

**AN ALTERNATIVE APPROACH TO FACILITY LAYOUT
PLANNING: SPIRAL FACILITY LAYOUT PLANNING**

by

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May 2010

**AN ALTERNATIVE APPROACH TO FACILITY LAYOUT
PLANNING: SPIRAL FACILITY LAYOUT PLANNING**

by

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AN ALTERNATIVE APPROACH TO FACILITY LAYOUT PLANNING: SPIRAL FACILITY LAYOUT PLANNING

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M. S. Thesis - Industrial Engineering
May 2010

Supervisor: Assist Prof. Fahrettin Eldemir

ABSTRACT

This study is concerned with construction and improvement of a new layout algorithm. This new algorithm is called Spiral Facility Layout Algorithm (SFLA). Positioning of the facilities begin with locating a department at a center point and continue like a hologram from center to outside. The aim is to increase the adjacency between related facilities and reduce the material handling cost. The algorithm uses the pairwise exchange methodology. Several different problems are selected to test the efficiency of the algorithm. The results of SFLA are compared with the results of MCRAFT algorithm which also uses the pairwise exchange methodology.

Keywords: Facility layout planning, Facility layout algorithms, Pairwise exchange method, Material Handling.

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ÖZ

Bu çalışma, yeni bir tesis planlama algoritmasının geliştirilmesini kapsar. Geliştirilen bu algoritmaya “Spiral Tesis Planlama Algoritması”, SFLA, denilmiştir. Tesis üzerinde, departmanların yerleştirilme işlemi, bir departmanın merkeze konulması ve böylece merkezden dışa doğru hologram şeklinde ilerlemesiyle gerçekleşir. Amaç, birbirleriyle yakından ilişkili departmanların bitişikliğini arttırmak ve malzeme taşıma maliyetlerinde bir düşüş sağlamaktır. Algoritma, departmanların yer değişiklikleri için “ikili yer değiştirme” metodu kullanmaktadır. Algoritmanın etkinliğini ölçmek için çeşitli problemler üzerinde çalışılmış ve çıkan sonuçlar, aynı metodu kullanan başka bir algoritma olan MCRAFT ile karşılaştırılmıştır.

Anahtar Kelimeler: Tesis planlama, Tesis planlama algoritmaları, İkili yer değiştirme metodu, Malzeme taşıma.

To my family

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL/ ABBREVIATION

SFLA	: Spiral Facility Layout Algorithm
FLP	: Facility Layout Problem
QAP	: Quadratic Assignment Problem
MIP	: Mixed Integer Programming
OFV	: Objective Function Value
CTC	: Centroid to Centroid
DCTC	: Distributed Centroid to Centroid
f_{ij}	: the flow between facilities i and j
c_{ij}	: the cost of moving a unit of load between facilities i and j
d_{ij}	: the distance between facilities i and j
R_{ij}	: the numeric value given for the flow between facilities i and j .

CHAPTER 1

INTRODUCTION

Facility Layout Problem (FLP) is considered to be the most important 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” (Bozer *et al.*, 1994).

The flow between departments is considered with the aspect of reducing the distance between departments with high flows. An efficient and effective design of a facility can reduce the time and effort that a system has to spend and it creates great advantages on material handling.

According to Bozer *et al.* (2002) material handling is an activity that uses the right method to provide right amount of the right material at the right place, at the right time, in the right sequence, in the right position, and at the right cost.

Especially for the manufacturing facilities, one of the most important issues is the material handling. According to the researches, between 20 and 50% of the total operating expenses within manufacturing is attributed to material handling and it is assumed that, an effective facilities plan can reduce these costs by at least 10 to 30%.

Overall, it can be seen that, facilities design can cause great benefits to reduce the operating costs.

Facility layout problem has been studied by researchers for years. Several methodologies have been tried in order to find the efficient algorithm. There are two common algorithms in heuristic approaches; construction type algorithms and the improvement type algorithms. It can be said that improvement algorithms are more frequently encountered. At this thesis research, steepest-descent type improvement algorithms had the focus on. A review of the existing algorithms has been made. Specifically, the steepest descent improvement type of algorithms. A new space filling algorithm is generated which uses steepest descent improvement method. It is compared with the existing algorithms.

The newly introduced model is named, Spiral Facility Layout Algorithm (SFLA). Like the other algorithms, it aims to reduce the material handling cost and to increase the availability of the most frequently used resources. Overall increase in the efficiency has been sought. The foundations of the approach are given in the literature review part in Chapter 2. Comparable algorithms are deeply examined in Chapter 3. The details of the SFLA are given in Chapter 4. The computations are performed and comparisons of the results are discussed in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

Facility layout problems have been studied over many years. Most of the facility layout planning algorithm are working on a principle that assigning n facilities to n locations. An important type of this problem is called Quadratic Assignment Problem (QAP). The heuristic methods to solve this problem generally classified as improvement or construction type. Construction algorithms form the initial layouts and do not make improvements on it. Improvement algorithms have been characterized as yielding better solutions largely due to their multi-pass nature. They require an initial layout, which is often generated by a construction algorithm, and seek to iteratively improve the initial configuration (Ligget, 1981). Most of the algorithms in the literature can be classified as improvement type algorithm. Literature review part is divided into sections based on the specifications of the improvement type layout algorithms.

For the representation of the sections on the layout, both, ‘facility’ and ‘department’ are used in the literature. In the thesis, mostly, the word ‘facility’ is used, however ‘department’ can be used, as well.

2.1 REPRESENTATION TYPES

There are many facility layout representation systems; however most of the heuristics use two kinds of them to allocate the facility area; discrete representation and continuous representation. The Quadratic Assignment Problems can be defined in the discrete representation group. Discrete representation, divides the facility area into grids with fixed dimensions. The areas of the facilities are represented with the number of

2.1.2 Continuous Representation

Continuous representation does not use the grid system and it is more flexible. Most of the continuous represented layouts are designed as Mixed Integer Programming model. All the facilities are placed anywhere within the planar site and must not overlap each other (Meller, 1999).

The facilities in the plant site are located either by their centroid coordinates (x_i, y_i) , half length l_i and half width w_i or by the coordinates of bottom-left corner, length L_i and width W_i of the facility (Chwif *et al.*, 1998). The disjunctive constraints and the large number of binary integer variables that prevent departmental overlap are the basic difficulties about the MIP-FLP. (Liu and Meller, 2005). Continuous representation can be shown in Figure 2.2 below.

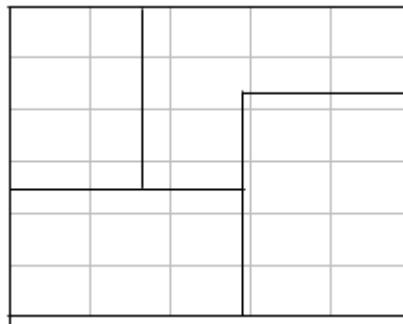


Figure 2.2 Continuous Representation (Adapted from Bozer *et al.* (2002))

2.2 MATERIAL HANDLING

Due to the observations, a well designed material handling design process can be the main backbone of a company's overall production execution strategy (Bozer *et al.*, 2002). As it is known that, material handling and facility design are integrated and generally they do not considered separately.

Material handling can be defined as the science of moving, storing, protecting and controlling the material (Bozer *et al.*, 2002). According to the researches, material handling accounts for 15% to 70% cost of an industrial facility. This amount is very important and, it is known that great savings can be provided from this issue.

While making facility design, it is assumed that the main issue is to minimize this cost and design an optimum plant area.

2.3 THE OBJECTIVE FUNCTION

The objective function seeks to find the optimum cost of the layout while it is iteratively improved. It can be calculated in two ways; the distance based objective and the adjacency based objective. The objective function keeps the minimum cost, while the distance based objective function is used and it keeps the maximum adjacency score, while the adjacency based objective function is used. Further information is given below.

2.3.1 The Distance Based Objective Function

The distance based objective is calculated by multiplying the distance, flow and cost between facilities i and j as the formula can be seen in equation 2.1. This objective function is based on the idea that the cost of material handling is increased with the distance that a load must travel.

$$\text{Min } \sum_i \sum_j (f_{ij} c_{ij}) d_{ij} \quad (2.1)$$

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 distance between departments can be calculated in two ways; centroid to centroid distance and the distributed centroid to centroid distance.

2.3.1.1 Centroid to Centroid Distance Approach

The distance between the centers of departments is called Centroid to Centroid distance. We assume that, the flow is between the centers of the departments. This distance can both be measured as Euclidean or Rectilinear. Figure 2.3 shows the distances between two facilities.

Euclidean distance metric is

$$d_{ij} = [(x_i - x_j)^2 + (y_i - y_j)^2]^{0.5}. \quad (2.2)$$

Euclidean finds the shortest path between facilities on a facility layout.

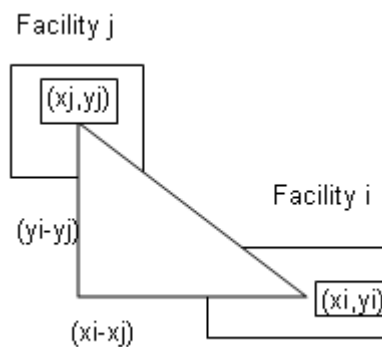


Figure 2.3 Distance between two facilities (Adapted from Heragu (1997)).

Rectilinear distance metric is

$$d_{ij} = [|x_i - x_j| + |y_i - y_j|]. \quad (2.3)$$

Rectilinear distance is easy to calculate and appropriate for many practical problems.

2.3.1.2 Distributed Centroid to Centroid Distance Approach

Another approach is first discussed by Bozer and Meller (1996) , which is called Distributed Centroid to Centroid. “When a (real) flow, say f_{ij} , is distributed between the subdepartments of departments i and j , then generally speaking, no flow occurs from the centroid of i to the centroid of j . Rather a flow $f_{ij}/(a_i a_j)$ units occurs from each subdepartment of i to each subdepartment of j . Because each such flow value is

multiplied by the distance from centroid of a subdepartment of i to the centroid of a subdepartment of j , we will refer to the resulting problem as a QAP with distributed centroid to centroid (DCTC) distances.” (Bozer, Meller 1996). At this approach, we assume that the flow occurs from every part of a department to every part of another department.

The objective function can be calculated as;

$$\text{Min} \sum_i \sum_{k \in s(i)} \sum_j \sum_{l \in s(j)} \left(\frac{f_{ij}}{a_i a_j} \right) c_{ij} d_{kl} \quad (2.4)$$

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

a_i and a_j are the areas of facilities i and j

The approach can be represented with an example. This example is taken from the article of Bozer and Meller (1996).

Assume that we have two facilities i and j , that is represented in Figure 2.4



Figure 2.4 Facilities i and j (Adapted from Bozer and Meller (1996))

The CTC distance for these two facilities is equal to 1 unit which is the distance from the center point of facility i to the center point of facility j .

DCTC distance is calculated as the total distances from each grid of department i to each grid of department j . Then it is divided to the result of $(a_i a_j)$. The result is 1.89.

The DCTC distance is more accurate since it assumes that there is flow from every part of one department to every part of another department, rather than assuming that the flow occurs between the centers of departments.

2.3.2 The Adjacency Based Objective Function

The adjacency based cost is calculated based on the interaction between facilities.

$$\text{Max } \sum_i \sum_j (r_{ij})x_{ij} \quad (2.5)$$

If the department i and j share a border, the x_{ij} equals 1 and 0 otherwise. r is the numeric value given, according to the strength of the relationship (Letters A, E, I, O, U and X are used for the letter representation.) The aim is to maximize the adjacency score. Some of the algorithms, such as BLOCPLAN use adjacency score. For more information about BLOCPLAN, Chapter 3 can be checked.

2.4 PAIRWISE EXCHANGE ALGORITHM

Pairwise exchange considers only two facilities for exchange at a time. At the first step, the algorithm considers exchanging the positions of the facilities 1 and 2. If the objective function value, based on this exchange is better than the initial layout's OFV, it is stored as candidate. If not, it is discarded and the algorithm considers an exchange in the positions of the facilities 1 and 3. If the resulting OFV is better than, what is currently best, the previous one is discarded and this solution is taken as candidate. Thus, whenever a better solution is found, the algorithm discards the previous best solution. This procedure continues, until all the pairwise exchanges are considered. Assuming that there are n_f numbers of facilities, each facility can be exchanged with $(n_f - 1)$ facilities. Therefore $(n_f) * (n_f - 1)$ exchanges are possible. The exchange of the position of i with that of j is the same as the exchange of the position of j with i . So we need to consider $(n_f) * (n_f - 1) / 2$ distinct exchanges. These $(n_f) * (n_f - 1) / 2$ exchanges are considered in step 2.

The solution retained at the end of step 2 is the one that provides the most improvement in the OFV. In the following iterations, starting with improved layout obtained from previous iteration, the algorithm repeats step 2 to find better solution. At some stage, no improvement in the current best solution is observed. And then, the algorithm terminates. The current best solution is returned to the user (Heragu, 1997).

2.5 OPTIMAL LAYOUT VS. HEURISTIC APPROACH

Solution techniques or procedures are commonly called algorithms. If a given algorithm can produce at least one optimal solution (when multiple optimal solutions exist), then it is called an optimal algorithm; otherwise, it is called a heuristic algorithm or simply a heuristic.

2.5.1 Optimal Algorithms

Optimal algorithms can produce the best solution. However, they are considered as unrealistic because of the high memory and computational time requirements. Some algorithms require years of computer run time.

Heragu(1996) classify the optimal algorithms in three categories;

1. Branch and Bound Algorithms
2. Decomposition Algorithms
3. Cutting Plane Algorithms

2.5.2 Heuristic Algorithms

Heuristic algorithms can be classified in three groups; construction algorithms, improvement algorithms and the hybrid algorithms which consist of both construction and improvement algorithms.

Construction algorithms generate a facility layout from scratch. It starts with an empty layout and adds facilities one after another until all the facilities are placed. Improvement algorithms start with a given initial layout and make changes on this initial layout. If it is improved, the changes become permanent; otherwise it tries other alternative changes. While searching for the improved layout, some of the algorithms use path dependent, steepest descent methodology. According to this methodology, the changes on the initial layout can be done if and only if it improves the objective function value. It leads us to find the local minimum.

More advanced improvement heuristics, like Simulated Annealing, Genetic Algorithms etc. do not guarantee the global optimality; however they are less likely to get trapped in local minima or maxima, compared to techniques based on steepest descent. (Al-Hakim, 2000).

2.6 IMPROVEMENT ALGORITHMS

2.6.1 CRAFT and MCRAFT

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 (1980). 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. The layout form of the MCRAFT is shown in Figure 2.5.

	1	2	3	4	5	6
1	1	1	7	8	8	8
2	1	2	7	7	8	8
3	2	3	6	7	9	10
4	3	3	6	6	11	11
5	3	4	5	5	11	11
6	4	4	4	4	11	11

Figure 2.5 MCRAFT Layout, 11 facilities and bandwidth 1.

2.6.2 MULTIPLE

MULTIPLE was developed by Bozer, Meller and Erlebacher. MULTIPLE has similarities with CRAFT. The exchange procedure is different and the main difference is the layout formation. Both algorithms uses from-to-chart for input data and uses distance based objective with distance measured as rectilinear. The layout is represented with discrete representation. The initial layout is specified by the user and like CRAFT, MULTIPLE does the improvement. Improvements are done through two-way exchanges, and at each iteration the exchanges which makes the largest cost reduction is selected. For this reason, it can be said that the MULTIPLE is a steepest descent algorithm. (Tompkins,White,Bozer,Tanchoco, 2002)

2.6.3 BLOCPLAN

BLOCPLAN is an interactive program developed by Donaghey and Pire (1991). BLOCPLAN can develop both single story and multistory layouts. Quantitative and qualitative data can be used as input. The user can also enter the product-routing data and based on those data, BLOCPLAN calculates the flow or frequency of the movements. The user can choose the rectangular shape of the building from four pre-defined and one user defined dimension ratios. The user can manually insert the facilities.

As the BLOCPLAN generates initial layout and makes improvement on those layouts, it can be defined as both construction and improvement algorithm. The user can optionally choose the randomly construction, embedded improvement and automatic search.

The random layout algorithm generates initial layout without considering the flow or interaction between facilities. The improvement algorithm requires at least one initial layout be available and saved. The automatic search algorithm generates an initial layout randomly using the random initial layout algorithm and then uses the improvement algorithm to improve it (Heragu, 1996).

CHAPTER 3

IMPROVEMENT TYPE ALGORITHMS

3.1 CRAFT

CRAFT requires;

- The dimensions of the building
- The dimensions of the facilities
- Flow data between facility pairs
- Fixed facilities if exists

CRAFT cannot create the initial layout. It is defined by the user. After the initial layout is formed by the user, the algorithm determines the distance between centers of the facilities. The cost of material handling between facility pairs is the product of the distance between centers of the facilities i and j by the flow between the facility pairs i and j . The cost of the initial layout is the sum of these material handling costs for all the facility pairs.

After the cost of the initial layout is calculated, the algorithm does the pairwise exchanges. The details of the pairwise exchange can be found in Chapter 2.

However, CRAFT has a limitation for the pairwise exchange. The facilities can be exchanged if only they are adjacent or they have the same area. By doing this, the centers of the other facilities are not changing and thus it is easier to calculate the new cost, while making pairwise exchanges.

Normally the algorithm has to make $n(n-1)/2$ number of exchanges where n is the number of facilities. However, since it has a limitation, fewer exchanges are performed.

The exchange that results greatest estimated cost is made. As well as two-way exchanges, CRAFT can perform three-way exchanges.

The estimated cost is calculated by assuming that the coordinates of facilities i and j are interchanged. The expression is taken from the study of Heragu (1997).

$$\sum_{k=1, k \neq i, k \neq j}^n f_{ik} d_{ik} + \sum_{k=1, k \neq i, k \neq j}^n f_{jk} d_{jk} - \sum_{k=1, k \neq i, k \neq j}^n f_{jk} d_{ik} - \sum_{k=1, k \neq i, k \neq j}^n f_{ik} d_{jk} \quad (3.1)$$

f : the flow between facilities

d : the distance.

The facilities can be fixed to specific locations which is sometimes required in daily life applications.

Example 3.1

Assume that we have to design a layout with eight facilities. The unit cost c_{ij} is 1. The layout area is 14 m. in width and 15 m. in length. Total area is 210 m². All the grids equal to 1 X 1 m. The area of the facilities and the flow data are given in Table 3.1 and Table 3.2 respectively.

Table 3.1 Area of the facilities

Dept 1	A	25
Dept 2	B	10
Dept 3	C	45
Dept 4	D	20
Dept 5	E	35
Dept 6	F	50
Dept 7	G	15
Dept 8	H	10

Table 3.2 Flow between facilities

	Dept 1	Dept 2	Dept 3	Dept 4	Dept 5	Dept 6	Dept 7	Dept 8
Dept 1		45	70	30	14	25	50	34
Dept 2			37	54	80	28	27	65
Dept 3				30	40	27	45	45
Dept 4					18	30	40	26
Dept 5						50	30	48
Dept 6							35	45
Dept 7								28
Dept 8								

The initial layout is assumed to be given as it can be seen in Figure 3.1;

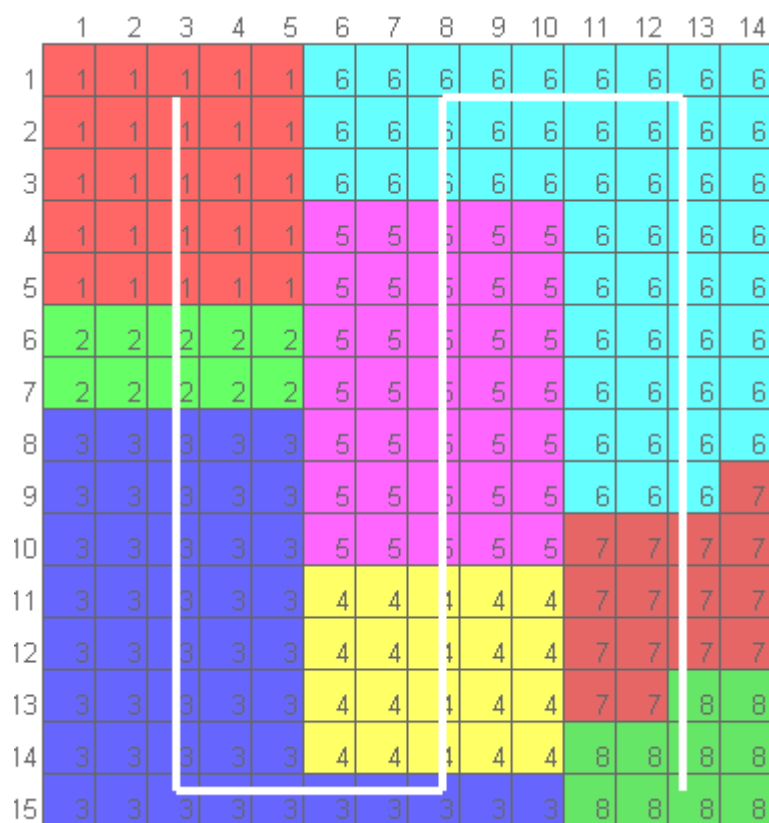
**Figure 3.1** The initial layout for the Example 3.1

Table 3.3 The centroids of the facilities for the Example 3.1

x-centroid	y-centroid
2,5	2,5
2,5	6
3,05555558	11,3888893
7,5	12
7,5	6,5
10,6199999	3,51999998
11,9666662	10,6333332
12,1999998	13,6999998

Once the centroids of facilities are calculated, the distance between facilities centroids' and the flow between facilities are multiplied and the objective function is found. Rectilinear distance is used. For example, the rectilinear distance between facilities 1 and 4 is 14,5. The flow between facilities 1 and 4 is 30, and the cost is (14,5 X 30) 435. These costs are calculated for each department pairs, then the objective function is found. The objective function value for the initial layout of this problem is; $z = 11052$ unit.

Then the pairwise exchanges are performed. For this problem, the algorithm first performs the exchange of facilities 4 and 8. The cost is reduced to 10153. The second exchange is for the departments 5 and 1. The cost is reduced to 9621. The third exchange is for the departments 1 and 8. The cost is reduced to 9118. Then another iteration is performed however, since this iteration increases the cost, the iterations stop and the program terminates. Since the cost begin to increase, we can say that the local optimum is $z = 9118$. The final layout is given in Figure 3.2.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	5	5	5	5	5	6	6	6	6	6	6	6	6	6
2	5	5	5	5	5	6	6	6	6	6	6	6	6	6
3	5	5	5	5	5	6	6	6	6	6	6	6	6	6
4	5	5	5	5	5	5	5	1	8	8	6	6	6	6
5	5	5	5	5	5	5	5	1	8	8	6	6	6	6
6	2	2	2	2	2	5	5	1	8	8	6	6	6	6
7	2	2	2	2	2	5	1	1	1	8	6	6	6	6
8	3	3	3	3	3	5	1	1	1	8	6	6	6	6
9	3	3	3	3	3	5	1	1	1	8	6	6	6	7
10	3	3	3	3	3	5	1	1	1	8	7	7	7	7
11	3	3	3	3	3	1	1	1	4	4	7	7	7	7
12	3	3	3	3	3	1	1	1	4	4	7	7	7	7
13	3	3	3	3	3	1	1	4	4	4	7	7	4	4
14	3	3	3	3	3	1	1	4	4	4	4	4	4	4
15	3	3	3	3	3	3	3	3	3	3	4	4	4	4

Figure 3.2 The final layout for Example 3.1

3.2 MCRAFT

MCRAFT shows approximately the same characteristics with CRAFT, as it was mentioned in Chapter 2. However the constraint about the pairwise exchange is relaxed. CRAFT can only make exchanges between the departments which are adjacent or have the same area. MCRAFT relaxed this constraint and makes all possible exchanges. This relaxation made very big contribution while searching for the best objective function value since the CRAFT cannot perform every possible exchange.

