n)(n-1) /2 number of exchanges are considered, where n is the number of departments [11]. CRAFT has a constraint about departmental exchanges. It performs only if the departments are adjacent or equal in area. However SFLA consider all the exchanges and do not put any constraint about it.

## 4. Example Problems and Computational Results

This experimental study has been completed by comparing the MCRAFT and SFLA Algorithms. Some of the data are taken from the literature and some of them are generated randomly. Different numbers of departments are used.

Results for the MCRAFT and SFLA are compared statistically. For each data, 200 samples are generated and the same initial layouts are used in order to measure the performance of the algorithms with paired-t test.

The procedure is described step by step.

1. **Define the problem.**
2. **Choose the algorithms** Choose the algorithms that is desired to compare. (SFLA, MCRAFT, MULTIPLE, BLOCPLAN etc.)
3. **Generate 200 alternative layouts.** Generate 200 random initial layouts for the problem and make an improvement on each of the selected algorithms. Sample size is kept high because the choice of the sample size and the probability of type II error -failing to reject the null hypothesis, when it is false- $\beta$ are closely connected. The $\beta$ error decreases as the sample size increases. That is, a specified difference in means is easier to detect in large sample sizes [9].
4. **Apply paired-t test.** To improve the precision by making comparisons within matched pairs, the same initial layouts are used for the algorithms. Since the same initial layouts are used for improvement, the paired-t test can be applied and the p-values can be checked to see if the data is significant or not. P value is significant while it is smaller than 0,05.
5. **Increase the sample size.** If the results are not significant, the sample size is increased to 1000.
6. **Apply Kolmogorov-Smirnov test.** Kolmogorov-Smirnov test [10] is applied in order to compare a sample data with a reference distribution or two sample data if they are drawn from the same distribution.

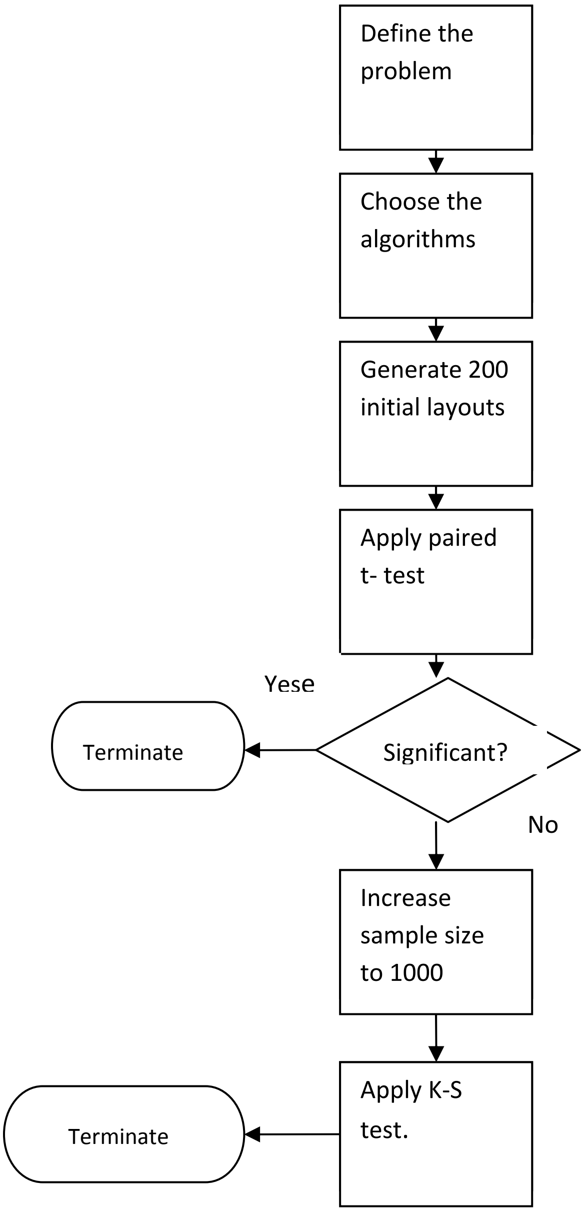



Figure 4.1: Flow diagram of experimentation procedure.

## 4.1 Numeric Example

Problem 1 is presented as an example to demonstrate the SFLA.