Example 3.2

Consider the same data given in Example 3.1. We choose the same bandwidth with the one used for CRAFT. The same initial layout is formed.

The objective function value for the initial layout is the same, $z = 11052$ units. Three pairwise exchanges are performed. First one is between the departments 8 and 6. The objective function value is reduced to 10108 units. The second iteration changes the

departments 7 and 3, OFV is 8947. The third iteration changes the departments 7 and 2. The new objective function value is 8705. Then the program terminates. The final layout is given below in Figure 3.3.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	1	1	1	1	3	3	3	3	3	3	3	3	3
2	1	1	1	1	1	3	3	3	3	3	3	3	3	3
3	1	1	1	1	1	3	3	3	3	3	3	3	6	6
4	1	1	1	1	1	3	3	3	3	3	6	6	6	6
5	1	1	1	1	1	3	3	3	3	3	6	6	6	6
6	7	7	7	7	7	3	3	3	3	3	6	6	6	6
7	7	7	7	7	7	3	3	3	3	3	6	6	6	6
8	7	7	7	7	7	8	8	8	8	8	6	6	6	6
9	2	2	2	2	2	8	8	8	8	8	6	6	6	6
10	2	2	2	2	2	5	5	5	5	5	6	6	6	6
11	4	4	4	4	4	5	5	5	5	5	6	6	6	6
12	4	4	4	4	4	5	5	5	5	5	6	6	6	6
13	4	4	4	4	4	5	5	5	5	5	6	6	6	6
14	4	4	4	4	4	5	5	5	5	5	6	6	6	6
15	5	5	5	5	5	5	5	5	5	5	6	6	6	6

Figure 3.3 The final layout for Example 3.2

The results of CRAFT and MCRAFT show a difference. If the results are compared as ratios, we can say that, MCRAFT shows 4.5% improvement according to CRAFT, for this problem

3.3 BLOCPLAN

BLOCPLAN can both be defined as an improvement and construction algorithm. The user can optionally choose the randomly construction, embedded improvement or automatic search.

The random layout algorithm generates initial layout without considering the flow or interaction between departments. The improvement algorithm requires at least one initial layout be available and saved. The automatic search algorithm generates an initial

layout randomly using the random initial layout algorithm and then uses the improvement algorithm to improve it.

BLOCPLAN can be both used for single story layouts and multistory layouts. Unlike the CRAFT and MCRAFT, it uses only continuous representation. The user can use qualitative data, as well as quantitative data. Qualitative data is used for representing the flow between facilities. The qualitative data is represented with the letters (A, E, I, O, U and X).

The highest value in the flow matrix is found and then this value is divided into 5. The result is the range for each letters. The first range is assigned to U, the second is assigned to O and so on. For example, if we assume that the largest value in the flow matrix is 500.

Then the ranges will be,

Table 3.4 Letter Assignments

Flow between departments i and j	Letters Assigned
401-500	A
301-400	E
201-300	I
101-200	O
0-100	U

Each value in the flow matrix is assigned to a letter by using these range indicators. There is a limitation for the number of facilities. The program can handle maximum 18 facilities.

The user can choose the plant area width to length ratio. There are four predefined and one user defined ratio. One of them can be chosen before creating the layout.

The bandwidth for the layout is determined by the program and generally 2 or 3 bands are used.

The program can be executed in three ways.

- 1) Random layout: A random layout can be used. By using this algorithm, a random layout is generated without considering the flow of the facilities.
- 2) The improvement algorithm: Improvement algorithm uses a given initial layout and improves it by making exchanges. The adjacency based cost and rel-dist costs are calculated.
- 3) The automatic search algorithm generates a random initial layout and then makes improvements on this initial, when it finds an optimum layout, it takes this layout as initial and then makes improvements on this. Maximum number of layouts that can be generated is 20.

The exchange of facilities can also be done. The desired facilities for exchange are given as input, then the algorithm makes the exchange of desired facilities and adjust the positions of the other departments.

The costs are calculated with adjacency based score and the rel-dist score. For more information about adjacency based cost, see Chapter 2. The adjacency score is calculated by dividing the adjacency based cost to the total possible adjacencies. It can be treated as a normalized value.

The formula can be represented as;

$$TC_{Adjacency} = \frac{\sum_{i=1}^{n-1} \sum_{j=i+1}^n R_{ij} D_{ij}}{\sum_{i=1}^{n-1} \sum_{j=i+1}^n R_{ij}} \quad (3.2)$$

The rel-dist score is calculated by using the distance between departments.

The formula can be represented as;

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^n d_{ij} R_{ij} \quad (3.3)$$

R_{ij} is the numeric value given for the flow between facilities i and j .

D_{ij} 1 if facilities i and j are adjacent, 0 otherwise

n is the total number of facilities

d_{ij} rectilinear distance between facilities i and j

R represents the numeric values are used to represent the relationship letters (A, E, I, O, U).

Any value can be used, however BLOCPLAN generally uses;

(A: 10, E:5, I:2, O:1 and U:0, negative value is given for X:-10.). In Equation 3.2, the negative values are not calculated at the denominator of the formula.

The rel-dist score is also normalized. Two terms are used for this; lower bound and upper bound.

Lower bound is calculated by forming two vectors; distance and the numeric values of the flows between facility pairs. The distance vector is arranged in nondecreasing order and, the flow vector is arranged in nonincreasing order. By doing this we can find the lower bound and if we turn the order of the vectors vice versa, we can find the upper bound. The R-score can be calculated as;

$$\text{R-score} = 1 - (\text{rel-dist score} - \text{lower bound}) / (\text{upper bound} - \text{lower bound})$$

If the result is near 1, it means that the rel-dist score equals to lower bound. The smaller values for the R-score yield better layouts at this point.

Example 3.3

The same example, Example 3.1 is used for testing the BLOCPLAN. BLOCPLAN first requires the number of facilities and the area requirements for these facilities. Then the relationship chart is required. The relationship chart is filled according to the letter representation of values, which is explained at this section.

The numerical values for the letters are assigned. We choose the standart values (A: 10, E:5, I:2, O:1 and U:0, negative value is given for X:-10.).

The next step is to choose the length-to-width ratio for the departments. This ratio can be given by the user or, the user can choose from one of the already given values. We have choosen the 1-by-1 ratio.

The departments with fixed location can be located manually to the appropriate places on the layout. Then the algorithm can be executed. First of all, the layout algorithm is executed to form the initial layout. After this layout is saved, the improvement layout can be executed. Another way is to choose the Automatic Search from the menu.

The results of the final layout;

Lower bound= 496,22

Upper bound= 990,22

R-Score= 0,78

Rel-Dist Score= 604,58

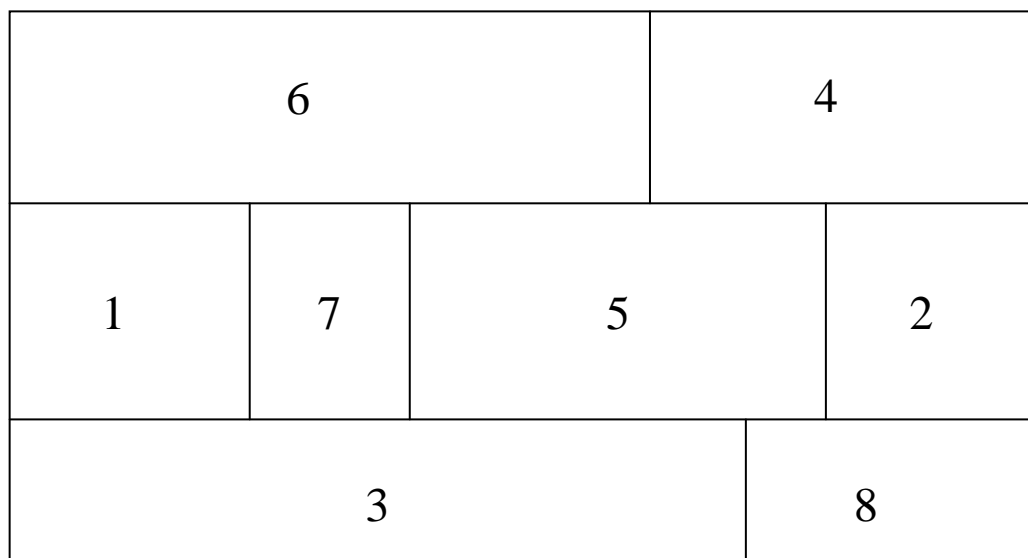


Figure 3.4 BLOCPLAN Layout

Table 3.5 Centroids and dimensions of the facilities

Dept. No	Dept.	X	Y	Length	Width	L/W
1	A	2.1	6.7	4.3	5.9	0.7
2	B	13.6	6.7	1.7	5.9	0.3
3	C	5.9	1.9	11.9	3.8	3.1
4	D	12.4	12.1	4.1	4.8	0.9
5	E	9.8	6.7	6.0	5.9	1.0
6	F	5.2	12.1	10.4	4.8	2.1
7	G	5.5	6.7	2.6	5.9	0.4
8	H	13.2	1.9	2.6	3.8	0.7

The objective function according to the distance based value =9922,3

CHAPTER 4

SFLA ALGORITHM

4.1 INTRODUCTION TO 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.

4.2 THE CONCEPT OF THE ALGORITHM

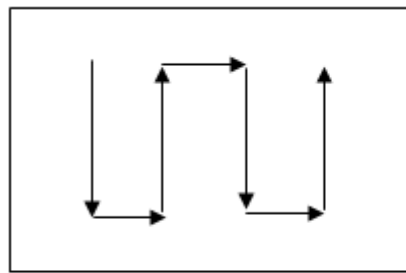
The concept of the algorithm is quite similar to MCRAFT. The dimension of the plant area and the area of the facilities are required. The algorithm uses quantitative data. The flow and the cost of moving a part between departments are given by the user.

The difference is become visible at the second stage. MCRAFT requires a bandwidth to form its route in the plant area. However, the SFLA algorithms form a spiral route in the facility area and to achieve this, band length is also required. By using the bandwidth and band length, blocks are formed. Blocks can be considered as the units of the plant area. The facilities are assigned to the blocks.

The block system is useful in order to protect the department shapes. Sometimes, unrealistic shapes which cannot be adapt to a real life problems may occur, however, these shapes can be fitted by making little changes. Initial layout is formed and pairwise exchange algorithm is applied. The details of these issues are explained in further sections.

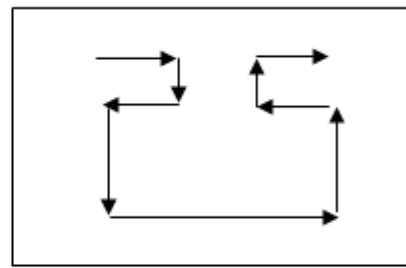
4.2.1 Spiral Initial Layout Curve

Discrete representation systems generally follow a route 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. as shown in Figure 4.1 and 4.2.



Sweeping Pattern

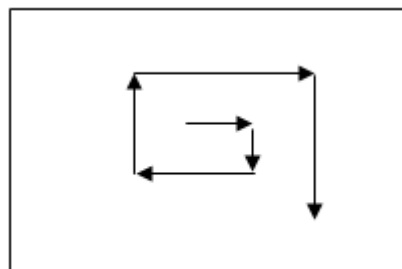
Figure 4.1 Sweeping Pattern



Space Filling Pattern

Figure 4.2 Space filling pattern

A spiral curve is used by the algorithm SFLA that 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 4.3 below.



Spiral Pattern

Figure 4.3 Spiral pattern

4.2.2 Calculating the block size

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.

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.

$$\text{Width} = \sqrt{\frac{\text{totalarea}}{(\sqrt{\#ofdepartments})^2}} * \frac{\text{facilitywidth}}{\text{facilitylength}} \quad (4.1)$$

$$\text{Length} = \sqrt{\frac{\text{totalarea}}{(\sqrt{\#ofdepartments})^2}} * \frac{\text{facilitylength}}{\text{facilitywidth}} \quad (4.2)$$

This formulation has applied because; the block width and the length directly affect the length and the width of the total area. In order to keep the total facility area in the required ratios, we used this ratio to find the appropriate sizes.

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 4.4 Spiral Layout for 11 departments, block width 2, block length 3.

4.2.3 Initial Sequence Generation

SFLA is a path dependent and steepest descent algorithm. As it is mentioned in previous sections, for the path dependent algorithms, the final cost is strongly related with the initial layout that the algorithm started with. For this reason, SFLA optionally uses two kinds of initial layout generation. Also the user can identify the initial layout. First one is; randomly generating. Second one is called enhanced initial layout algorithm. For the enhanced initial layout algorithm, the initial layout is selected not randomly, but by using the departmental flow data. Relationship chart is constructed according to the flow between departments. The department which has the most “A” relationships is selected and put into the center of the layout. Consequently, the next department which has the strongest relationship with the previous selected department is selected and located at the tail of the previous one. A spiral route is followed while locating the selected departments. According to the dimensional situations; L, U or square shape is selected for the shape of the departments. For a clear identification of the shapes of the departments, layout is divided into blocks. The number of blocks is calculated according to the layout dimensions and the dimensions of the blocks.

According to our observations, enhanced initial algorithm start with a better layout cost and performs less number of iterations. However, after the iterative improvement, randomly generated initial layout yields better results.

4.2.4 Pairwise Exchange Algorithm

The algorithm uses the pairwise exchange method. As it is mentioned in the literature review chapter, pairwise exchange considers only two facilities for exchange at a time. For further information about the pairwise exchange algorithm, literature review chapter can be checked.

4.3 HOW THE SOFTWARE WORKS?

A software version of the model is generated by using the Excel VBA codes. Initially the area requirements and the dimensions of the plant area are given as input. The flow index and the cost index are filled at this step.

At the second step, the band width and the band length is required in order to form the spiral route for the facility. The band width and the band length are directly related with the plant area because; the spiral route is formed by using blocks. The dimensions of the blocks are found by multiplying the band width by band length. Defining the block width and length puts a limitation for the undesired department shapes. After the block width and length is given, the algorithm can define the space filling curve for the layout. As the next step, the spiral curve and the plant area is formed.

55	56	57	64	65	72	73	74
54	53	58	63	66	71	76	75
51	52	59	62	67	70	77	78
50	49	60	61	68	69	80	79
47	48	1	8	9	10	81	82
46	45	2	7	12	11	84	83
43	44	3	6	13	14	85	86
42	41	4	5	16	15	88	87
39	40	29	28	17	18	89	90
38	37	30	27	20	19	92	91
35	36	31	26	21	22	93	94
34	33	32	25	24	23	96	95
125	124	117	116	109	108	97	98
126	123	118	115	110	107	100	99
127	122	119	114	111	106	101	102
128	121	120	113	112	105	104	103

E	E	E	F	F	F	F	F
E	E	E	F	F	F	F	F
E	E	E	F	F	F	G	G
E	E	F	F	F	F	G	G
E	E	A	A	A	A	G	G
E	D	A	A	A	A	G	G
C	D	A	A	A	B	G	G
C	C	A	A	B	B	G	G
C	C	C	C	B	B	G	G
C	C	C	C	B	B	H	G
C	C	C	B	B	B	H	H
C	C	C	B	B	B	H	H
H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H

Figure 4.5 Number Representation **Figure 4.6** Letter Representation

The spiral curve is formed by using numbers initially. Figure 4.5(a) shows a spiral curve with band width 2, band length 4. Then the departments are located in the place of numbers as next step. The departments can be seen in Figure 4.5(b).

The initial layout can be formed sequentially, randomly or by forming an enhanced initial. Sequential layout use the sequence, beginning from 1 to given number

of departments. Random layout forms a random sequence and the enhanced initial uses an improved sequence as it is mentioned in part 4.2.3.

According to the desired initial layout, the departments are assigned to the plant area. The centroids of the departments and the cost of the initial layout are calculated. The layout design process continues with the pairwise exchange optimization. The algorithm terminates with the layout that gives the most reduction at the initial layout cost.

Example 4.1

The same problem data in Chapter 3 is used, in order to make a comparison. As it is done in MCRAFT, band width is asked in SFLA. However, different from MCRAFT, the band length is needed in order to form the spiral curve. The program gives suggested bandwidth and band length values. These values can be used or they can be given by the user. We use the same bandwidth which is used for CRAFT and MCRAFT at the previous problems. The initial layout is formed and the centroids of the facilities are calculated. The initial layout is given below in Figure 4.6.

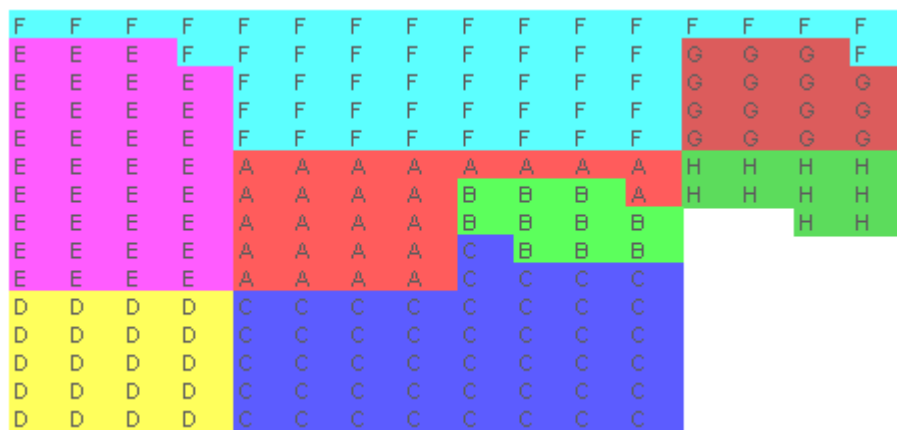


Figure 4.7 The initial layout for Example 4.1

Table 4.1 The centroids of the departments

Department	A	B	C	D	E	F	G	H
X -Center	7,4	11	8,7	2,5	2,5	8,6	14	15
Y -Center	7,6	8	13	13	6,1	2,6	3,6	6,8

The initial layout cost is 10957,46. Pairwise algorithm is applied, at the third iteration, the objective function value is 8720,2. Then the algorithm terminates.

The final layout is given below in Figure 4.7.

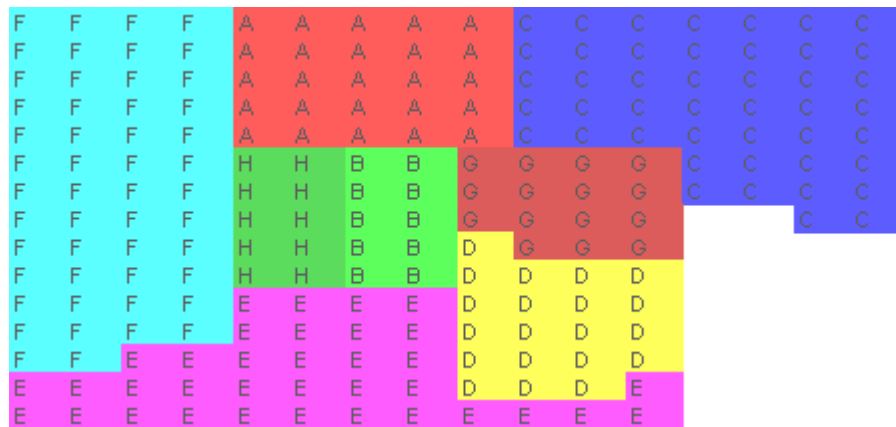


Figure 4.8 The final layout of Example 4.1

To make a comparison between the objective function values found by the algorithms that we have used, Table 4.2 can be checked.

Table 4.2 Comparison of the results

	Objective Function Value
CRAFT	9118
MCRAFT	8705
BLOCPLAN	9922,3
SFLA	8720,2

CHAPTER 5

EXPERIMENTAL RESULTS

5.1 INTRODUCTION

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 at this section. 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- β are closely connected. The β error decreases as the sample size increases. That is, a specified difference in means is easier to detect in large sample sizes.
- 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 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.

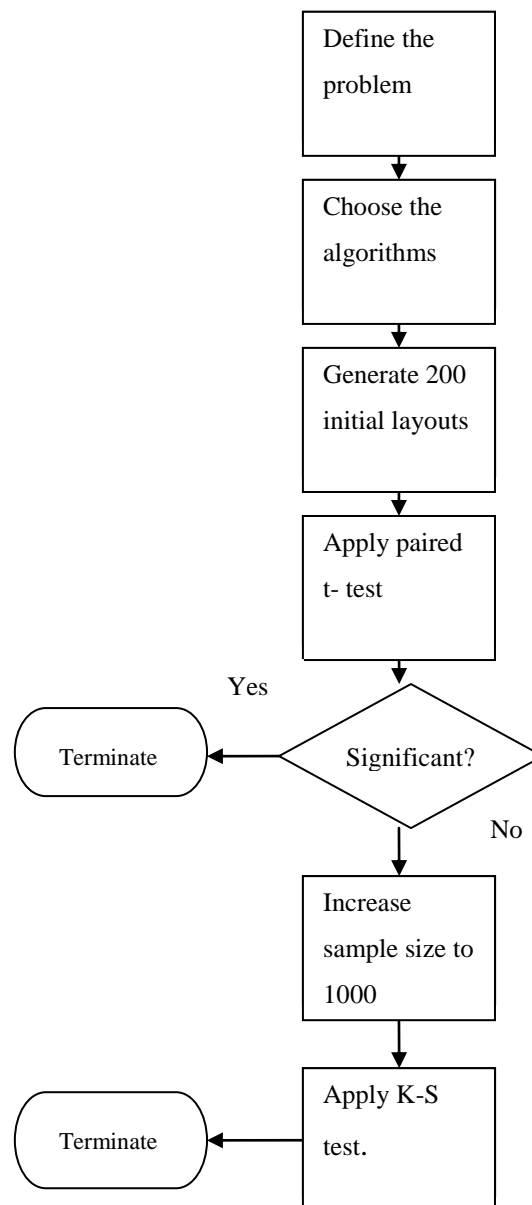


Figure 5.1 Flow diagram of experimentation procedure.

According to the observations, several factors have defined that affect the results of the layout algorithms. These factors are;

1. Bandwidth

The bandwidth directly affects the centroids of the facilities. An optimal bandwidth provides optimum distance between the centroids. Different bandwidths are used while the test problems are solved.

2. Initial layout

The algorithms that we are working on are steepest descent algorithms. It means that, the algorithm is beginning with the initial layout and process continues based on this layout. The better layout yields more efficient results.

3. Number of departments

Some of the algorithms work more efficient with lower number of facilities. For example BLOCPLAN can be used for maximum 18 facilities. We have observed that, the efficiency of SFLA also changes at problems with different number of facilities.

4. Shape of the departments

According to the researches the shape of the facility directly affects the results of the algorithms. Several methodologies are used to protect the shape of the facilities. For the algorithm MULTIPLE, it is assumed that the ideal shape for a facility is rectangular. The perimeter for facility i is P_i . The minimum perimeter for facility i , P_i^* , is equal to $4\sqrt{A_i}$. A normalized shape measure for facility i , say Ω_i is;

$$\Omega_i = \frac{P_i \div A_i}{P_i^* \div A_i} = \frac{P_i}{P_i^*} = \frac{P_i}{4\sqrt{A_i}} = \frac{1}{4} P_i A_i^{-0.5} \quad (5.1)$$

As Ω_i value increases, the facility shapes become more irregular. (Bozer *et al.*,1994).

To protect the shape of the facilities, SFLA algorithm's block system works efficiently. When a block is filled, a facility starts to fill the next block. Sometimes undesired department shapes like L, may occur, however it is assumed that these shapes can be adapted in real life problems.