Table 4.1: Area Requirements for Problem 1

| | | | |
|---|---|---|---|
| Dept 1 | 49 | Dept 9 | 9 |
| Dept 2 | 28 | Dept 10 | 44 |
| Dept 3 | 24 | Dept 11 | 1 |
| Dept 4 | 50 | Dept 12 | 16 |
| Dept 5 | 16 | Dept 13 | 37 |
| Dept 6 | 37 | Dept 14 | 36 |
| Dept 7 | 17 | Dept 15 | 15 |
| Dept 8 | 21 | | |

Table 4.2: Flow Matrix for Problem 1

| | D 1 | D 2 | D 3 | D 4 | D 5 | D 6 | D 7 | D 8 | D 9 | D 10 | D 11 | D 12 | D 13 | D 14 | D 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D 1 | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 12 | 2 | 13 | 2 | 0 | 16 | 8 | 0 |
| D 2 | 3 | 0 | 0 | 0 | 16 | 16 | 4 | 7 | 0 | 3 | 0 | 7 | 0 | 14 | 0 |
| D 3 | 0 | 0 | 0 | 9 | 12 | 3 | 0 | 14 | 0 | 0 | 5 | 4 | 17 | 0 | 10 |
| D 4 | 0 | 0 | 9 | 0 | 14 | 0 | 2 | 0 | 18 | 0 | 2 | 2 | 4 | 15 | 0 |
| D 5 | 0 | 16 | 12 | 14 | 0 | 0 | 1 | 10 | 10 | 0 | 9 | 18 | 2 | 14 | 9 |
| D 6 | 1 | 16 | 3 | 0 | 0 | 0 | 16 | 0 | 4 | 0 | 0 | 3 | 10 | 2 | 14 |
| D 7 | 0 | 4 | 0 | 2 | 1 | 16 | 0 | 0 | 15 | 17 | 8 | 9 | 14 | 0 | 16 |
| D 8 | 12 | 7 | 14 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 14 | 15 | 13 |
| D 9 | 2 | 0 | 0 | 18 | 10 | 4 | 15 | 0 | 0 | 19 | 0 | 2 | 4 | 18 | 0 |
| D 10 | 13 | 3 | 0 | 0 | 0 | 0 | 17 | 0 | 19 | 0 | 10 | 18 | 0 | 9 | 0 |
| D 11 | 2 | 0 | 5 | 2 | 9 | 0 | 8 | 12 | 0 | 10 | 0 | 1 | 7 | 7 | 17 |
| D 12 | 0 | 7 | 4 | 2 | 18 | 3 | 9 | 0 | 2 | 18 | 1 | 0 | 0 | 0 | 13 |
| D 13 | 16 | 0 | 17 | 4 | 2 | 10 | 14 | 14 | 4 | 0 | 7 | 0 | 0 | 13 | 16 |
| D 14 | 8 | 14 | 0 | 15 | 14 | 2 | 0 | 15 | 18 | 9 | 7 | 0 | 13 | 0 | 1 |
| D 15 | 0 | 0 | 10 | 0 | 9 | 14 | 16 | 13 | 0 | 0 | 17 | 13 | 16 | 1 | 0 |

The initial layout of the algorithm is given in Figure 4.2;

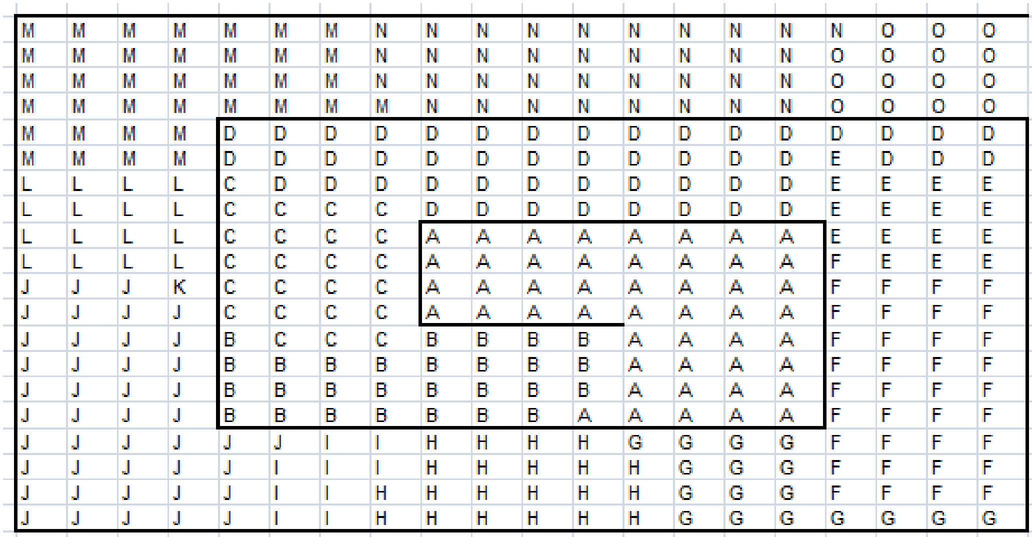


Figure 4.2: Initial layout of Problem 1

For this example, bandwidth and bandlength are taken as 4 units. The initial cost is calculated as, 19389.65. Unit cost for all the departments is taken as 1 unit. SFLA performs 10 iterations and finds the final cost of 12691.79. MCRAFT performs 8 iterations and yields the final cost of 12728 for the same problem. The final layout of SFLA is given in Figure 4.3;

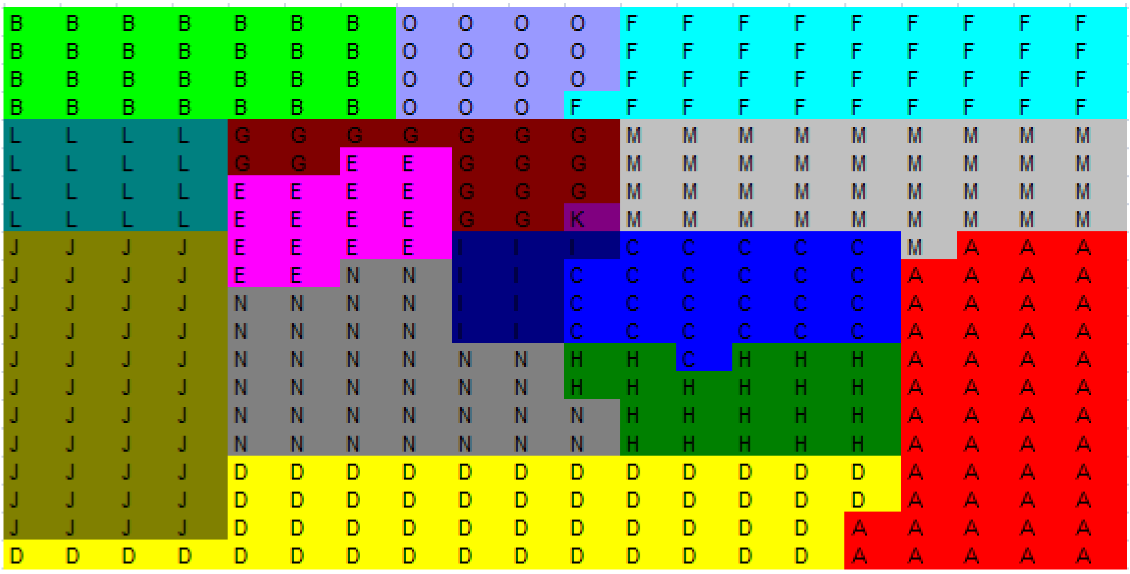


Figure 4.3: Final layout of Problem 1

## 4.2 Computational Results and Comparison of the Algorithms

6 problems' results are presented at this section. Three of the problems are taken from the literature and three of the problems are generated randomly. The results are represented in tables. SFLA results and MCRAFT result columns give the average result of 200 samples. Best result columns give the lowest result of 200 samples. The bold results show the lowest results in order to indicate which algorithm yields the lowest. The results of Problem 1 are given in Table 4.3;