5.2 RESULTS

There are seven different problems selected. Three of them are taken from the literature. One of the data set is taken from the article of Armour and Buffa(1964), one of them is taken from the R.D. Meller's doctoral thesis (1992) and, one of them is taken from a study of Bozer *et al.* (1996). Four of the problems are generated randomly. They are named as Problem 1, Problem 2, Problem 3 and Problem 4 respectively.

As it is mentioned, for each of the problems 200 different initial layouts are generated. For three of the problems different dimensions and bandwidths are applied in order to measure the effects.

Paired-t test is applied with 95% level of confidence. The hypothesis is as follows;

H_0 = Two algorithms are not significantly different

H_1 = One algorithm performs significantly better.

All the data sets and detailed results of one of the problems, Problem 3, are given in the next sections. Unit cost of transporting material from one department to another, c_{ij} , is taken 1 unit for all.

5.2.1 Problem 1

This data set is only applied with its original dimensions and the results are given below. Sometimes, the SFLA may not exactly match the given dimensions for specific block widths and lengths. For instance, a plant area of 25 by 36 is required. For a given block width and block length, the shape of the plant may be formed as 24 by 38. For this kind of problem, we give a tolerance limit of 0,15 to the width and length of the plant area. This deviation can be tolerable and can be adapted in real life problems.

The problem data, flow and area informations are given in Table 5.1, Table 5.2 and Table 5.3 respectively.

Table 5.1 Data set for Problem 1

Number of Departments	11
Plant Width	8
Plant Length	9
Total Area	72

Table 5.2 Area of the facilities for Problem 1

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

Table 5.3 Flow between departments for Problem 1

	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

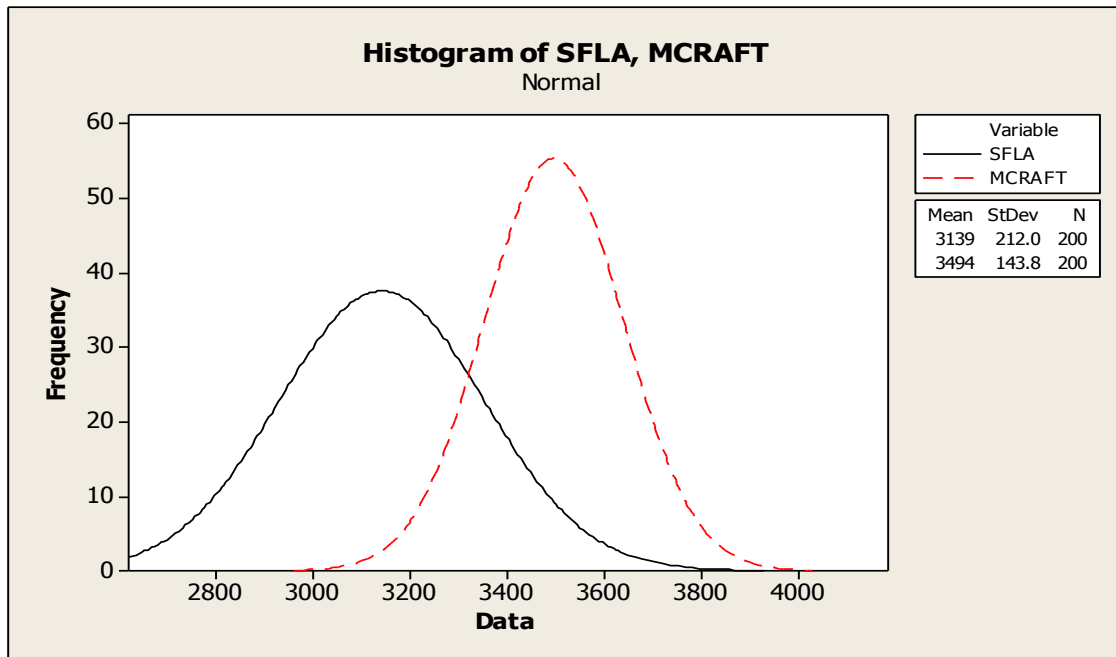


Figure 5.2 Histogram of Problem 1

	N	Mean	StDev	SE Mean
SFLA	200	3139.00	211.97	14.99
MCRAFT	200	3493.89	143.78	10.17
Difference	200	-354.887	255.883	18.094

95% CI for mean difference: (-390.567, -319.207)

T-Test of mean difference = 0 (vs not = 0): T-Value = -19.61 P-Value = 0.000

Figure 5.3 Minitab results of Problem 1

According to the results in Figure 5.2 and Figure 5.3, SFLA yields a better result on average. If the lowest values are checked, SFLA yields 2912.4 and MCRAFT yields 3214.9. The dominance of the SFLA in terms of yielding lowest results can be seen at this problem.

5.2.2 Problem 2

For problem 2, four different plant width and plant length are used while the total area kept constant; 20 X 20 , 10 X 40, 25 X 16 and, 8 X 50. Three different bandwidths are applied for each of these different dimensions; 4, 5 and 10 respectively. The problem data, flow and area informations are given in Table 5.4, Table 5.4 and Table 5.6 respectively.

Table 5.4 Data set for Problem 2

Number of Departments	15
Plant Width	20
Plant Length	20
Total Area	400

Table 5.5 Area of the departments for Problem 2

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 5.6 Flow between departments for Problem 2

	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 results are given in Table 5.7. SFLA Result and MCRAFT Result columns show the average value of the 200 samples. The bold results show the lowest results. For the best results columns, the lowest values in 200 samples are given. In these columns, the bold results show the lowest value of SFLA and MCRAFT for the problem. The lowest result is 10753.3 and yielded by the MCRAFT.

Table 5.7 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
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

5.2.3 Problem 3

Problem 3 has been tested for equal area and different dimensions. Five different dimensions are used; 30X30, 18X50, 20X45, 15X60 and 25X36. Three different bandwidths are applied to all problems. Bandwidth 5, 6 and 10 respectively.

The tolerance limit of 0.15 is used for the plant layout, while it is necessary for this problem. The problem data, flow and area informations are given in Table 5.8, Table 5.9 and Table 5.10 respectively.

Table 5.8 Problem data for Problem 3

Number of Departments	10
Plant Width	30
Plant Length	30
Total Area	900

Table 5.9 Area of the departments for Problem 3

Dept 1	127	Dept 6	106
Dept 2	4	Dept 7	78
Dept 3	91	Dept 8	134
Dept 4	46	Dept 9	170
Dept 5	6	Dept 10	138

Table 5.10 Flow between departments for Problem 3

	D 1	D 2	D 3	D 4	D 5	D6	D7	D 8	D 9	D 10
D 1	0	4	0	3	8	17	6	0	0	17
D 2	4	0	16	0	16	19	14	7	12	2
D 3	0	16	0	0	0	6	0	13	0	0
D 4	3	0	0	0	0	12	9	12	0	18
D 5	8	16	0	0	0	4	3	0	17	7
D 6	17	19	6	12	4	0	0	2	8	10
D 7	6	14	0	9	3	0	0	0	6	14
D 8	0	7	13	12	0	2	0	0	11	9
D 9	0	12	0	0	17	8	6	11	0	18
D 10	17	2	0	18	7	10	14	9	18	0

Problem 3 (25by36) Bandwidth 5

The results are given in Figure 5.4 and Figure 5.5. The results of SFLA are lower than MCRAFT and the deviation of the SFLA is more than MCRAFT. This can be seen from the bell shape. The more deviation means the larger bell shape.

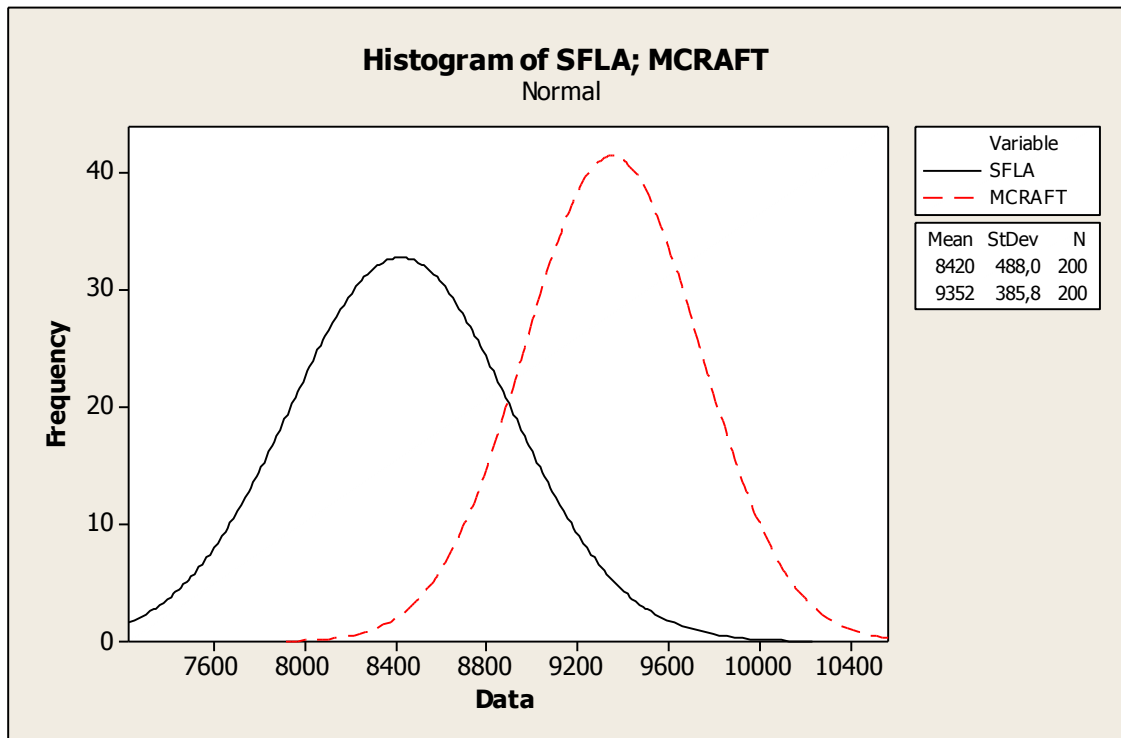


Figure 5.4 Histogram of Problem 3 (25X36) bandwidth 5

	N	Mean	StDev	SE Mean
SFLA	200	8419,88	487,97	34,50
MCRAFT	200	9351,90	385,79	27,28
Difference	200	-932,013	611,691	43,253

95% CI for mean difference: (-1017,306; -846,719)

T-Test of mean difference = 0 (vs not = 0): T-Value = -21,55 P-Value = 0,000

Figure 5.5 Minitab results of Problem 3 (25X36) bandwidth 5

Problem 3 (25by36) Bandwidth 6

The results are given in Figure 5.6 and Figure 5.7. According to the histogram, SFLA has distinctively larger standard deviation than MCRAFT. However, the results of MCRAFT clustered at a higher value, the mean of the MCRAFT is higher than SFLA.

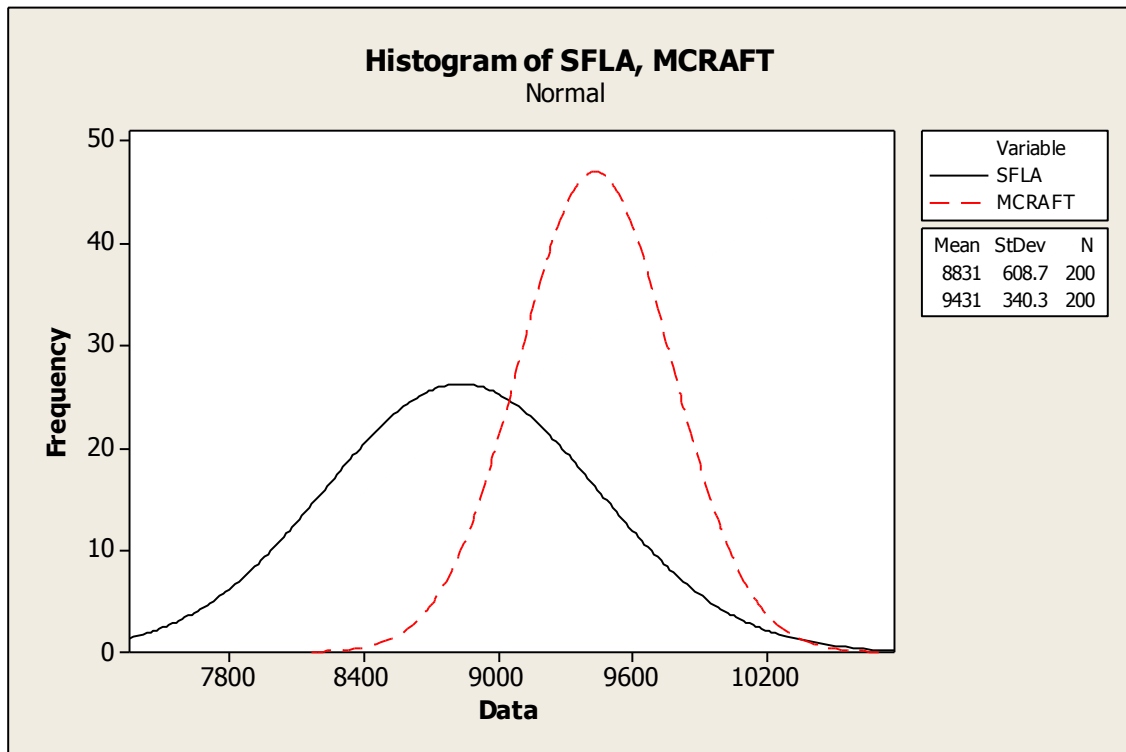


Figure 5.6 Histogram of Problem 3 (25X36) bandwidth 6

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	8831.39	608.66	43.04
MCRAFT	200	9430.99	340.29	24.06
Difference	200	-599.606	677.831	47.930

95% CI for mean difference: (-694.122, -505.091)

T-Test of mean difference = 0 (vs not = 0): T-Value = -12.51 P-Value = 0.000

Figure 5.7 Minitab results of Problem 3 (25X36) bandwidth 6

Problem 3 (25by36) Bandwidth 10

The results are given in Figure 5.8 and 5.9 respectively. It can be seen from the histogram that, the mean of the MCRAFT is lower than SFLA. For the standard deviation of the values, MCRAFT has a larger deviation than SFLA.

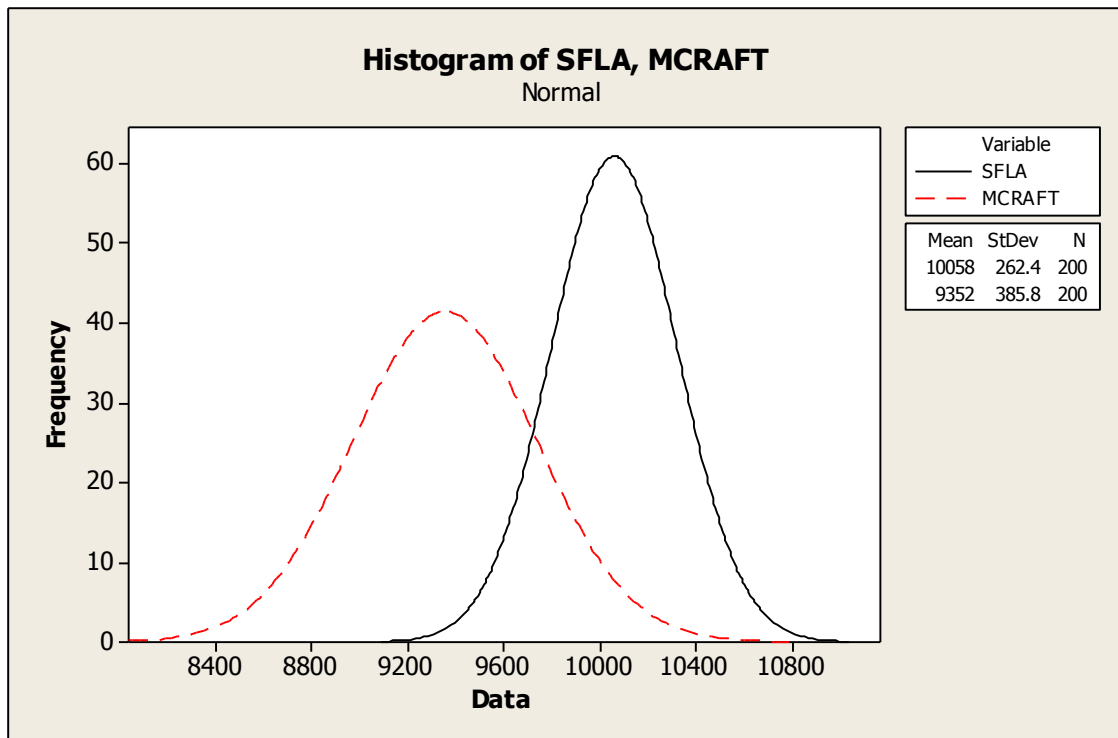


Figure 5.8 Histogram of Problem 3 (25X36) bandwidth 10

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10057.6	262.4	18.6
MCRAFT	200	9351.9	385.8	27.3
Difference	200	705.681	432.192	30.561

95% CI for mean difference: (645.417, 765.945)

T-Test of mean difference = 0 (vs not = 0): T-Value = 23.09 P-Value = 0.000

Figure 5.9 Minitab results of Problem 3 (25X36) bandwidth 10

Problem 3 (15by60) Bandwidth 5

The results are given in Figure 5.10 and 5.11 respectively. For this dimensions, SFLA has a higher mean also the standard deviation of SFLA is larger than MCRAFT. The results of the MCRAFT are clustered at lower costs.

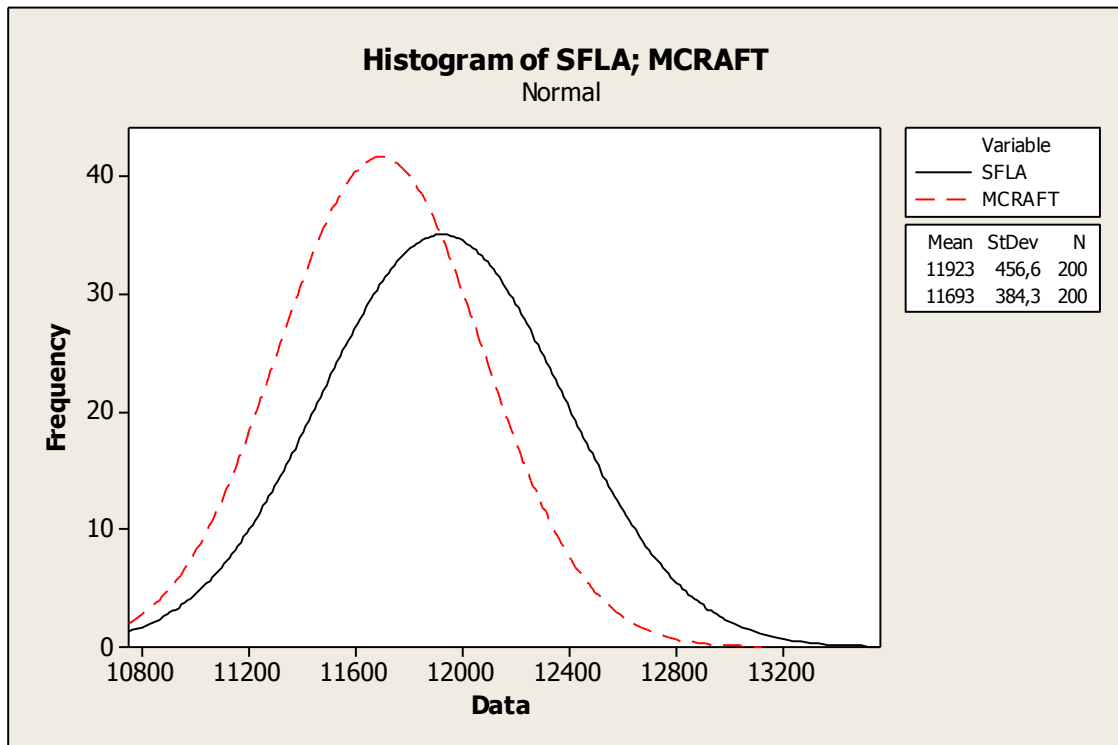


Figure 5.10 Histogram of Problem 3 (15X60) bandwidth 5

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	11922,8	456,6	32,3
MCRAFT	200	11693,3	384,3	27,2
Difference	200	229,558	609,760	43,117

95% CI for mean difference: (144,534; 314,582)

T-Test of mean difference = 0 (vs not = 0): T-Value = 5,32 P-Value = 0,000

Figure 5.11 Minitab results of Problem 3 (15X60) bandwidth 5

Problem 3 (15by60) Bandwidth 6

The results are given in Figure 5.12 and Figure 5.13 respectively. MCRAFT has a lower mean value. The standard deviation of MCRAFT is larger and spans a larger value interval.

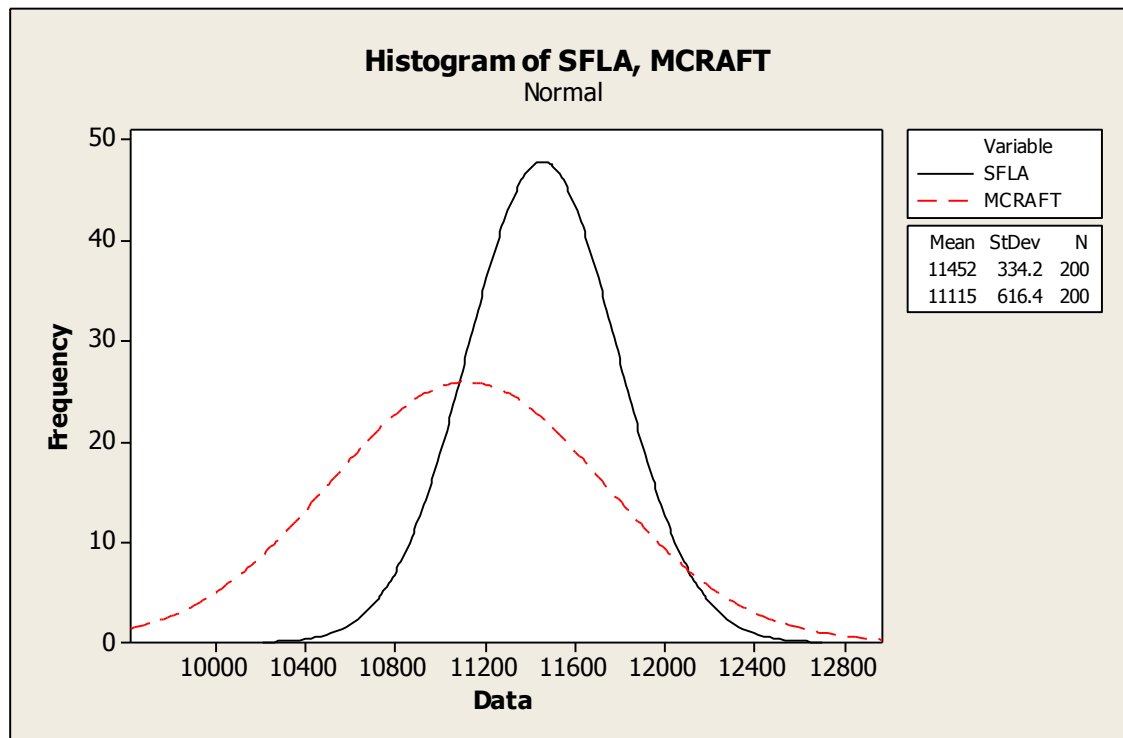


Figure 5.12 Histogram of Problem 3 (15X60) bandwidth 6

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	11452.3	334.2	23.6
MCRAFT	200	11115.0	616.4	43.6
Difference	200	337.388	717.125	50.708

95% CI for mean difference: (237.393, 437.383)

T-Test of mean difference = 0 (vs not = 0): T-Value = 6.65 P-Value = 0.000

Figure 5.13 Minitab results of Problem 3 (15X60) bandwidth 6

Problem 3 (15by60) Bandwidth 10

The mean value of SFLA is lower than MCRAFT. The values of MCRAFT are clustered at a higher value with a lower standard deviation. The deviation of SFLA is larger than MCRAFT and if the smallest values are checked, the smallest value of SFLA is around 8000 while the smallest value of MCRAFT is around 10500. The results can be seen in Figure 5.14 and Figure 5.15 below.