Table 4.3: Results of Problem 1

| **Area** | **Width (W)** | **Length ( L)** | **b (L/W)** | **Band width (w)** | **Band length (l)** | **SFLA Result** | **MCRAFT Result** | **Best Result SFLA** | **Best Result MCRAFT** |
|---|---|---|---|---|---|---|---|---|---|
| 400 | 20 | 20 | 1 | 4 | 4 | 12802 | **12698** | 11779.4 | 11957.4 |
| 400 | 20 | 20 | 1 | 5 | 5 | 12875.3 | **12700** | 12089 | 11743 |
| 400 | 20 | 20 | 1 | 10 | 10 | 12067.6 | **11666.8** | **11262** | 10997 |
| 400 | 10 | 40 | 4 | 4 | 15 | **14389.7** | 15304.1 | 13500.9 | 14471.9 |
| 400 | 10 | 40 | 4 | 5 | 20 | 15029.9 | **14918.3** | 14149.5 | 14274.1 |
| 400 | 40 | 10 | 0.25 | 10 | 4 | 15865.6 | **14936.8** | 14979 | 13351 |
| 400 | 25 | 16 | 0.64 | 4 | 3 | **12900.8** | 12919.4 | 11794.81 | 11936 |
| 400 | 25 | 16 | 0.64 | 5 | 4 | 13149.3 | **12912.3** | 12324.8 | 12116.9 |
| 400 | 25 | 16 | 0.64 | 10 | 16 | 13779.7 | **12038.9** | 13014 | **10753.3** |
| 400 | 8 | 50 | 6.25 | 4 | 25 | 17416.7 | **17259.4** | 16385.3 | 16768.2 |
| 400 | 8 | 50 | 6.25 | 5 | 25 | **16290.1** | 17150.6 | 15241.8 | 16417.9 |
| 400 | 50 | 8 | 0.16 | 10 | 2 | 17870.0 | **17330.7** | 16771.2 | 16028.6 |

The data set of Problem 2 is taken from the study of Armour and Buffa (1964). The results are given in Table 4.4.

Table 4.4: Results of Problem 2

| **Area** | **Width (W)** | **Length ( L)** | **b (L/W)** | **Band width (w)** | **Band length (l)** | **SFLA Result** | **MCRAFT Result** | **Best Result SFLA** | **Best Result MCRAFT** |
|---|---|---|---|---|---|---|---|---|---|
| 600 | 20 | 30 | 1.5 | 4 | 6 | **6568.4** | 6622.2 | 5606.7 | 5808 |
| 600 | 20 | 30 | 1.5 | 5 | 10 | **6227.8** | 6445 | 5325.7 | 5764.6 |
| 600 | 20 | 30 | 1.5 | 10 | 15 | 5811.8 | **5330.8** | **4842.1** | **4719.3** |
| 600 | 10 | 60 | 6 | 4 | 20 | **7577.31** | 7858.18 | 6302.5 | 6268.2 |
| 600 | 10 | 60 | 6 | 5 | 30 | 7738.03 | **7352.07** | 6467.6 | 6203.5 |
| 600 | 60 | 10 | 6 | 10 | 2 | 8286.98 | **5777.97** | 6597.8 | 5034.2 |
| 600 | 15 | 40 | 2.67 | 4 | 13 | **6636.79** | 6865.26 | 5588.4 | 5736.8 |
| 600 | 15 | 40 | 2.67 | 5 | 20 | **6583.7** | 6639.44 | 5535.5 | 5731.8 |
| 600 | 40 | 15 | 2.67 | 10 | 5 | 6557.8 | **6232.51** | 5404.2 | 5310.2 |
| 600 | 25 | 24 | 0.96 | 4 | 4 | **6444.66** | 6537.04 | 5813.7 | 5577.6 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 600 | 25 | 24 | 0.96 | 5 | 6 | **6353.93** | 6419.88 | 5794.5 | 5549 |
| 600 | 25 | 24 | 0.96 | 10 | 8 | 6127.94 | **5544.81** | 5143.3 | 4867.3 |
| 600 | 12 | 50 | 4.17 | 4 | 25 | 7297.73 | **7256.29** | 6339.2 | 6022.9 |
| 600 | 12 | 50 | 4.17 | 5 | 25 | 7083.87 | **7047.5** | 5859.6 | 5813.3 |
| 600 | 50 | 12 | 0.24 | 10 | 3 | 7392.3 | **6833.59** | 5993.1 | 5576.3 |

The data set of Problem 3 is taken from the study of Bozer et al. (1994). The results are given in Table 4.5

Table 4.5: The results of Problem 3

| **Area** | **Width (W)** | **Length ( L)** | **b (L/W)** | **Band width (w)** | **Band length (l)** | **SFLA Result** | **MCRAFT Result** | **Best Result SFLA** | **Best Result MCRAFT** |
|---|---|---|---|---|---|---|---|---|---|
| 156 | 12 | 13 | 1.08 | 3 | 4 | 539.8 | **530** | 524.9 | 510.5 |
| 156 | 12 | 13 | 1.08 | 4 | 4 | 550.7 | **534** | 531.9 | 511.5 |
| 156 | 12 | 13 | 1.08 | 6 | 6 | 529 | **505** | 491.3 | **485.2** |
| 156 | 6 | 26 | 4.33 | 3 | 13 | **640** | 662 | 606.2 | 641 |
| 156 | 6 | 26 | 4.33 | 4 | 13 | **612** | 636 | 582 | 609.5 |
| 156 | 6 | 26 | 4.33 | 6 | 13 | **458** | 568 | **431.2** | 566.4 |

The data set of Problem 4 is taken from the the study of Meller (1992). Only the given dimensions applied. SFLA yields 2662.23 on average of the 200 samples and MCRAFT yields 2809.24

The data set of Problem 5 is generated randomly and can be found in Appendix. The results are given in Table 4.6.

Table 4.6: The results of Problem 5

| **Area** | **Width (W)** | **Length ( L)** | **b (L/W)** | **Band width (w)** | **Band length (l)** | **SFLA Result** | **MCRAFT Result** | **Best Result SFLA** | **Best Result MCRAFT** |
|---|---|---|---|---|---|---|---|---|---|
| 72 | 8 | 9 | 1.125 | 1 | 1 | **3139** | 3476.5 | **2912.5** | **3214.9** |
| 72 | 6 | 12 | 2 | 1 | 1 | **3656.12** | 3972 | 3330.5 | 3722.15 |
| 72 | 4 | 18 | 4.5 | 1 | 1 | **4940.3** | 5013.9 | 4681.4 | 4691.8 |

The data set of Problem 6 is generated randomly and can be found in Appendix. Only the given dimensions are applied. SFLA yields 54816.6 on the average of 200 samples. MCRAFT yields 54435.

Overall, it can be seen that…………..

# 6. CONCLUSION

Facility layout problem has been studied for several years. Most common approach to FLP is the Quadratic Assignment Problem (QAP) which is the assignment of discrete entities to discrete locations. Researchers have been worked on different branches of this problem. One of the most popular branch is the steepest descent type algorithms that their results are depend on the initial layout and make improvements. More efficient algorithms are also generated like simulated annealing and mixed integer programming. However as it is mentioned the most common and also the most popular way is the steepest descent.

At this study we have designed a new steepest descent type algorithm, Spiral Facility Layout Algorithm (SFLA). The difference of SFLA is, it uses a centralization philosophy while assigning the facilities. The idea is that, putting the most used department at the center of the plant area and assign the most related departments around it, with a circular route. While designing this model, possible material handling advantages are considered.

The other difference of this study is that, a statistical approach has been used to compare the results of different algorithms. To test the significance, 200 samples are generated for both algorithms and the same initial layouts are used for the improvement. The aim of using the same initials, rather than generating randomly for both algorithms, is to use the paired-t test.

The result tables are arranged according to their bandwidth. However the distinct difference between SFLA and MCRAFT cannot be clearly identified at this point. There are factors that affect the result, these are; bandwidth, plant length to width ratio. The different level of these factors can create advantages for desired layouts. For instance, it is assumed that the SFLA is performing more efficient results for narrow bandwidths and MCRAFT performs more efficient results for large bandwidths.

The future research spans the identification of these factors with the factorial design. By using this factor screening experiments, the effects of the factors can seen and the question about which algorithm has advantages according to which factor, can be clearly identified.

# APPENDIX

## Problem 5: 11 Departments (Random)

This data is only applied with its original dimensions and the results are given below.