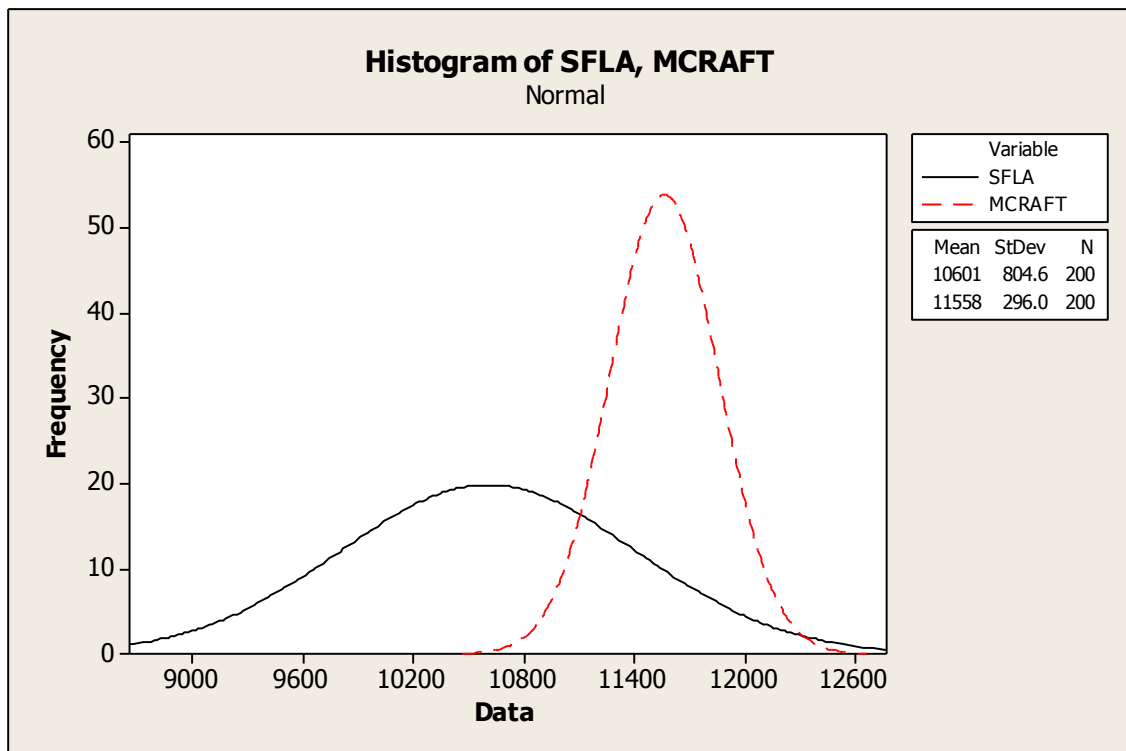


Figure 5.14 Histogram of Problem 3 (15X60) bandwidth 10

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10601.5	804.6	56.9
MCRAFT	200	11558.4	296.0	20.9
Difference	200	-956.914	872.615	61.703

95% CI for mean difference: (-1078.590, -835.238)

T-Test of mean difference = 0 (vs not = 0): T-Value = -15.51 P-Value = 0.000

Figure 5.15 Minitab results of Problem 3 (15X60) bandwidth 10

Problem 3 (20 by 45) bandwidth 5

The results are given in Figure 5.16 and Figure 5.17 below. The mean value of MCRAFT is lower than SFLA. The Standard deviations are close to each other, however MCRAFT has a smaller interval, SFLA yields higher results.

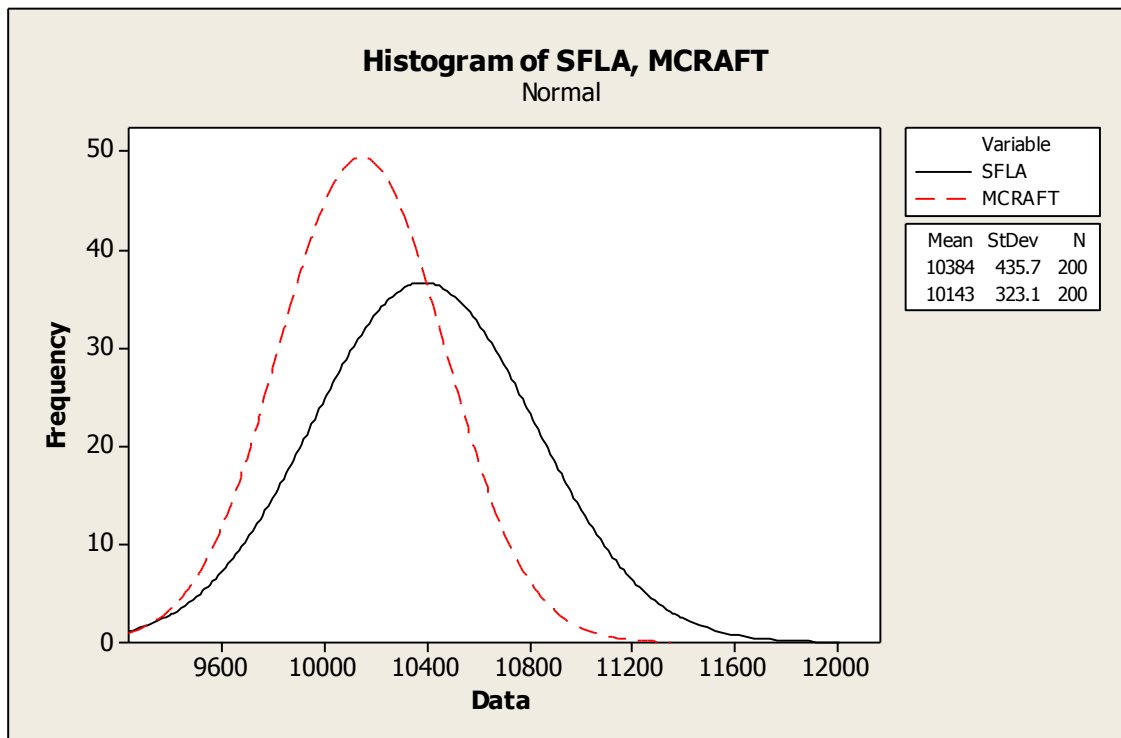


Figure 5.16 Histogram of Problem 3 (20X45) bandwidth 5

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10383.7	435.7	30.8
MCRAFT	200	10143.3	323.1	22.8
Difference	200	240.491	559.845	39.587

95% CI for mean difference: (162.427, 318.555)

T-Test of mean difference = 0 (vs not = 0): T-Value = 6.07 P-Value = 0.000

Figure 5.17 Minitab results of Problem 3 (20X45) bandwidth 5

Problem 3 (20 by 45) bandwidth 6

The results are given in Figure 5.16 and Figure 5.17 below. The mean value of SFLA is higher than MCRAFT. The standart deviations are very close however, MCRAFT yields the smallest values.

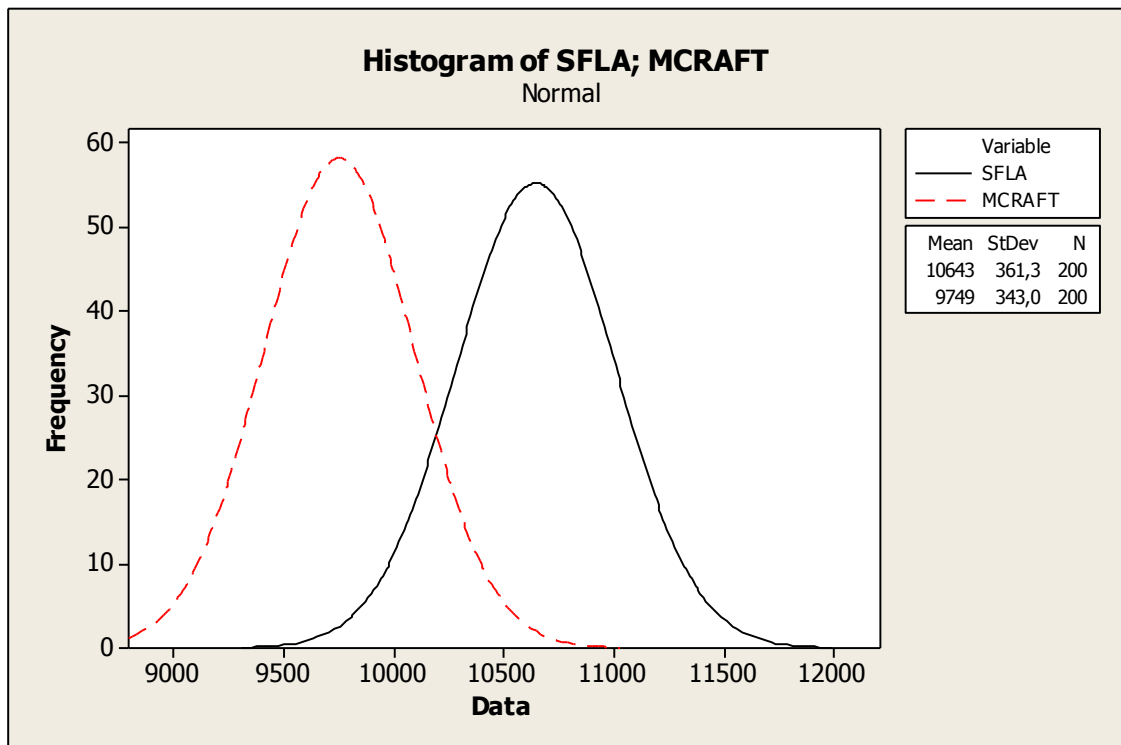


Figure 5.18 Histogram of Problem 3 (20X45) bandwidth 6

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10643,0	361,3	25,5
MCRAFT	200	9748,5	343,0	24,3
Difference	200	894,502	506,158	35,791

95% CI for mean difference: (823,924; 965,080)

T-Test of mean difference = 0 (vs not = 0): T-Value = 24,99 P-Value = 0,000

Figure 5.19 Minitab results of Problem 3 (20X45) bandwidth 6

Problem 3 (20 by 45) bandwidth 10

The results are given in Figure 5.20 and 5.21 below. The distributions are very close to each other. The mean value of MCRAFT is lower than SFLA. According to paired-t results, p value is significant.

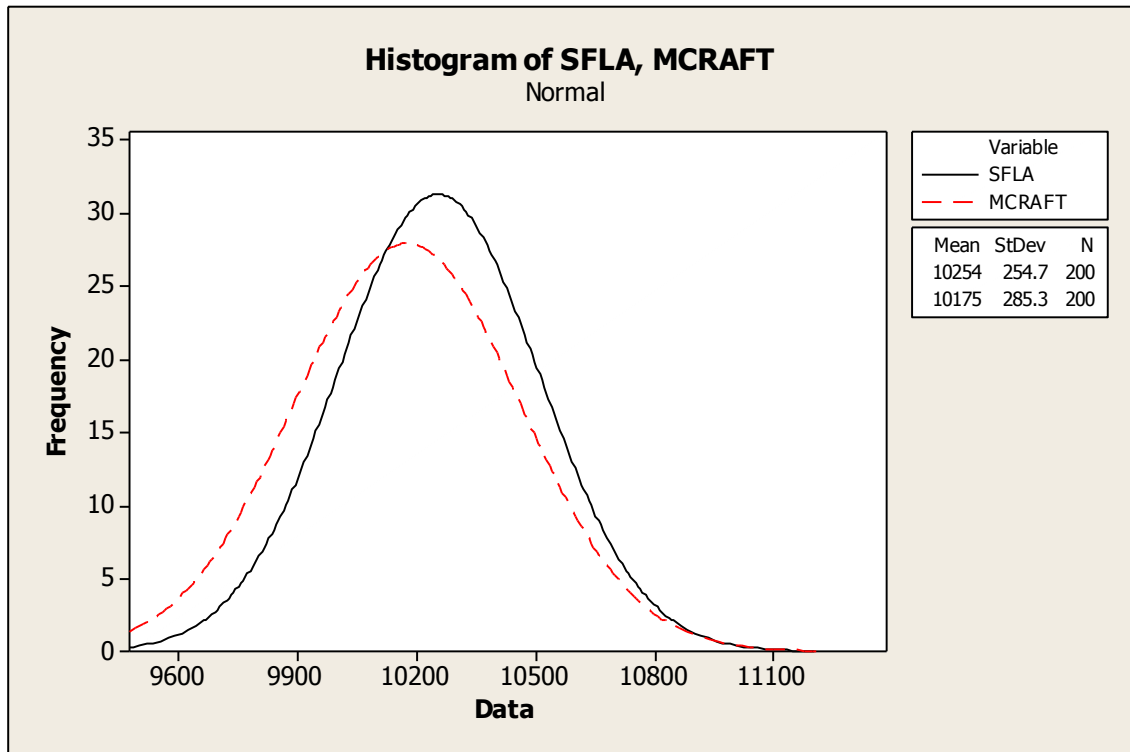


Figure 5.20 Histogram of Problem 3 (20X45) bandwidth 10

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10253.6	254.7	18.0
MCRAFT	200	10175.0	285.3	20.2
Difference	200	78.5099	400.3886	28.3117

95% CI for mean difference: (22.6804, 134.3394)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.77 P-Value = 0.006

Figure 5.21 Minitab results of Problem 3 (20X45) bandwidth 10

Problem 3 (18 by 50) bandwidth 5

The results are given in Figure 5.22 and 5.23 below. The distributions are very close to each other. There is only a little difference between the mean values and standard deviations.

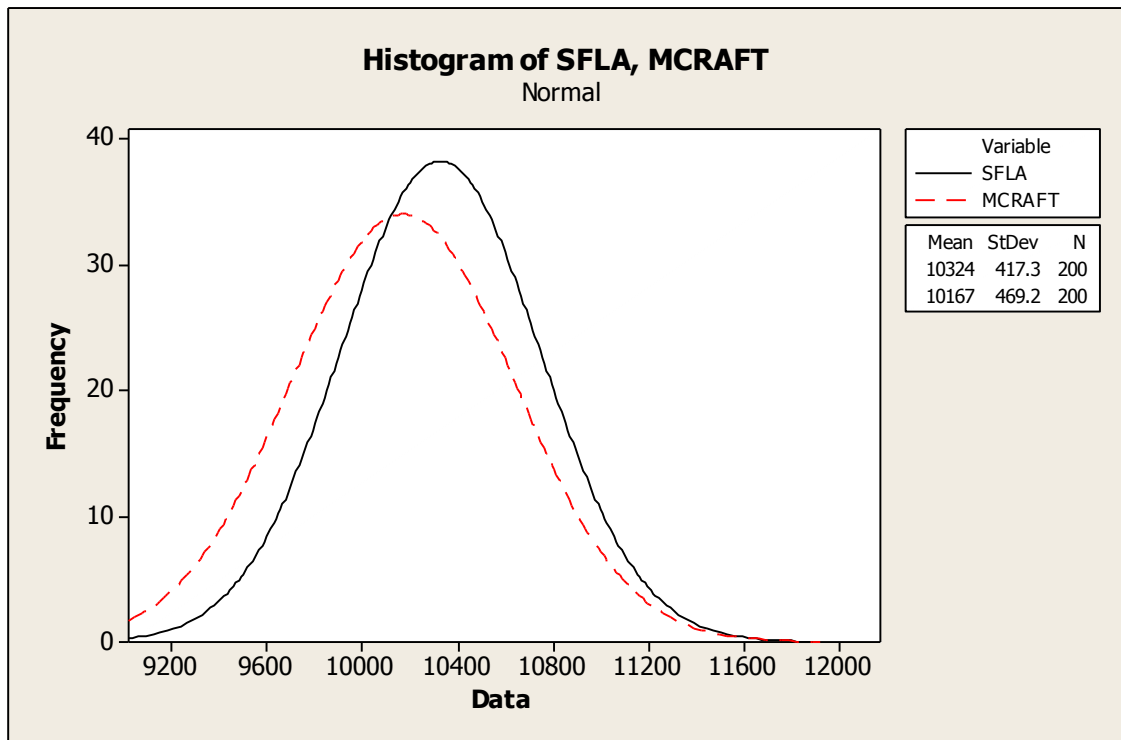


Figure 5.22 Histogram of Problem 3 (18X50) bandwidth 5

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10324.2	417.3	29.5
MCRAFT	200	10167.2	469.2	33.2
Difference	200	156.954	653.840	46.233

95% CI for mean difference: (65.784, 248.124)

T-Test of mean difference = 0 (vs not = 0): T-Value = 3.39 P-Value = 0.001

Figure 5.23 Minitab results of Problem 3 (18X50) bandwidth 5

Problem 3 (18 by 50) bandwidth 6

The results are given in Figure 5.22 and 5.23 below. The mean value of SFLA is lower than MCRAFT and the Standard deviation is also smaller. MCRAFT yields higher results than SFLA.

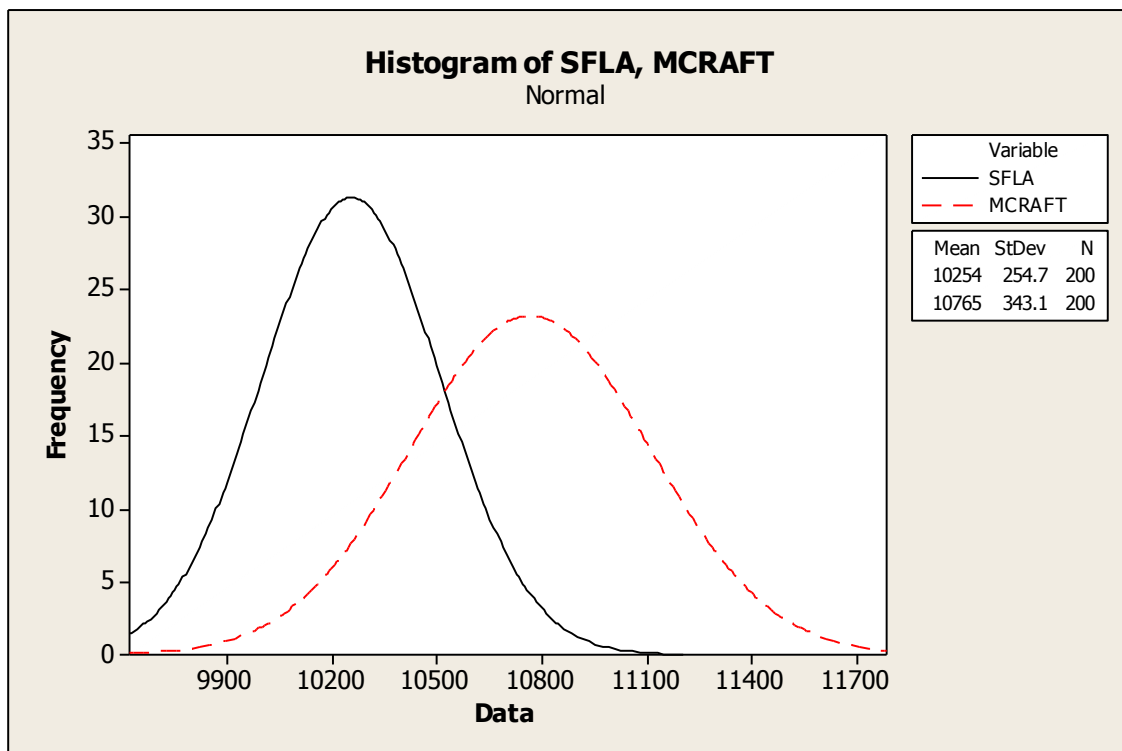


Figure 5.24 Histogram of Problem 3 (18X50) bandwidth 6

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10253.6	254.7	18.0
MCRAFT	200	10765.1	343.1	24.3
Difference	200	-511.540	412.800	29.189

95% CI for mean difference: (-569.101, -453.980)

T-Test of mean difference = 0 (vs not = 0): T-Value = -17.52 P-Value = 0.000

Figure 5.25 Minitab results of Problem 3 (18X50) bandwidth 6

Problem 3 (18 by 50) bandwidth 10

The distributions are almost the same. There is only a little difference between the Standard deviations and the lowest and highest values of the algorithms are almost the same. However the p value is very high, so the sample size is increased to 1000, and the test is repeated. The results are given in Figure 5.26 and Figure 5.27 respectively.

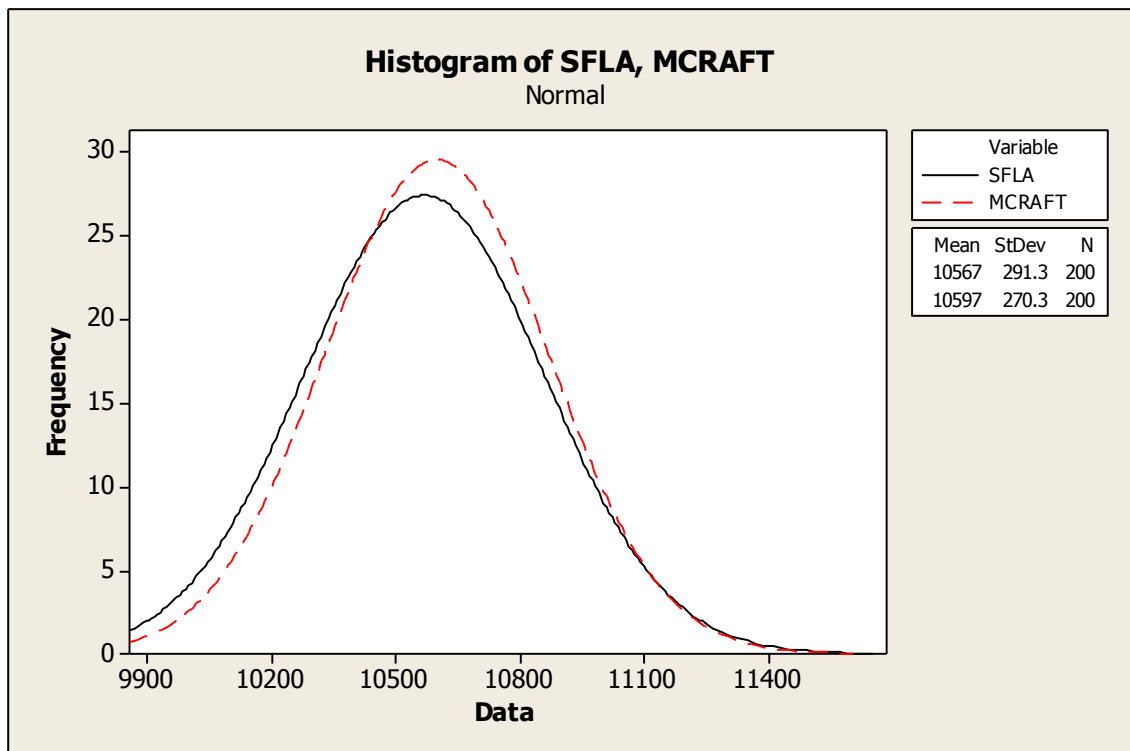


Figure 5.26 Histogram of Problem 3 (18X50) bandwidth 10 - 1

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	10567.3	291.3	20.6
MCRAFT	200	10597.2	270.3	19.1
Difference	200	-29.8570	384.2349	27.1695

95% CI for mean difference: (-83.4341, 23.7201)

T-Test of mean difference = 0 (vs not = 0): T-Value = -1.10 P-Value = 0.273

Figure 5.27 Minitab results of Problem 3 (18X50) bandwidth 10 - 1

P value is larger than desired so we increased the sample size to 1000. The histogram is very similar with the previous one. However, when the paired-t test is applied it can be seen that the p value is now significant. It can be seen that SFLA yields better results on average. Results are given in Figure 5.28 and Figure 5.29 respectively.