Table A.1: Data set of Problem 5

| | |
|---|---|
| Number of Dept. | 11 |
| Plant Width | 8 |
| Plant Length | 9 |
| Total Area | 72 |

Table A.2: Area Information of Problem 5

| | |
|---|---|
| Dept 1 | 2 |
| Dept 2 | 13 |
| Dept 3 | 8 |
| Dept 4 | 4 |
| Dept 5 | 7 |
| Dept 6 | 5 |
| Dept 7 | 8 |
| Dept 8 | 1 |
| Dept 9 | 12 |
| Dept 10 | 2 |
| Dept 11 | 10 |

Table A.3: Flow Matrix of Problem 5

| | Dept 1 | Dept 2 | Dept 3 | Dept 4 | Dept 5 | Dept 6 | Dept 7 | Dept 8 | Dept 9 | Dept 10 | Dept 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dept 1** | 0 | 9 | 9 | 18 | 17 | 0 | 15 | 15 | 5 | 0 | 9 |
| **Dept 2** | 9 | 0 | 18 | 8 | 0 | 1 | 2 | 17 | 0 | 18 | 19 |
| **Dept 3** | 9 | 18 | 0 | 0 | 9 | 10 | 10 | 14 | 0 | 0 | 13 |
| **Dept 4** | 18 | 8 | 0 | 0 | 7 | 0 | 13 | 13 | 18 | 15 | 2 |
| **Dept 5** | 17 | 0 | 9 | 7 | 0 | 15 | 19 | 11 | 5 | 10 | 15 |
| **Dept 6** | 0 | 1 | 10 | 0 | 15 | 0 | 0 | 9 | 0 | 10 | 3 |
| **Dept 7** | 15 | 2 | 10 | 13 | 19 | 0 | 0 | 0 | 4 | 18 | 7 |
| **Dept 8** | 15 | 17 | 14 | 13 | 11 | 9 | 0 | 0 | 6 | 15 | 14 |
| **Dept 9** | 5 | 0 | 0 | 18 | 5 | 0 | 4 | 6 | 0 | 5 | 2 |
| **Dept 10** | 0 | 18 | 0 | 15 | 10 | 10 | 18 | 15 | 5 | 0 | 3 |
| **Dept 11** | 9 | 19 | 13 | 2 | 15 | 3 | 7 | 14 | 2 | 3 | 0 |

**Problem 6: 25 Department (Random)**

This data is only applied with its original dimensions and the results are given below.

Table A.4: Data set of Problem 6

| | |
|---|---|
| Number of Departments | 25 |
| Plant Width | 30 |
| Plant Length | 20 |
| Total Area | 600 |

Table A.5: Area Information of Problem 6

| | | | | | |
|---|---|---|---|---|---|
| Dept 1 | 25 | Dept 11 | 37 | Dept 21 | 11 |
| Dept 2 | 24 | Dept 12 | 7 | Dept 22 | 3 |
| Dept 3 | 16 | Dept 13 | 41 | Dept 23 | 39 |
| Dept 4 | 45 | Dept 14 | 11 | Dept 24 | 11 |
| Dept 5 | 25 | Dept 15 | 36 | Dept 25 | 36 |
| Dept 6 | 25 | Dept 16 | 35 | | |
| Dept 7 | 22 | Dept 17 | 35 | | |
| Dept 8 | 15 | Dept 18 | 43 | | |
| Dept 9 | 9 | Dept 19 | 5 | | |
| Dept 10 | 3 | Dept 20 | 41 | | |