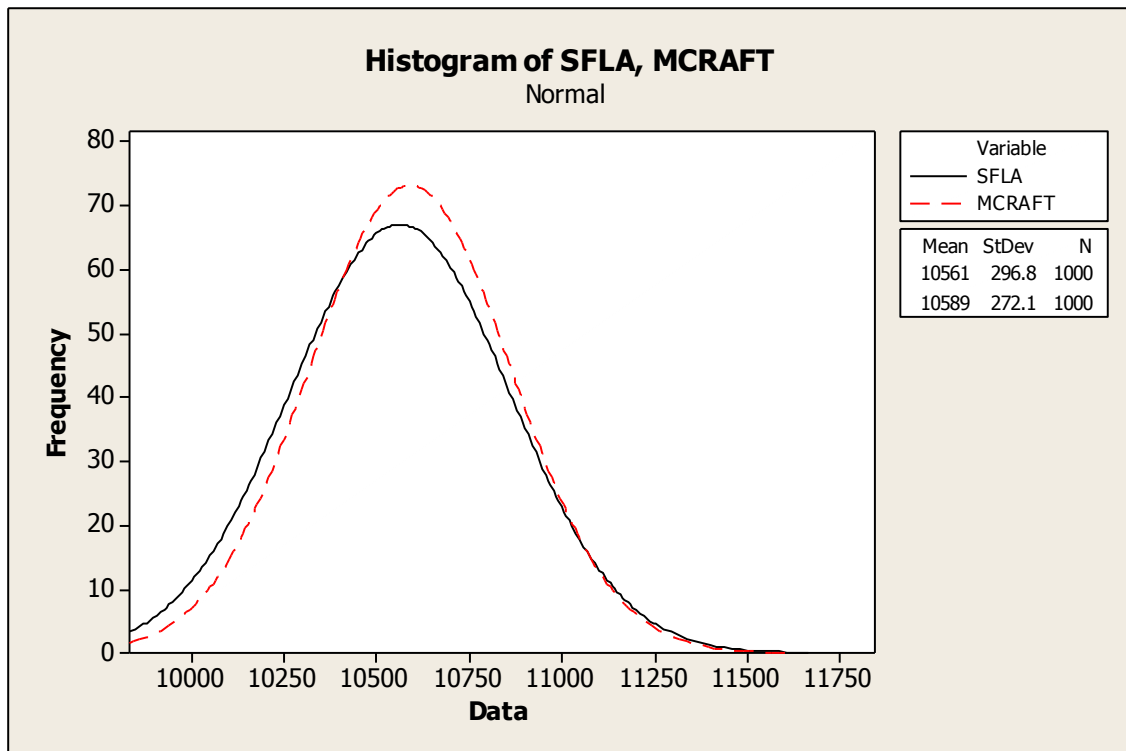


Figure 5.28 Histogram of Problem 3 (18X50) bandwidth 10 - 2

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	1000	10560.9	296.8	9.4
MCRAFT	1000	10589.0	272.1	8.6
Difference	1000	-28.0762	397.2701	12.5628

95% CI for mean difference: (-52.7287, -3.4238)

T-Test of mean difference = 0 (vs not = 0): T-Value = -2.23 P-Value = 0.026

Figure 5.29 Minitab results of Problem 3 (18X50) bandwidth 10 - 2

Problem 3 (30 by 30) bandwidth 5

The results are given in Figure 5.30 and 5.31 respectively. The mean value of SFLA is lower than MCRAFT and the Standard deviation of SFLA is higher than MCRAFT.

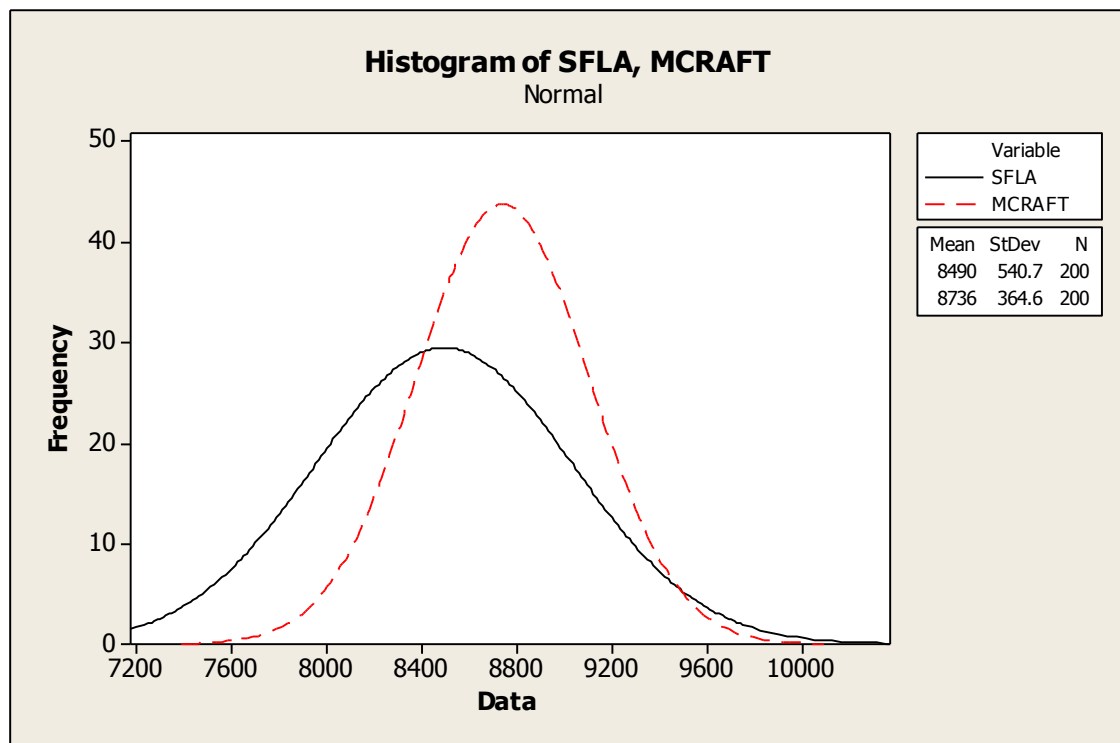


Figure 5.30 Histogram of Problem 3 (30X30) bandwidth 5

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	8489.98	540.68	38.23
MCRAFT	200	8735.74	364.57	25.78
Difference	200	-245.756	631.721	44.669

95% CI for mean difference: (-333.842, -157.670)
 T-Test of mean difference = 0 (vs not = 0): T-Value = -5.50 P-Value = 0.000

Figure 5.31 Minitab results of Problem 3 (30X30) bandwidth 5

Problem 3 (30 x 30) Bandwidth 6

The results are given in Figure 5.30 and Figure 5.31 respectively. The mean value of SFLA is lower than MCRAFT and the Standard deviation of the SFLA is higher.

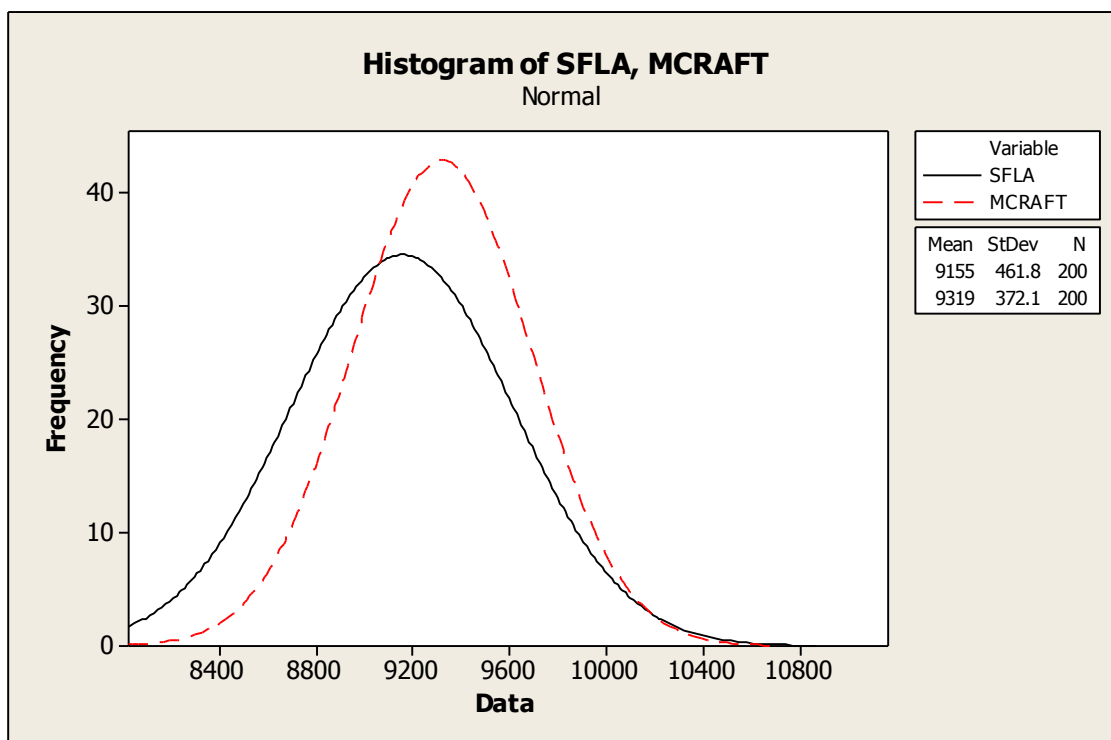


Figure 5.32 Histogram of Problem 3 (30X30) bandwidth 6

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	9154.89	461.84	32.66
MCRAFT	200	9319.14	372.07	26.31
Difference	200	-164.258	598.898	42.348

95% CI for mean difference: (-247.767, -80.748)
 T-Test of mean difference = 0 (vs not = 0): T-Value = -3.88 P-Value = 0.000

Figure 5.33 Minitab results of Problem 3 (30X30) bandwidth 6

Problem 3 (30 x 30) Bandwidth 10

The results are given in Figure 5.32 and 5.33 below. For bandwidth 10, the mean value of SFLA is higher than MCRAFT. The Standard deviations are almost the same. The distributions are very similar to each other.

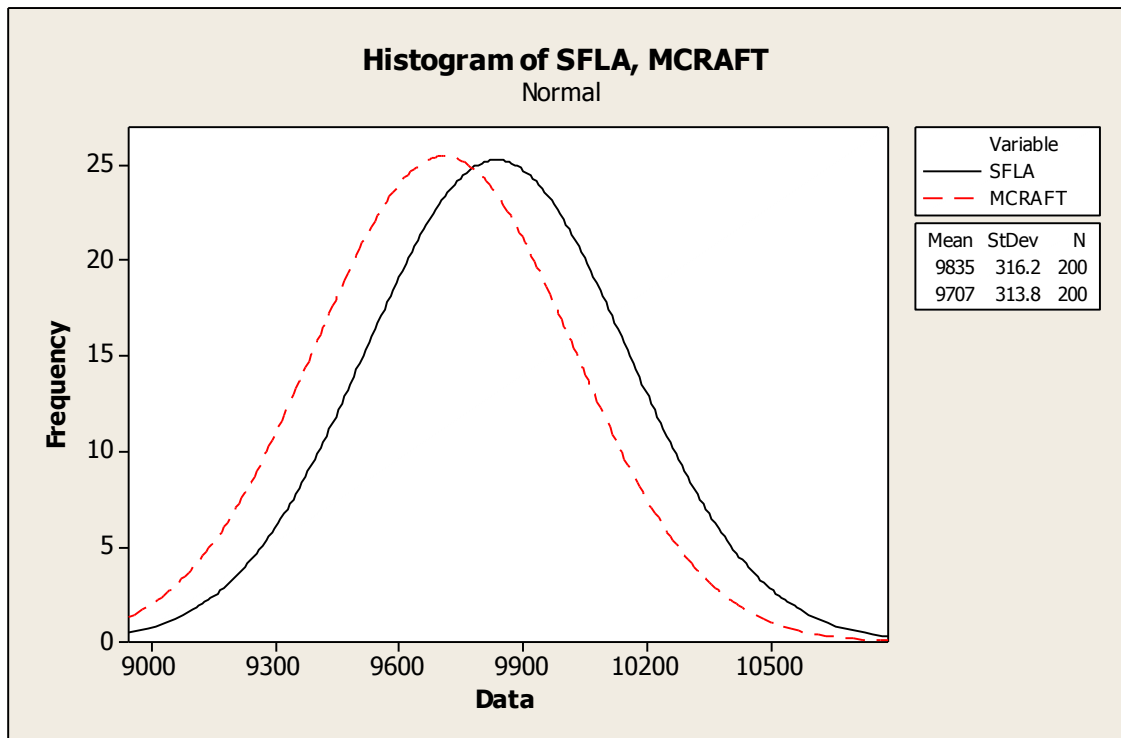


Figure 5.34 Histogram of Problem 3 (30X30) bandwidth 10

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	9834,68	316,24	22,36
MCRAFT	200	9707,50	313,79	22,19
Difference	200	127,178	476,826	33,717

95% CI for mean difference: (60,690; 193,665)

T-Test of mean difference = 0 (vs not = 0): T-Value = 3,77 P-Value = 0,000

Figure 5.35 Minitab results of Problem 3 (30X30) bandwidth 10

The results for Problem 3 are given in Table 5.11 below. SFLA Result and MCRAFT Result columns show the average value of the 200 samples. The bold results show the lowest results. For the best results columns, the lowest values in 200 samples are given. In these columns, the bold results show the lowest value of SFLA and MCRAFT for the problem. The lowest result is 7825 and yielded by the SFLA.

Table 5.11 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
900	25	36	1.44	5	4	8420	9351.9	7825.098	8287.3
900	25	36	1.44	6	4	8831,4	9431,2	8044.8	8697.2
900	25	36	1.44	10	8	10057,6	9351,9	9474.6	8650.6
900	15	60	4	5	20	11922,8	11693,3	11114.1	11037
900	15	60	4	6	20	11452,3	11115	10974.6	10317
900	15	60	4	10	3	10601,5	11558,4	9288.3	10966
900	20	45	2.25	5	12	10383,7	10143,3	9654.7	9452.5
900	20	45	2.25	6	15	10643	9748,5	9970.8	8895.4
900	20	45	2.25	10	23	10253,6	10175	9867	9653
900	18	50	2.78	5	13	10324,2	10167,2	9654.7	9311.8
900	18	50	2.78	6	17	10253.6	10765.1	9867	10097
900	18	50	2.78	10	25	10567.3	10597.2	10092	10139
900	30	30	1	5	5	8490	8735,7	7883.3	8027.6
900	30	30	1	6	6	9154,89	9319,14	8503.4	8478.3
900	30	30	1	10	10	9834,68	9707,5	9269.2	9218.1

5.2.4 Problem 4

This data is only applied with its original dimensions and the results are given below. The problem data, area of the departments and flow data are given in Table 5.12, 5.13 and 5.14 respectively.

Table 5.12 Problem data for Problem 4

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

Table 5.13 Area of the departments for Problem 4

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 5.14 Flow between departments for Problem 4

	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

Table 5.14 Flow between departments(cont.)

The results of the Problem 4 are given Figure 5.34 and 5.35 respectively.

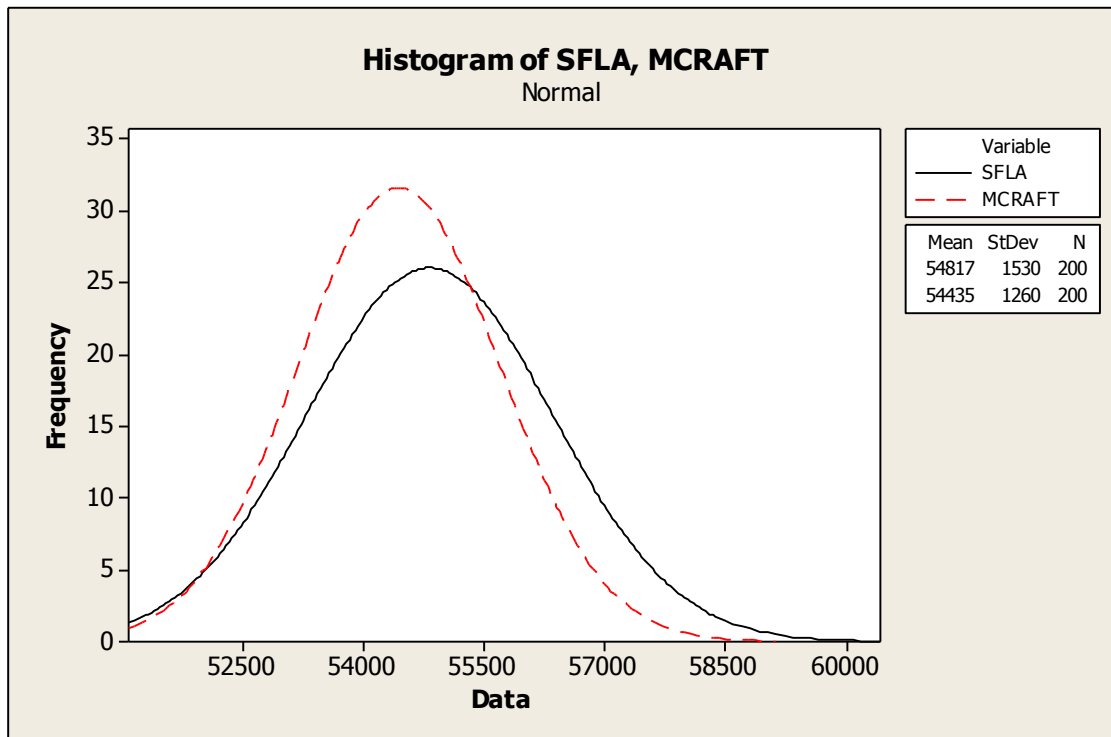


Figure 5.36 Histogram of Problem 4

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	54816.6	1530.1	108.2
MCRAFT	200	54435.0	1259.9	89.1
Difference	200	381.617	2108.370	149.084

95% CI for mean difference: (87.630, 675.605)
T-Test of mean difference = 0 (vs not = 0): T-Value = 2.56 P-Value = 0.011

Figure 5.37 Minitab results of Problem 4

5.2.5 Armour and Buffa Problem

For the Armour and Buffa data set, five different dimensions are used; 20 X 30, 10 X 60, 15 X 40, 12 X 50, 15 X 40 and 24 X 25, and three different bandwidths are applied for each of these different dimension; 4, 5 and 10. The problem data, area of the departments and the flow data are given in Table 5.15, Table 5.16 and Table 5.17 respectively.

The tolerance limit of 0.15 is applied where it is necessary for the plant layout.

Table 5.15 Problem data for A&B problem

Number of Departments	20
Plant Width	30
Plant Length	20
Total Area	600

Table 5.16 Area of the departments for A&B problem

Dept 1	27	Dept 11	60
Dept 2	18	Dept 12	42
Dept 3	27	Dept 13	18
Dept 4	18	Dept 14	24
Dept 5	18	Dept 15	27
Dept 6	18	Dept 16	75
Dept 7	9	Dept 17	64
Dept 8	9	Dept 18	41
Dept 9	9	Dept 19	27
Dept 10	24	Dept 20	45

Table 5.18 Armour and Buffa Data Results

Area	Width (W)	Length (L)	b (L/W)	Band width (w)	Band length (l)	SFLA Result	MCRAFT Result	Best Result SFLA	Best Result MCRAF
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

According to the results given in Table 5.18, SFLA yields better results for bandwidth 4 and 5 for most of the layouts. If the shape factor, given in Eq. 5.1 considered, the bandwidth 10 does not produce feasible department shapes. Thus, the dominance of the SFLA in terms of the performances can be seen. For this problem, CRAFT yields 7862 and MULTIPLE yields 6858, while SFLA yields 6568.4 and 6227.8 for different bandwidths.

5.2.6 9 Departments (Bozer)

For the Bozer data set, two different dimensions are used; 12 X 13 and 6 X 26. Three different bandwidths are applied for each of these different dimensions; 3, 4 and 6. Problem data, area of the departments and flow data are given in Table 5.19, 5.20 and 5.21 respectively.

Table 5.19 Problem data for 9 Departments problem

Number of Departments	9
Plant Width	12
Plant Length	13
Total Area	156

Table 5.20 Area of the departments for 9 Departments problem

Dept 1	16
Dept 2	16
Dept 3	16
Dept 4	36
Dept 5	36
Dept 6	9
Dept 7	9
Dept 8	9
Dept 9	9

Table 5.21 Flow between departments for 9 Departments problem

	Dept 1	Dept 2	Dept 3	Dept 4	Dept 5	Dept 6	Dept 7	Dept 8	Dept 9
Dept 1	0	0	0	5	5	0	0	0	1
Dept 2	0	0	0	3	3	0	0	0	1
Dept 3	0	0	0	2	2	0	0	0	1
Dept 4	5	3	2	0	0	4	4	0	0
Dept 5	5	3	2	0	0	3	0	0	4
Dept 6	0	0	0	4	3	0	0	0	2
Dept 7	0	0	0	4	0	0	0	0	1
Dept 8	0	0	0	0	0	0	0	0	0
Dept 9	1	1	1	0	4	2	1	0	0

The results for the problem are given in Table 5.22 below.

Table 5.22 Results for for 9 Departments problem

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

5.2.7 11 Departments (Meller)

Problem data, area of the departments and flow data are given in Table 5.19, 5.20 and 5.21 respectively.

Table 5.23 Problem data for 11 Departments problem

Number of Departments	11
Plant Width	6
Plant Length	6
Total Area	36

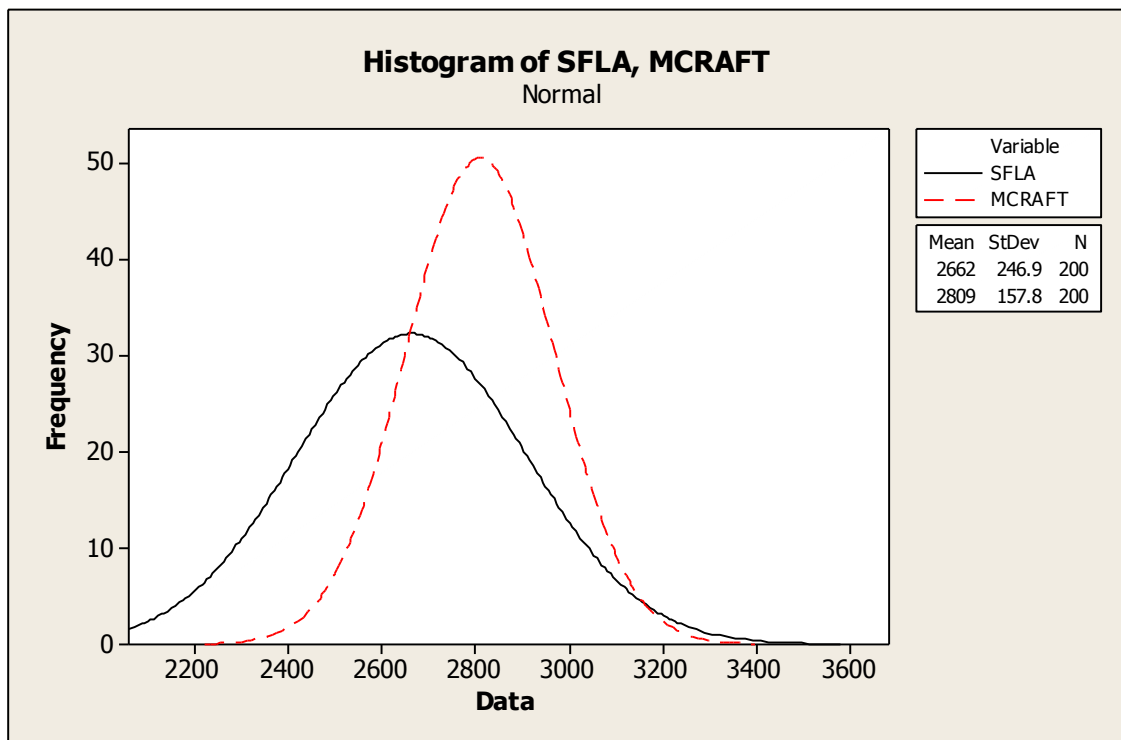
Table 5.24 Area of the departments for 9 Departments problem

Dept 1	3
Dept 2	2
Dept 3	4
Dept 4	5
Dept 5	2
Dept 6	3
Dept 7	4
Dept 8	5
Dept 9	1
Dept 10	1
Dept 11	6

Table 5.25 Flow between departments for 9 Departments problem

	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	0	0	0	140	90	20	0	40	0	146
Dept 2	0	0	10	0	10	0	0	0	0	0	0
Dept 3	0	10	0	10	0	10	0	0	0	0	0
Dept 4	0	0	10	0	0	0	0	0	0	0	4
Dept 5	140	10	0	0	0	0	40	0	0	20	0
Dept 6	90	0	10	0	0	0	0	0	20	0	0
Dept 7	20	0	0	0	40	0	0	10	0	0	0
Dept 8	0	0	0	0	0	0	10	0	0	0	10
Dept 9	40	0	0	0	0	20	0	0	0	20	0
Dept 10	0	0	0	0	20	0	0	0	20	0	20
Dept 11	146	0	0	4	0	0	0	10	0	20	0

The results are given in Figure 5.36 and 5.37 below. According to the results, SFLA yields lower costs than MCRAFT.