Table A.6: Flow Matrix of Problem 6

| | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 | D11 | D12 | D13 | D14 | D15 | D16 | D17 | D18 | D19 | D20 | D21 | D22 | D23 | D24 | D25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D1 | 0 | 17 | 11 | 12 | 0 | 0 | 6 | 0 | 0 | 11 | 0 | 3 | 2 | 17 | 0 | 12 | 6 | 9 | 5 | 17 | 0 | 3 | 1 | 0 | 9 |
| D2 | 17 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 15 | 0 | 6 | 8 | 6 | 16 | 9 | 0 | 8 | 18 | 16 | 12 | 0 | 4 |
| D3 | 11 | 3 | 0 | 15 | 17 | 0 | 0 | 17 | 0 | 1 | 0 | 10 | 16 | 0 | 7 | 4 | 18 | 7 | 17 | 2 | 5 | 6 | 0 | 14 | 14 |
| D4 | 12 | 0 | 15 | 0 | 0 | 8 | 2 | 7 | 0 | 17 | 0 | 0 | 5 | 15 | 0 | 9 | 0 | 5 | 7 | 6 | 0 | 13 | 15 | 0 | 0 |
| D5 | 0 | 0 | 17 | 0 | 0 | 0 | 12 | 6 | 13 | 0 | 0 | 6 | 11 | 13 | 0 | 0 | 8 | 12 | 0 | 19 | 0 | 2 | 15 | 19 | 14 |
| D6 | 0 | 0 | 0 | 8 | 0 | 0 | 8 | 4 | 10 | 12 | 5 | 5 | 6 | 7 | 9 | 9 | 10 | 11 | 0 | 11 | 19 | 7 | 15 | 0 | 17 |
| D7 | 6 | 0 | 0 | 2 | 12 | 8 | 0 | 13 | 8 | 11 | 0 | 19 | 12 | 0 | 13 | 13 | 0 | 10 | 2 | 13 | 10 | 0 | 3 | 15 | 8 |
| D8 | 0 | 0 | 17 | 7 | 6 | 4 | 13 | 0 | 16 | 0 | 4 | 5 | 0 | 2 | 5 | 0 | 3 | 2 | 12 | 18 | 0 | 4 | 18 | 10 | 11 |
| D9 | 0 | 11 | 0 | 0 | 13 | 10 | 8 | 16 | 0 | 1 | 3 | 14 | 0 | 0 | 0 | 16 | 2 | 17 | 7 | 0 | 0 | 16 | 0 | 0 | 0 |
| D10 | 11 | 0 | 1 | 17 | 0 | 12 | 11 | 0 | 1 | 0 | 9 | 17 | 5 | 3 | 3 | 0 | 0 | 0 | 1 | 16 | 16 | 19 | 13 | 11 | 3 |
| D11 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 4 | 3 | 9 | 0 | 11 | 3 | 6 | 0 | 5 | 6 | 0 | 14 | 0 | 10 | 0 | 0 | 15 | 11 |
| D12 | 3 | 15 | 10 | 0 | 6 | 5 | 19 | 5 | 14 | 17 | 11 | 0 | 2 | 6 | 0 | 0 | 0 | 14 | 13 | 19 | 18 | 0 | 13 | 0 | 1 |
| D13 | 2 | 0 | 16 | 5 | 11 | 6 | 12 | 0 | 0 | 5 | 3 | 2 | 0 | 0 | 4 | 7 | 17 | 0 | 0 | 17 | 13 | 4 | 19 | 0 | 15 |
| D14 | 17 | 6 | 0 | 15 | 13 | 7 | 0 | 2 | 0 | 3 | 6 | 6 | 0 | 0 | 19 | 17 | 6 | 18 | 13 | 14 | 0 | 16 | 10 | 19 | 7 |
| D15 | 0 | 8 | 7 | 0 | 0 | 9 | 13 | 5 | 0 | 3 | 0 | 0 | 4 | 19 | 0 | 12 | 18 | 0 | 14 | 7 | 14 | 19 | 0 | 13 | 19 |
| D16 | 12 | 6 | 4 | 9 | 0 | 9 | 13 | 0 | 16 | 0 | 5 | 0 | 7 | 17 | 12 | 0 | 18 | 12 | 1 | 3 | 14 | 7 | 8 | 0 | 4 |
| D17 | 6 | 16 | 18 | 0 | 8 | 10 | 0 | 3 | 2 | 0 | 6 | 0 | 17 | 6 | 18 | 18 | 0 | 0 | 14 | 17 | 0 | 10 | 7 | 17 | 6 |
| D18 | 9 | 9 | 7 | 5 | 12 | 11 | 10 | 2 | 17 | 0 | 0 | 14 | 0 | 18 | 0 | 12 | 0 | 0 | 12 | 0 | 18 | 13 | 12 | 3 | 1 |
| D19 | 5 | 0 | 17 | 7 | 0 | 0 | 2 | 12 | 7 | 1 | 14 | 13 | 0 | 13 | 14 | 1 | 14 | 12 | 0 | 5 | 14 | 0 | 0 | 19 | 19 |
| D20 | 17 | 8 | 2 | 6 | 19 | 11 | 13 | 18 | 0 | 16 | 0 | 19 | 17 | 14 | 7 | 3 | 17 | 0 | 5 | 0 | 0 | 13 | 8 | 12 | 0 |
| D21 | 0 | 18 | 5 | 0 | 0 | 19 | 10 | 0 | 0 | 16 | 10 | 18 | 13 | 0 | 14 | 14 | 0 | 18 | 14 | 0 | 0 | 0 | 7 | 19 | 17 |
| D22 | 3 | 16 | 6 | 13 | 2 | 7 | 0 | 4 | 16 | 19 | 0 | 0 | 4 | 16 | 19 | 7 | 10 | 13 | 0 | 13 | 0 | 0 | 1 | 6 | 8 |
| D23 | 1 | 12 | 0 | 15 | 15 | 15 | 3 | 18 | 0 | 13 | 0 | 13 | 19 | 10 | 0 | 8 | 7 | 12 | 0 | 8 | 7 | 1 | 0 | 0 | 12 |
| D24 | 0 | 0 | 14 | 0 | 19 | 0 | 15 | 10 | 0 | 11 | 15 | 0 | 0 | 19 | 13 | 0 | 17 | 3 | 19 | 12 | 19 | 6 | 0 | 0 | 19 |
| D25 | 9 | 4 | 14 | 0 | 14 | 17 | 8 | 11 | 0 | 3 | 11 | 1 | 15 | 7 | 19 | 4 | 6 | 1 | 19 | 0 | 17 | 8 | 12 | 19 | 0 |