**Figure 5.38** Histogram of 9 departments(Meller)

Paired T for SFLA - MCRAFT				
	N	Mean	StDev	SE Mean
SFLA	200	2662.23	246.92	17.46
MCRAFT	200	2809.24	157.80	11.16
Difference	200	-147.011	295.844	20.919

95% CI for mean difference: (-188.263, -105.759)

T-Test of mean difference = 0 (vs not = 0): T-Value = -7.03 P-Value = 0.000

Figure 5.39 Minitab results of 9 Departments(Meller)

5.3 COMPARISON OF THE RESULTS

According to the paired-t test results, MCRAFT and SFLA are not produced significantly different results for all the problems. If the mean values are evaluated, 51 problems are evaluated and for 22 of them, SFLA yields better results. For 29 of the problems, MCRAFT yields better results. All the results are given in Table 5.26.

Table 5.26 Average Results Comparison

Problem Name	Dimensions	Best Result	Problem Name	Dimensions	Best Result	
Problem 2	20 by 20 (4)	MCRAFT	Problem 3	25 by 16(5)	SFLA	
	20 by 20 (5)	MCRAFT		25 by 16(6)	SFLA	
	20 by 20 (10)	MCRAFT		25 by 16(10)	MCRAFT	
	10 by 40 (4)	SFLA		15 by 60(5)	MCRAFT	
	10 by 40 (5)	MCRAFT		15 by 60(6)	MCRAFT	
	10 by 40 (10)	MCRAFT		15 by 60(10)	SFLA	
	25 by 16 (4)	SFLA		20 by 45(5)	MCRAFT	
	25 by 16 (5)	MCRAFT		20 by 45(6)	MCRAFT	
	25 by 16 (10)	MCRAFT		20 by 45(10)	MCRAFT	
	8 by 50 (4)	MCRAFT		18 by 50(5)	MCRAFT	
	8 by 50 (5)	SFLA		18 by 50(6)	SFLA	
	8 by 50 (10)	MCRAFT		18 by 50(10)	SFLA	
	Armour and Buffa	20 by 30(4)		SFLA	9 Dept. Bozer	30 by 30 (5)
20 by 30(5)		SFLA	30 by 30 (6)	SFLA		
20 by 30(10)		MCRAFT	30 by 30 (10)	MCRAFT		
10 by 60(4)		SFLA	12 by 13(3)	MCRAFT		
10 by 60(5)		MCRAFT	12 by 13(4)	MCRAFT		
10 by 60(10)		MCRAFT	12 by 13(6)	MCRAFT		
15 by 40(4)		SFLA	6 by 26(3)	SFLA		
15 by 40(5)		SFLA	6 by 26(4)	SFLA		
15 by 40(10)		MCRAFT	6 by 26(6)	SFLA		
24 by 25(4)		SFLA	11 Dept. Meller	6 by 6(1)	SFLA	
24 by 25(5)		SFLA	Problem 1	8 by 9(1)	SFLA	
24 by 25(10)		MCRAFT		Problem 4	30 by 20(3)	MCRAFT
12 by 50(4)		MCRAFT				
12 by 50(5)		MCRAFT				
12 by 50(10)		MCRAFT				

The normal probability plots of the results for Problem 1 are given at the Appendix A. The normal probability plot is a graphical technique that is used for testing

the normality of the data set. The data sets are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this straight line indicate departures from normality. For instance, the probability plot for the Problem 1 with dimensions, 25 by 36, bandwidth 5 is given below.

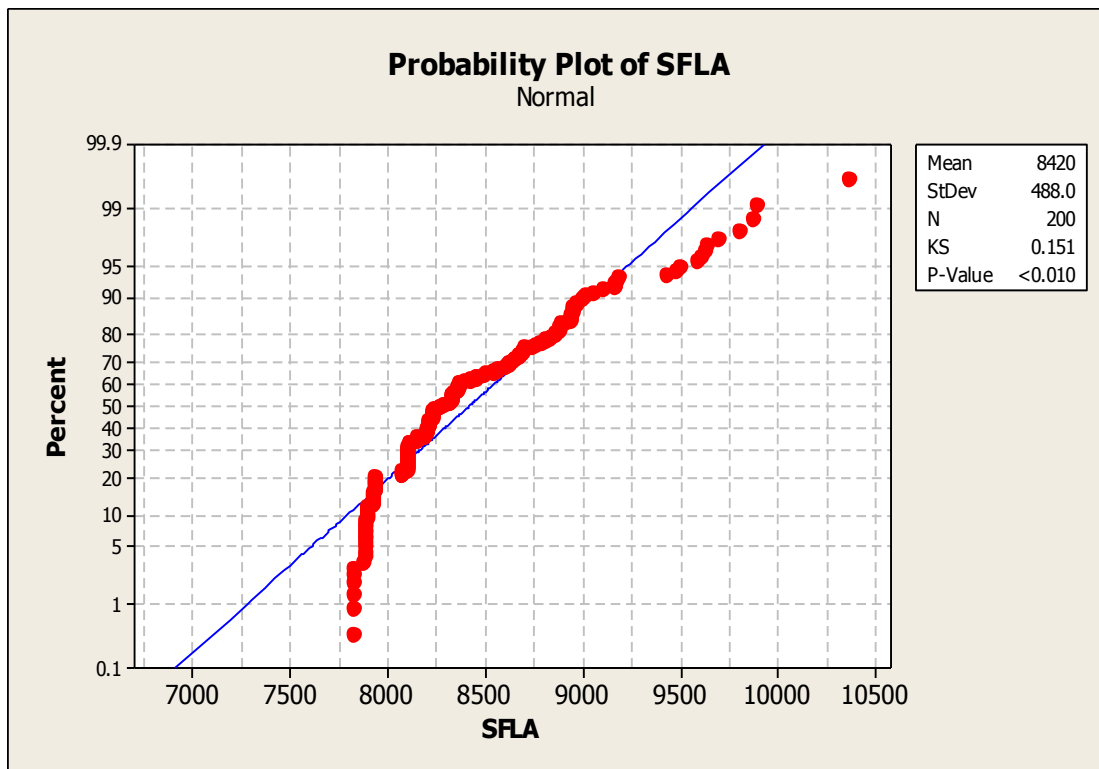


Figure 5.40 Normality plot of Problem 1 25 by 36 bandwidth 5

CHAPTER 6

CONCLUSION

Facility layout problem has been studied for several decades. 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 branches 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 algorthims. 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 the performances of SFLA and MCRAFT can not be clearly identified at this point. There are factors that might affect the result, these are;

bandwidth, plant length to width ratio. The different level of these factors can create advantages for desired layouts.

Overall, SFLA is an alternative approach to facility layout algorithms. It works as efficient as MCRAFT, which is the improved version of one of the most known algorithm, CRAFT. SFLA and MCRAFT BOTH yield better results than MULTIPLE and CRAFT.

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 be seen and the question about which algorithm has advantages according to which factor, can be clearly identified.

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APPENDIX A

Dot plot graphs of the problems

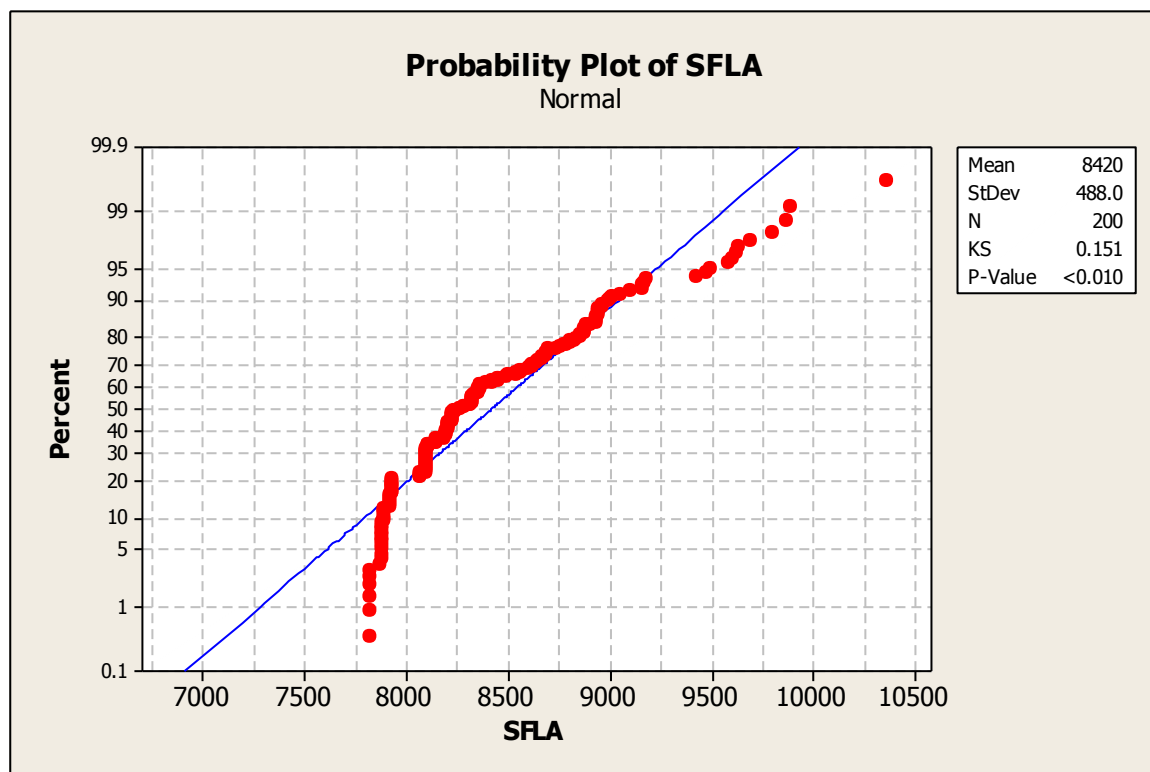


Figure 1 SFLA Result of Problem 1 (25 by 36) Bandwidth 5

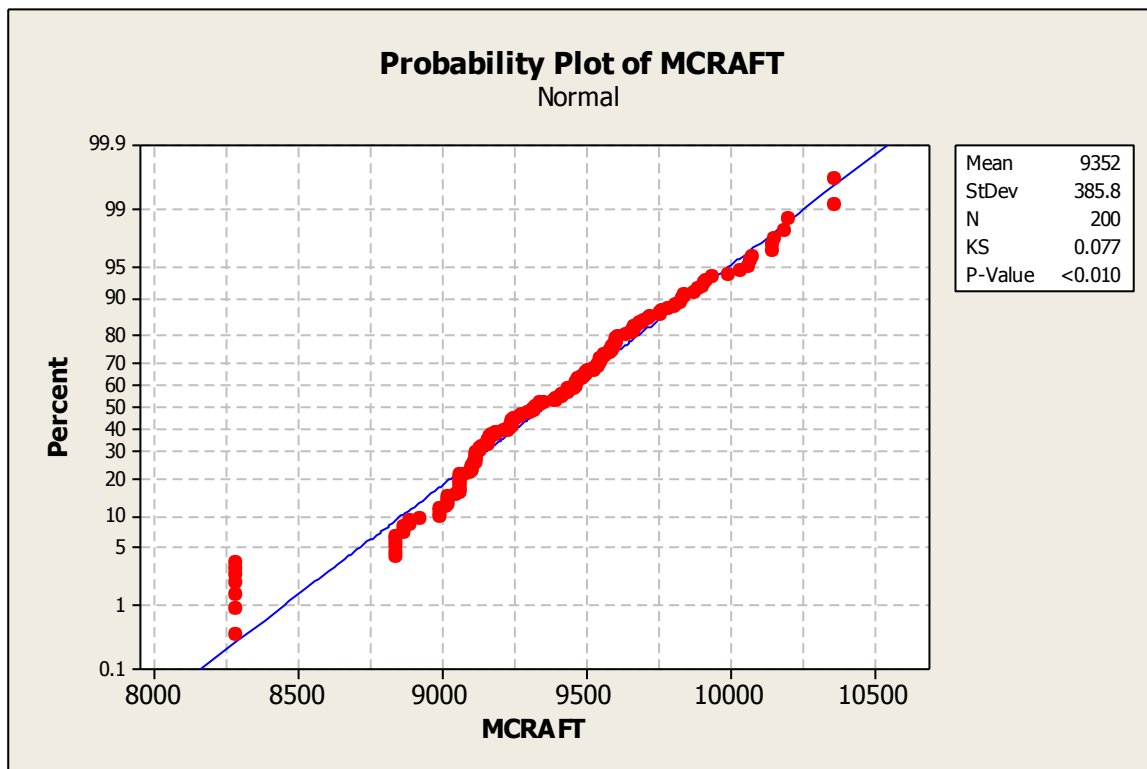


Figure 2 MCRAFT Result of Problem 1 (25 by 36) Bandwidth 5

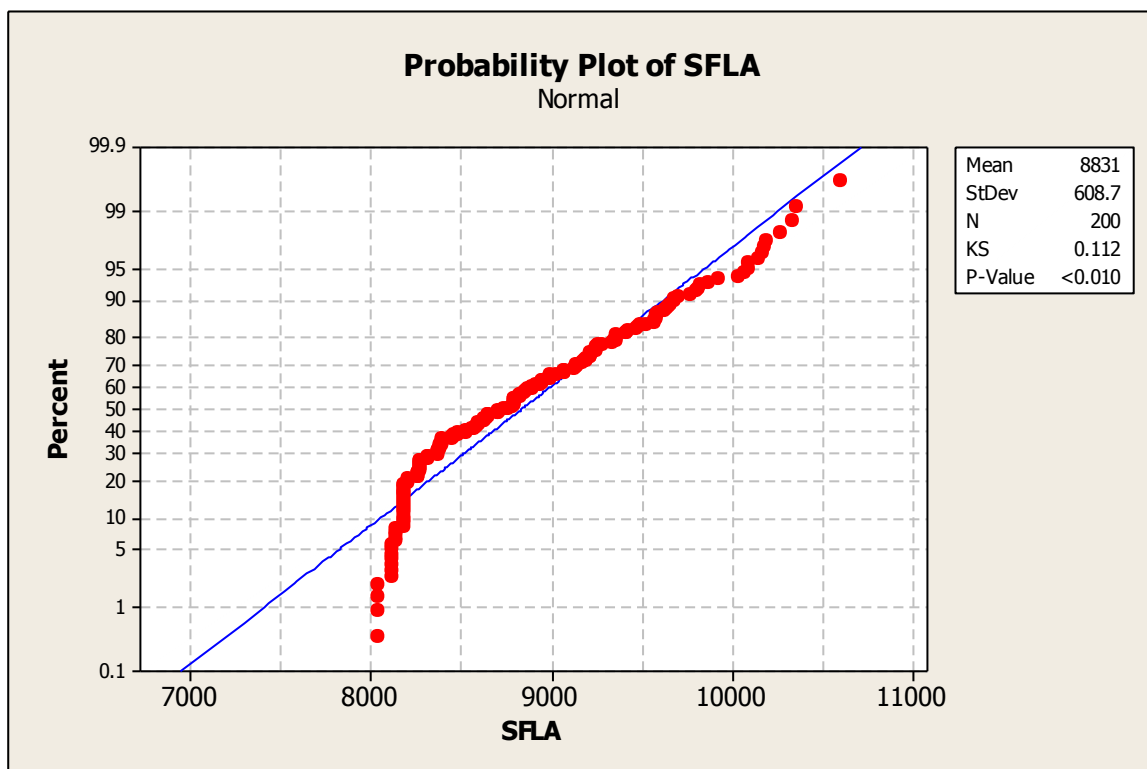


Figure 3 SFLA Result of Problem 1 (25 by 36) Bandwidth 6

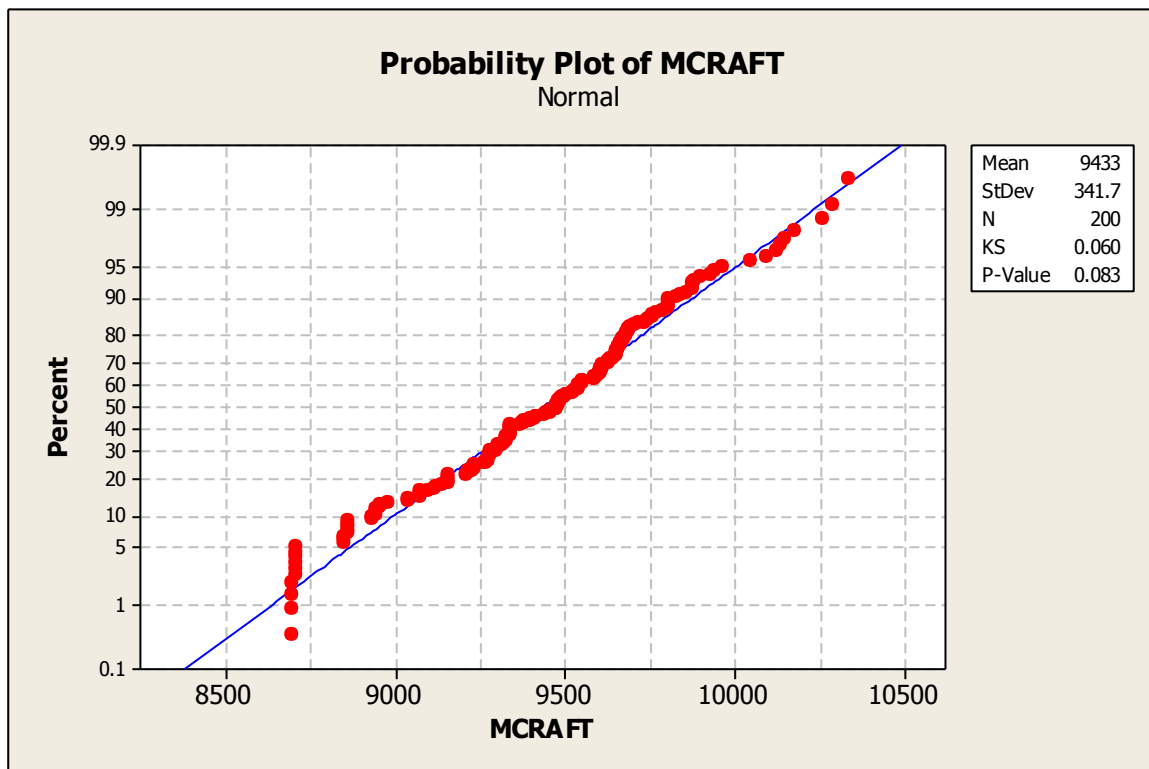


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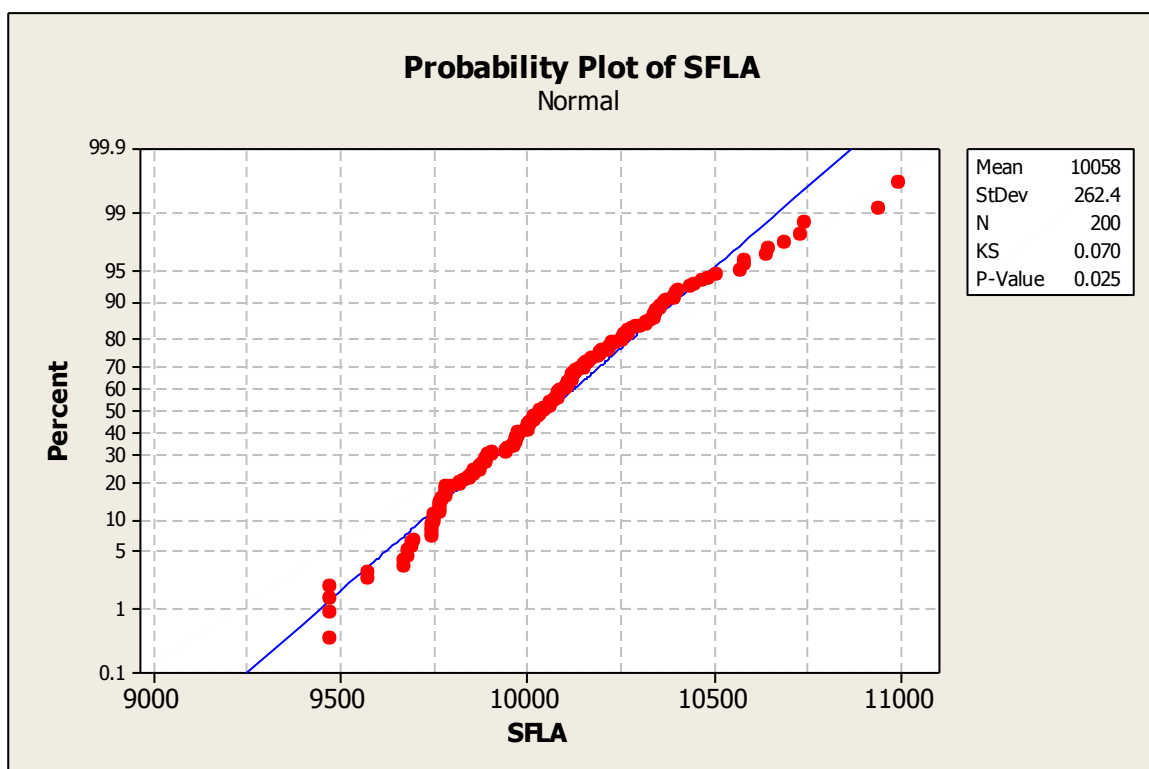


Figure 5 SFLA Result of Problem 1 (25 by 36) Bandwidth 10

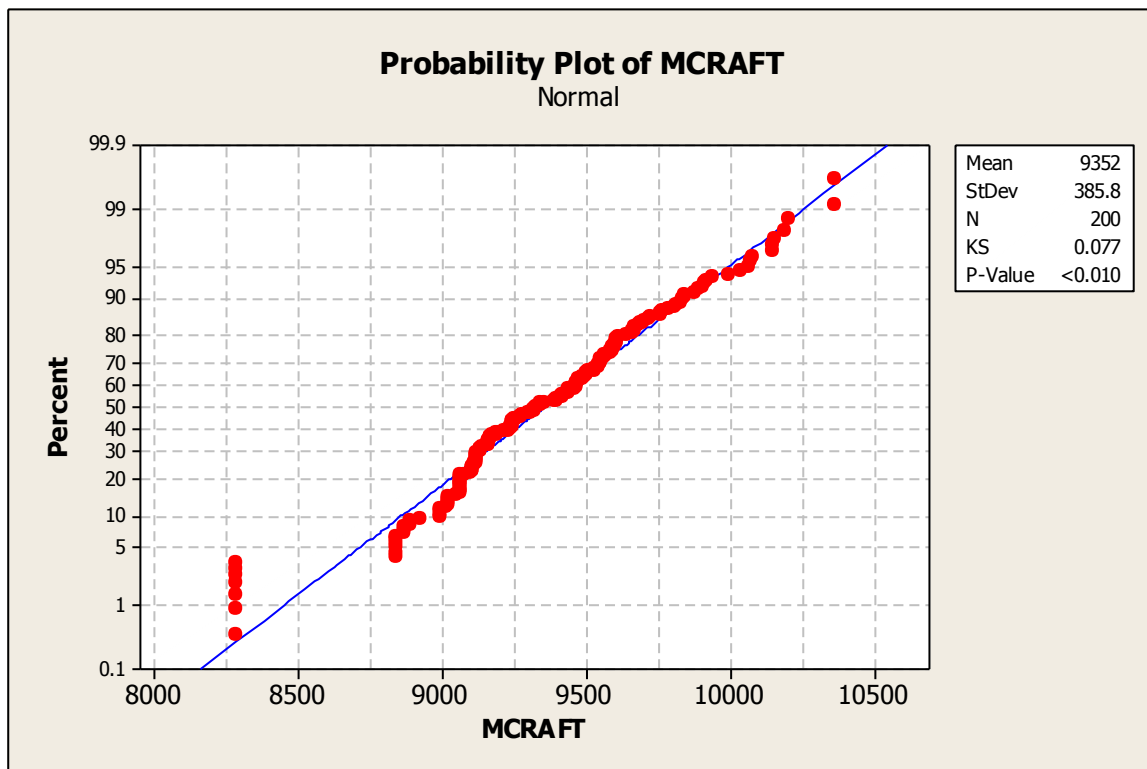


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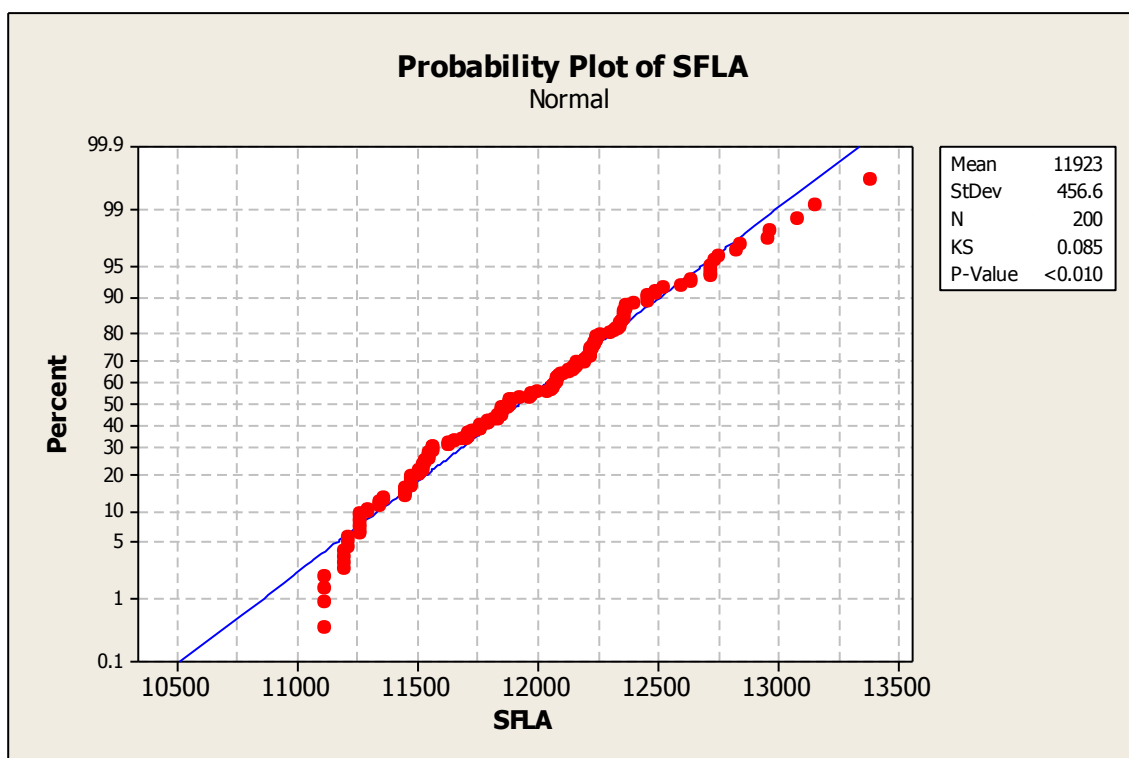


Figure 7 SFLA Result of Problem 1 (15 by 60) Bandwidth 5

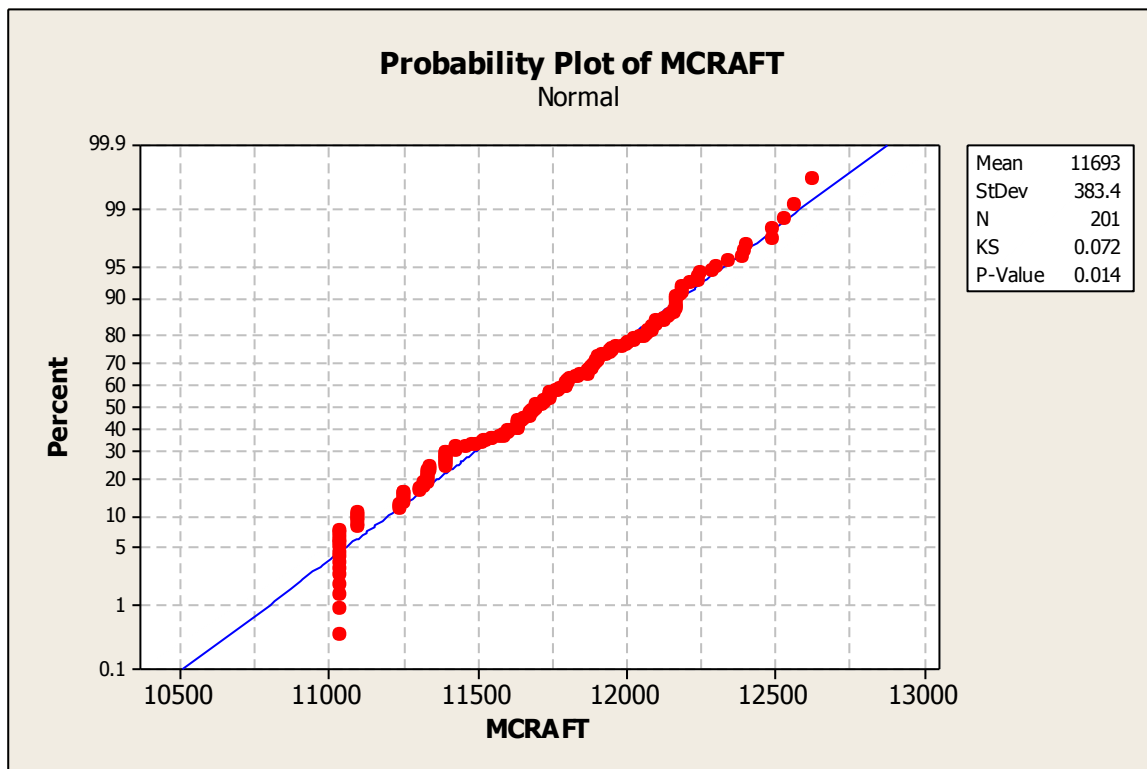


Figure 8 MCRAFT Result of Problem 1 (15 by 60) Bandwidth 5

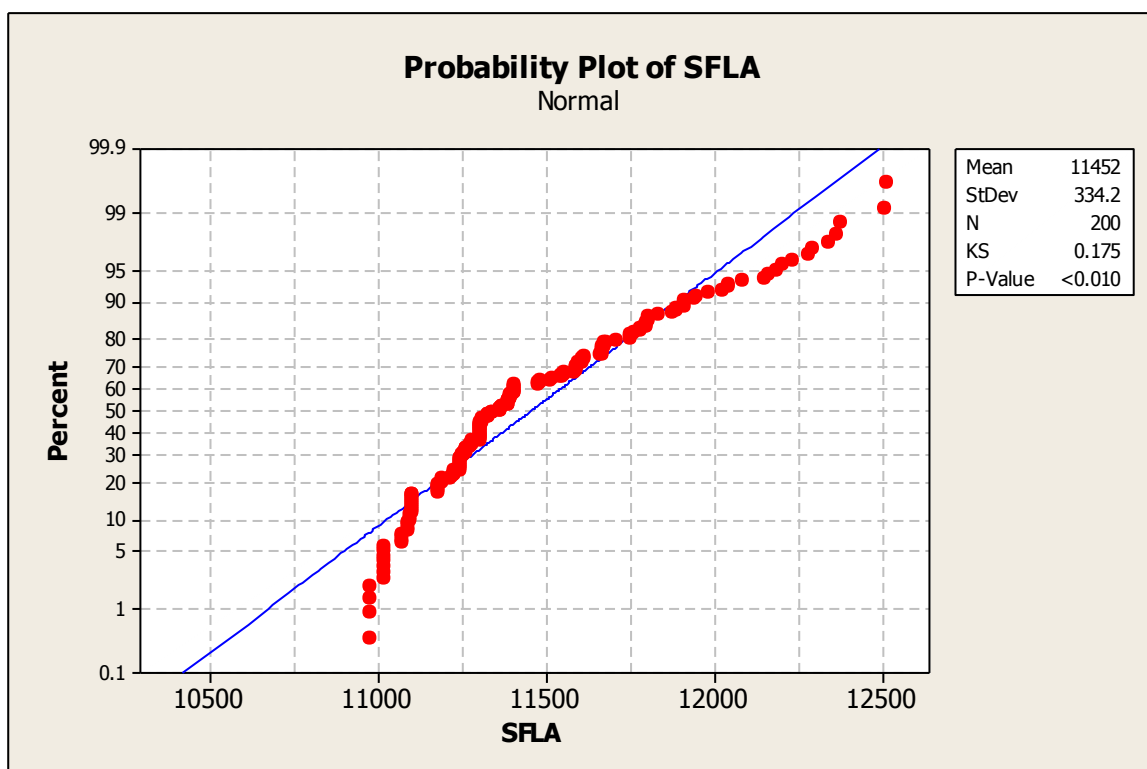


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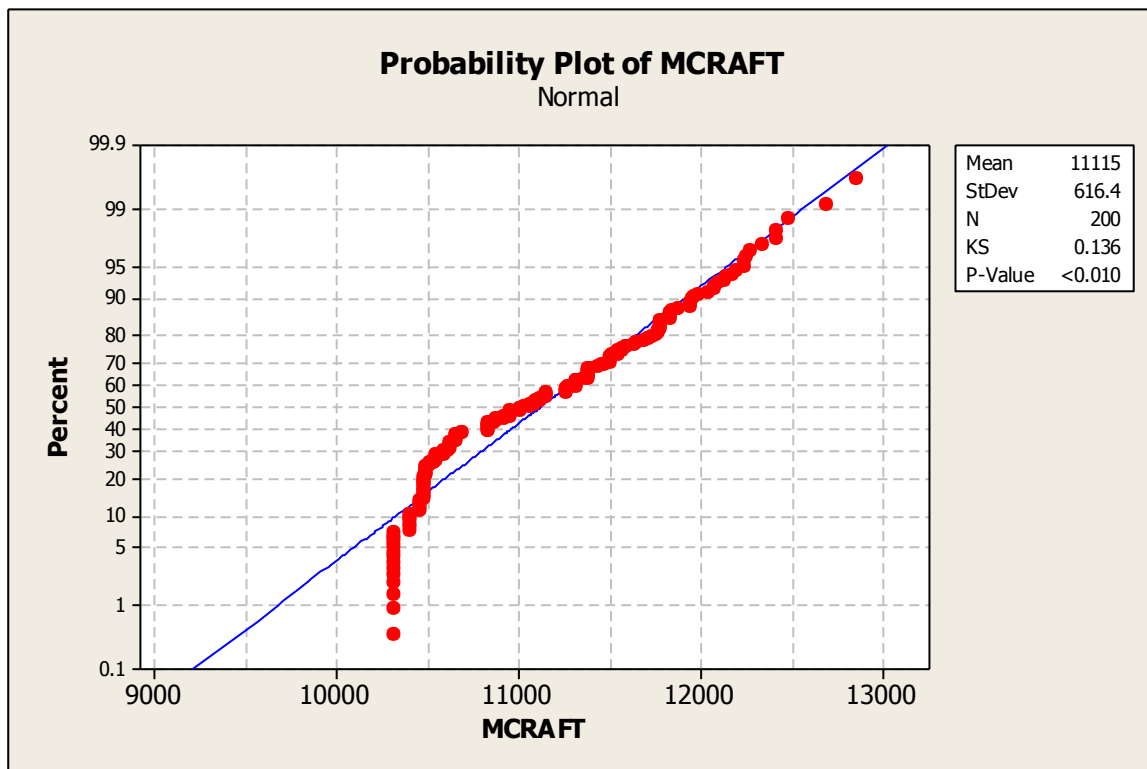