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## APPENDIX

### Problem 5: 11 Departments (Random)

This data is only applied with its original dimensions and the results are given below.

Table A.1: Data set of Problem 5

| | |
|---|---|
| Number of Dept. | 11 |
| Plant Width | 8 |
| Plant Length | 9 |
| Total Area | 72 |

Table A.2: Area Information of Problem 5

| | |
|---|---|
| Dept 1 | 2 |
| Dept 2 | 13 |
| Dept 3 | 8 |
| Dept 4 | 4 |
| Dept 5 | 7 |
| Dept 6 | 5 |
| Dept 7 | 8 |
| Dept 8 | 1 |
| Dept 9 | 12 |
| Dept 10 | 2 |
| Dept 11 | 10 |

Table A.3: Flow Matrix of Problem 5

| | **Dept 1** | **Dept 2** | **Dept 3** | **Dept 4** | **Dept 5** | **Dept 6** | **Dept 7** | **Dept 8** | **Dept 9** | **Dept 10** | **Dept 11** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Dept 1** | 0 | 9 | 9 | 18 | 17 | 0 | 15 | 15 | 5 | 0 | 9 |
| **Dept 2** | 9 | 0 | 18 | 8 | 0 | 1 | 2 | 17 | 0 | 18 | 19 |
| **Dept 3** | 9 | 18 | 0 | 0 | 9 | 10 | 10 | 14 | 0 | 0 | 13 |
| **Dept 4** | 18 | 8 | 0 | 0 | 7 | 0 | 13 | 13 | 18 | 15 | 2 |
| **Dept 5** | 17 | 0 | 9 | 7 | 0 | 15 | 19 | 11 | 5 | 10 | 15 |
| **Dept 6** | 0 | 1 | 10 | 0 | 15 | 0 | 0 | 9 | 0 | 10 | 3 |
| **Dept 7** | 15 | 2 | 10 | 13 | 19 | 0 | 0 | 0 | 4 | 18 | 7 |
| **Dept 8** | 15 | 17 | 14 | 13 | 11 | 9 | 0 | 0 | 6 | 15 | 14 |
| **Dept 9** | 5 | 0 | 0 | 18 | 5 | 0 | 4 | 6 | 0 | 5 | 2 |
| **Dept 10** | 0 | 18 | 0 | 15 | 10 | 10 | 18 | 15 | 5 | 0 | 3 |
| **Dept 11** | 9 | 19 | 13 | 2 | 15 | 3 | 7 | 14 | 2 | 3 | 0 |