Figure 10 MCRAFT Result of Problem 1 (15 by 60) Bandwidth 6

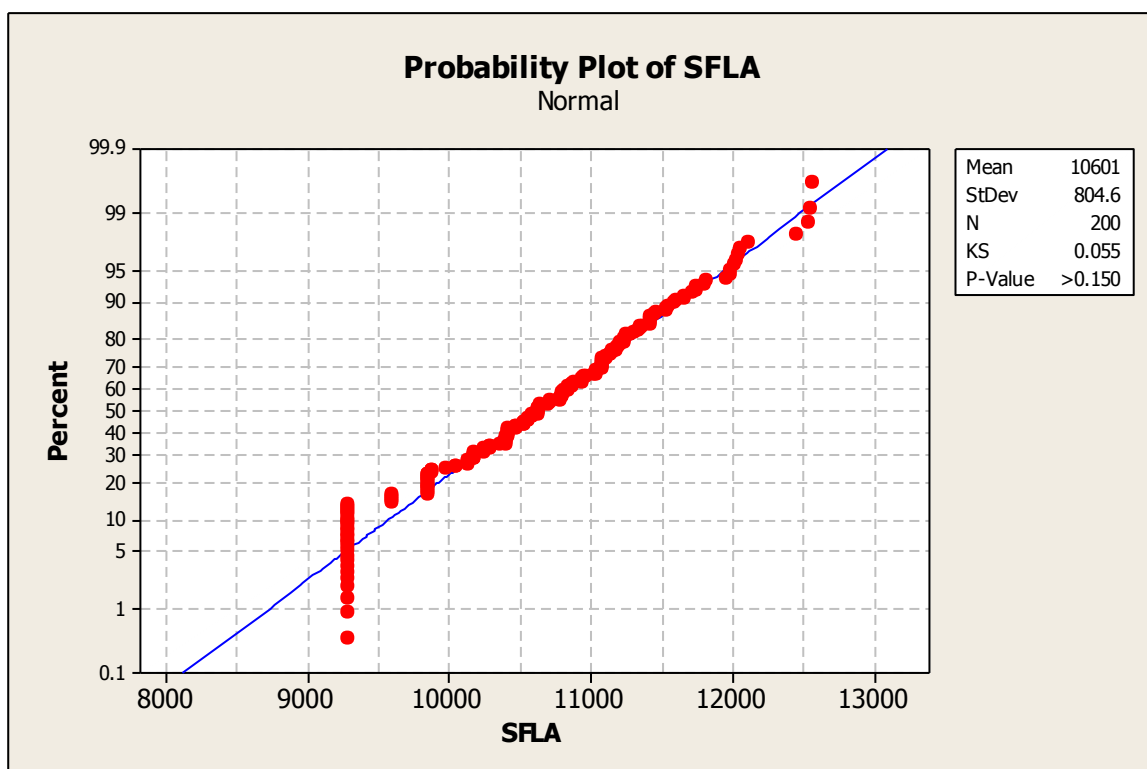


Figure 11 SFLA Result of Problem 1 (15 by 60) Bandwidth 10

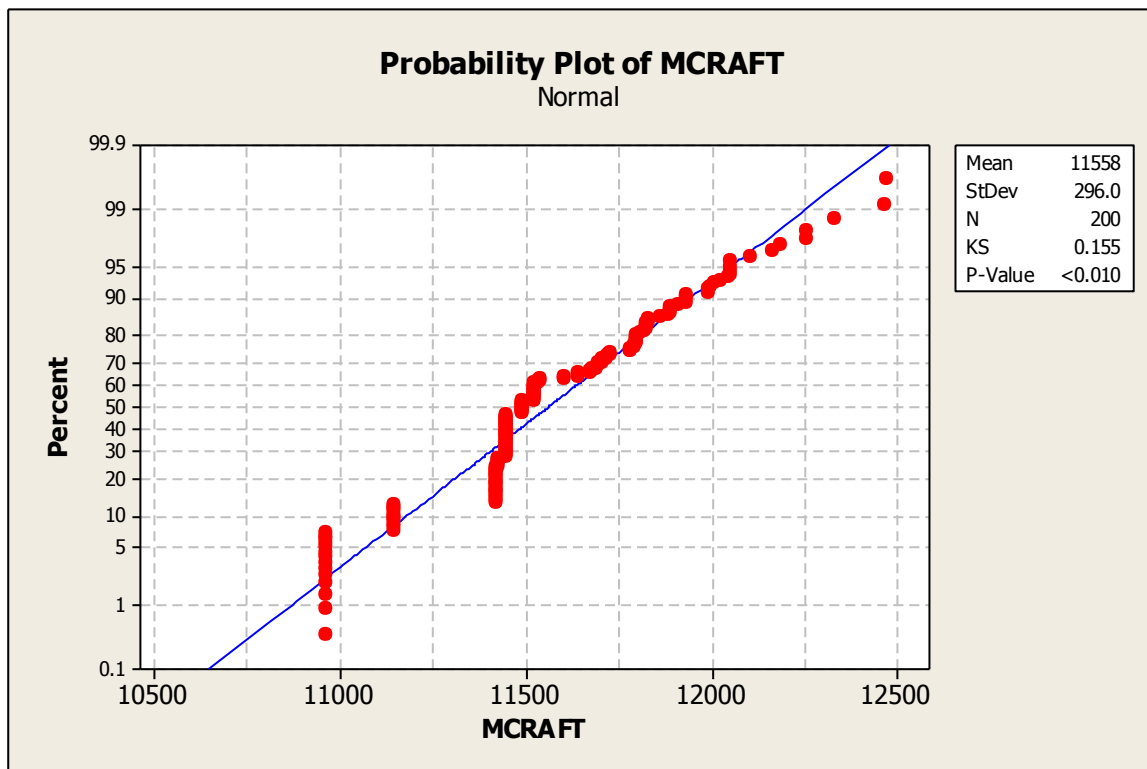


Figure 12 MCRAFT Result of Problem 1 (15 by 60) Bandwidth 10

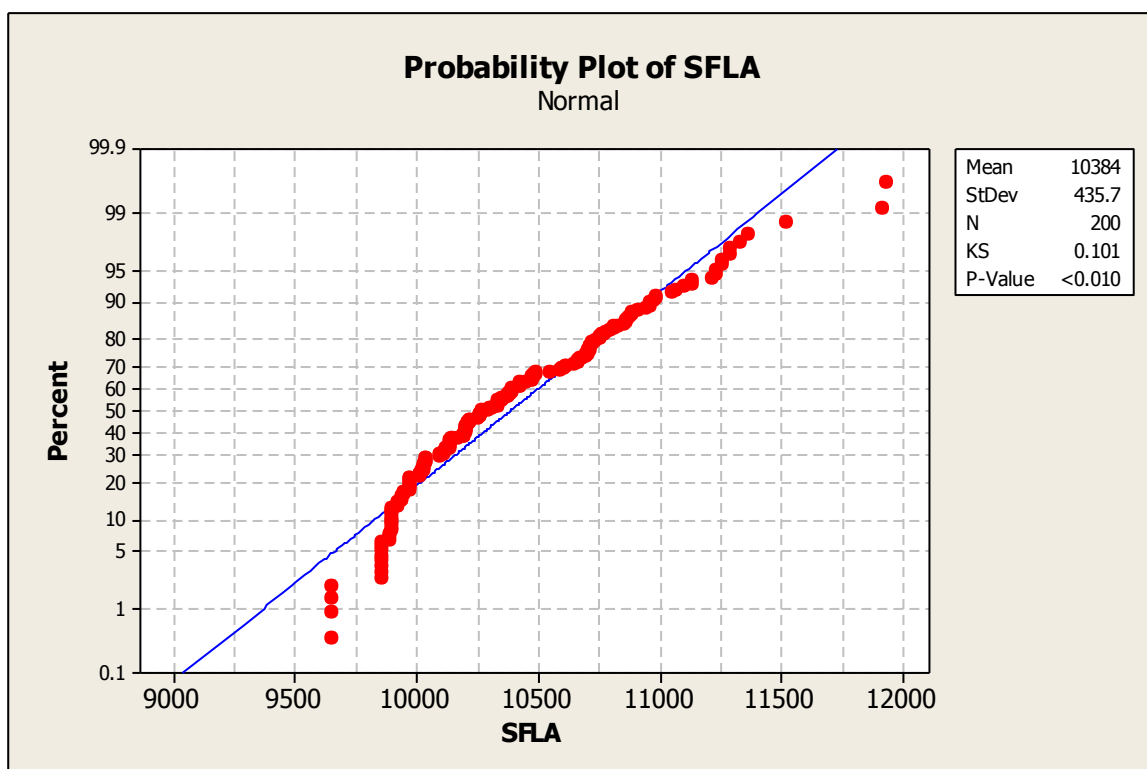


Figure 13 SFLA Result of Problem 1 (20 by 45) Bandwidth 5

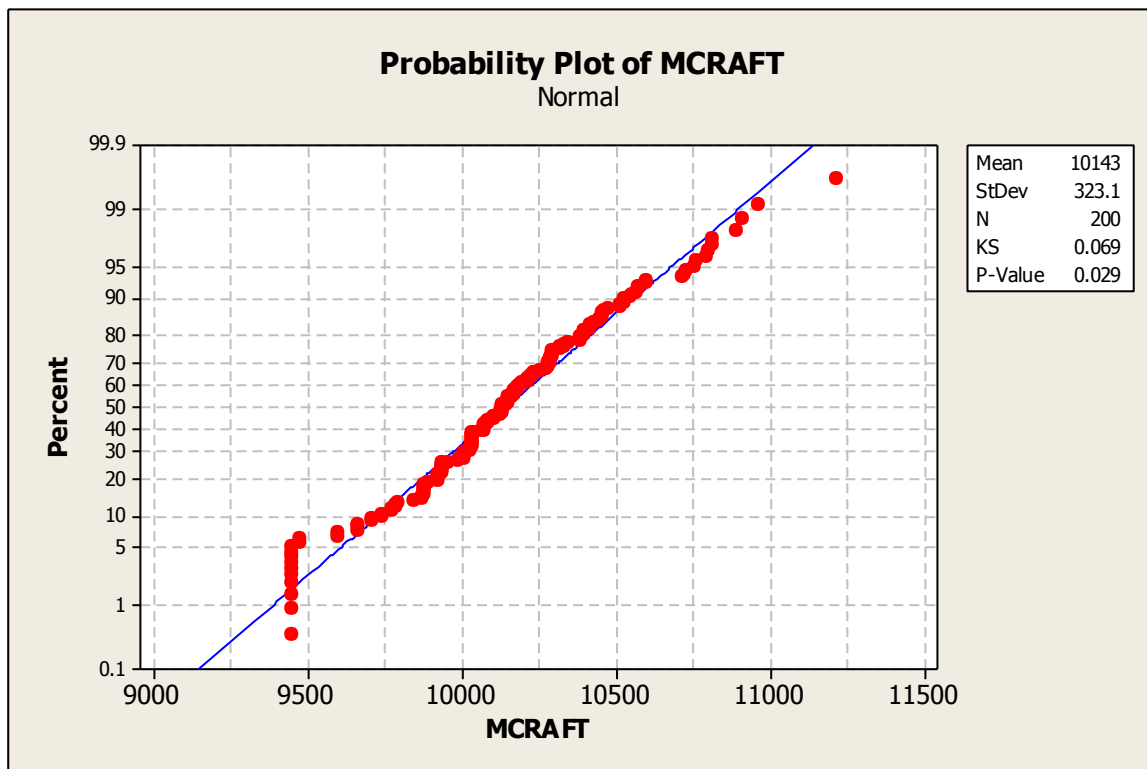


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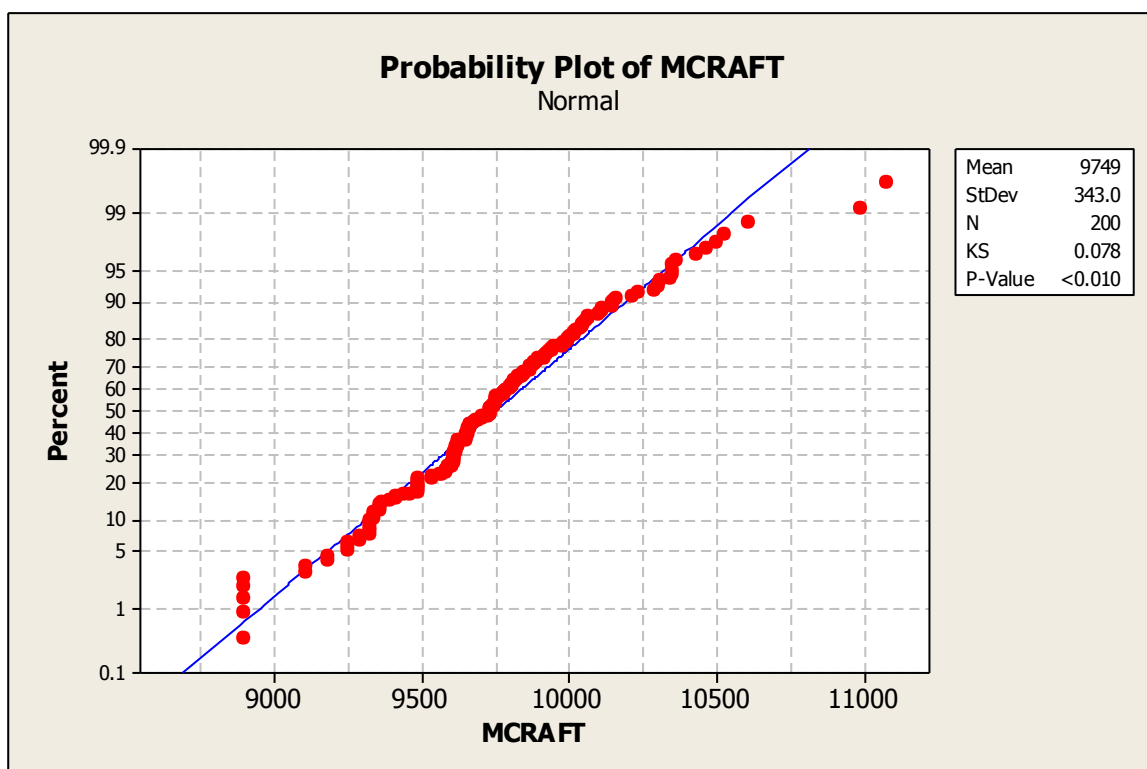


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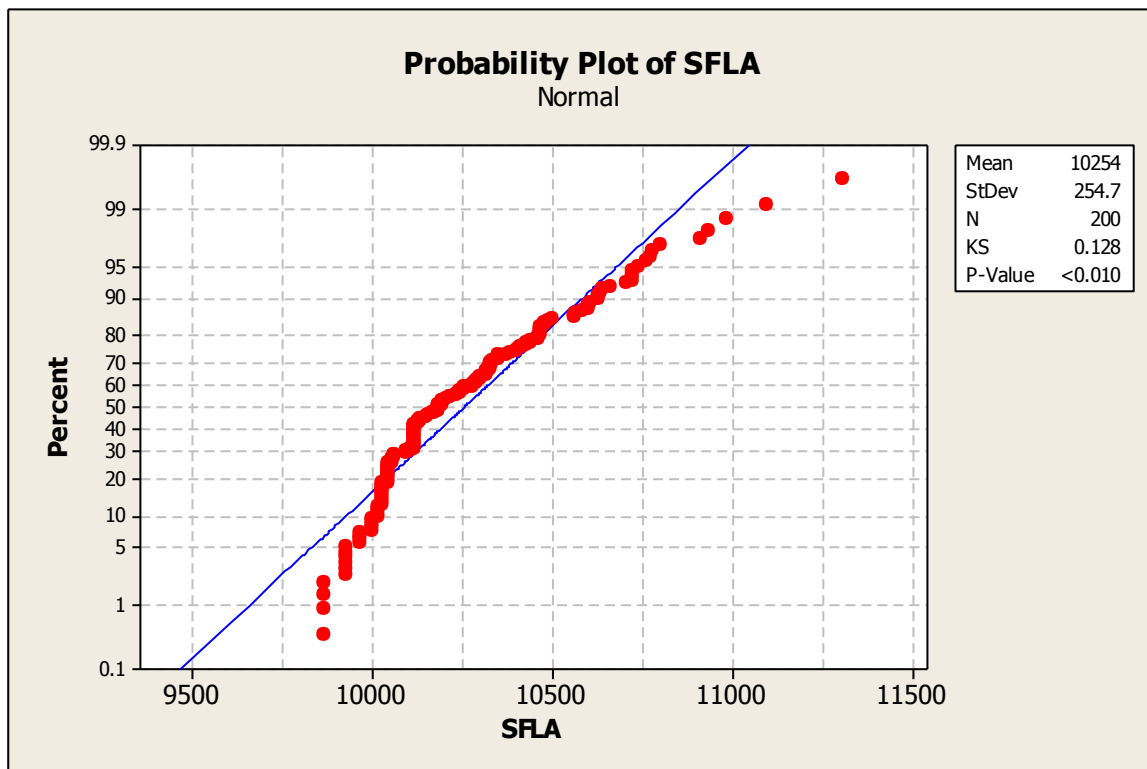


Figure 16 SFLA Result of Problem 1 (20 by 45) Bandwidth 10

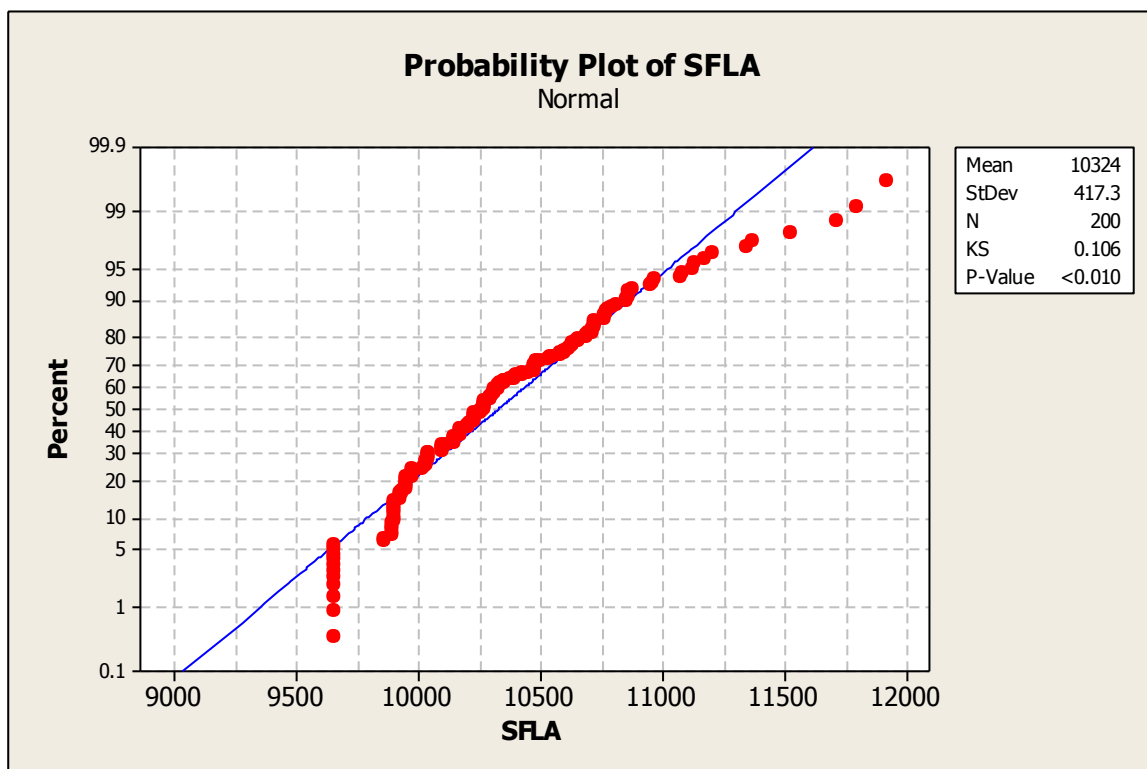


Figure 17 SFLA Result of Problem 1 (18 by 50) Bandwidth 5

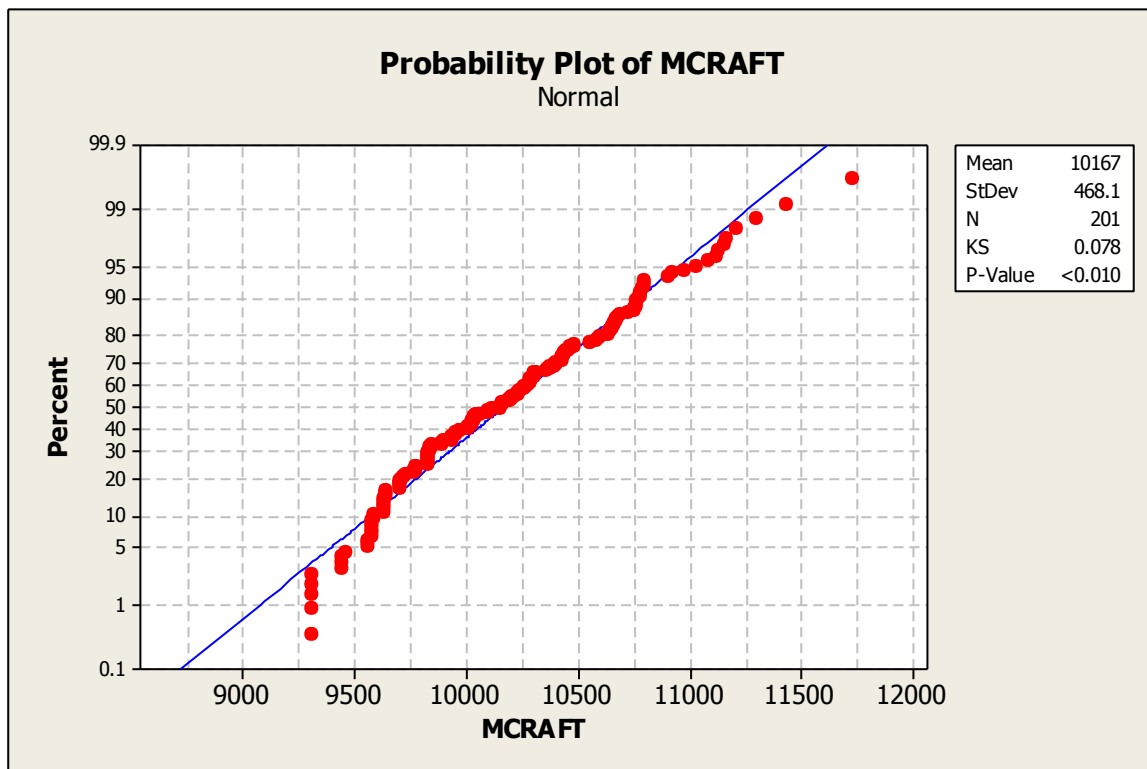


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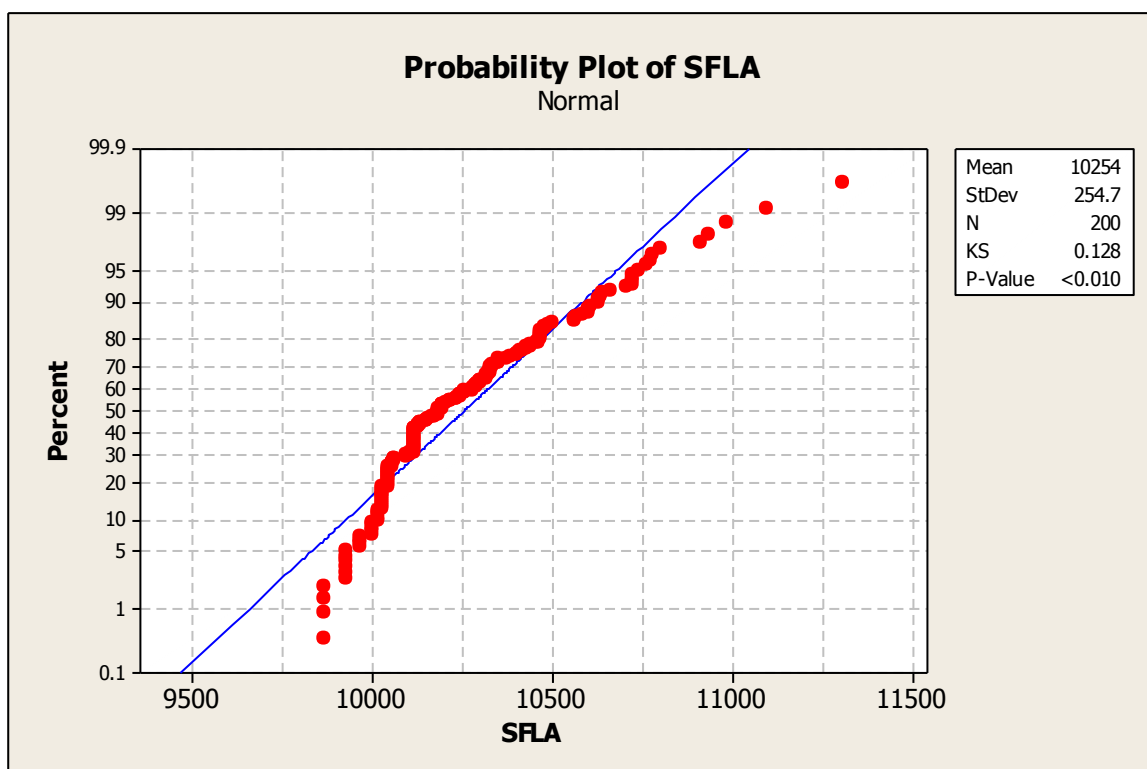


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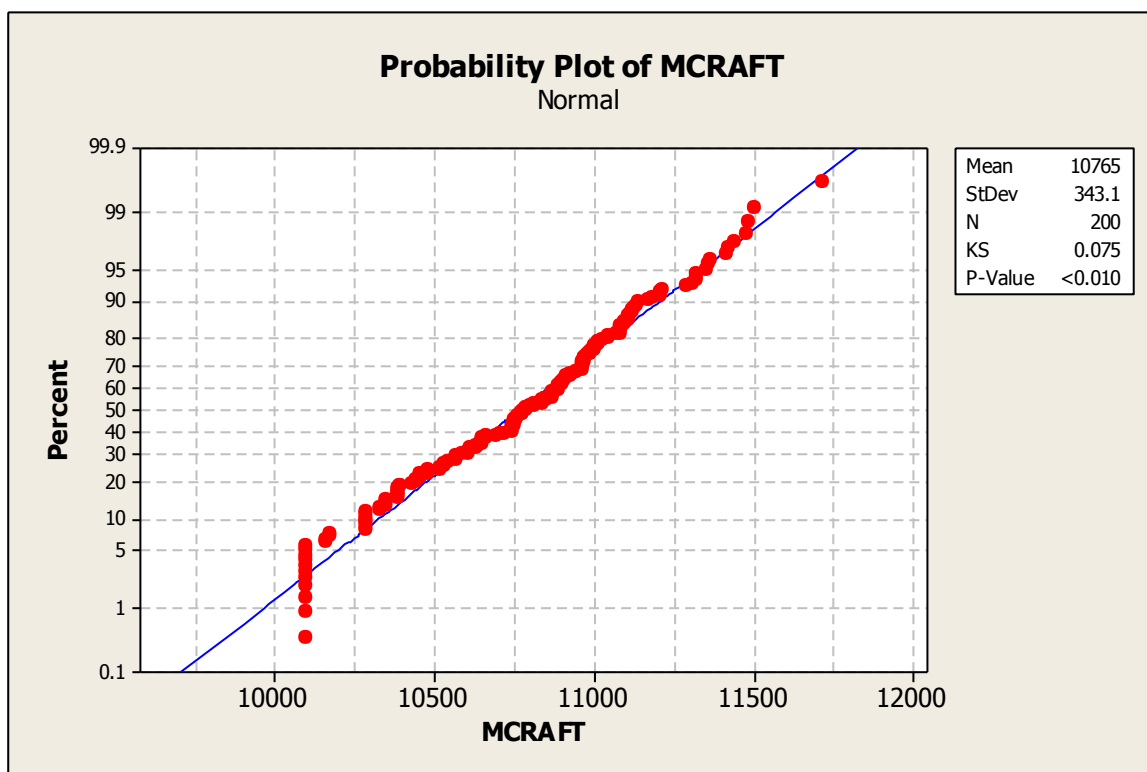


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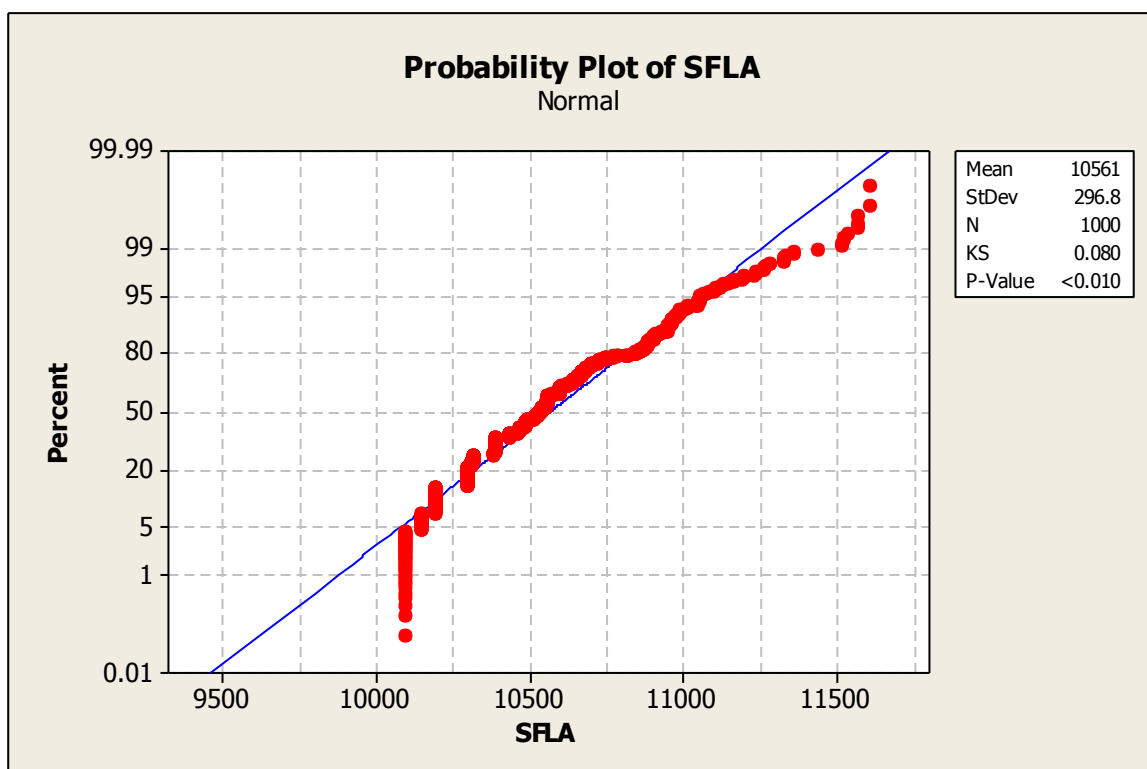


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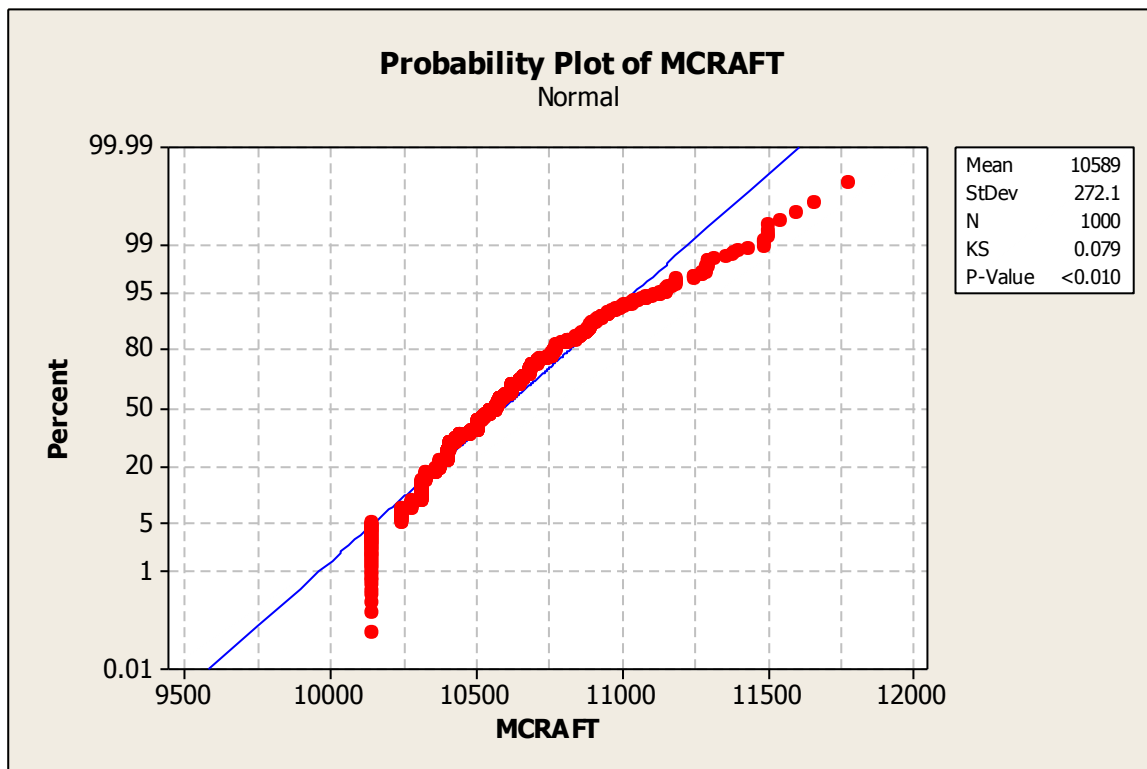


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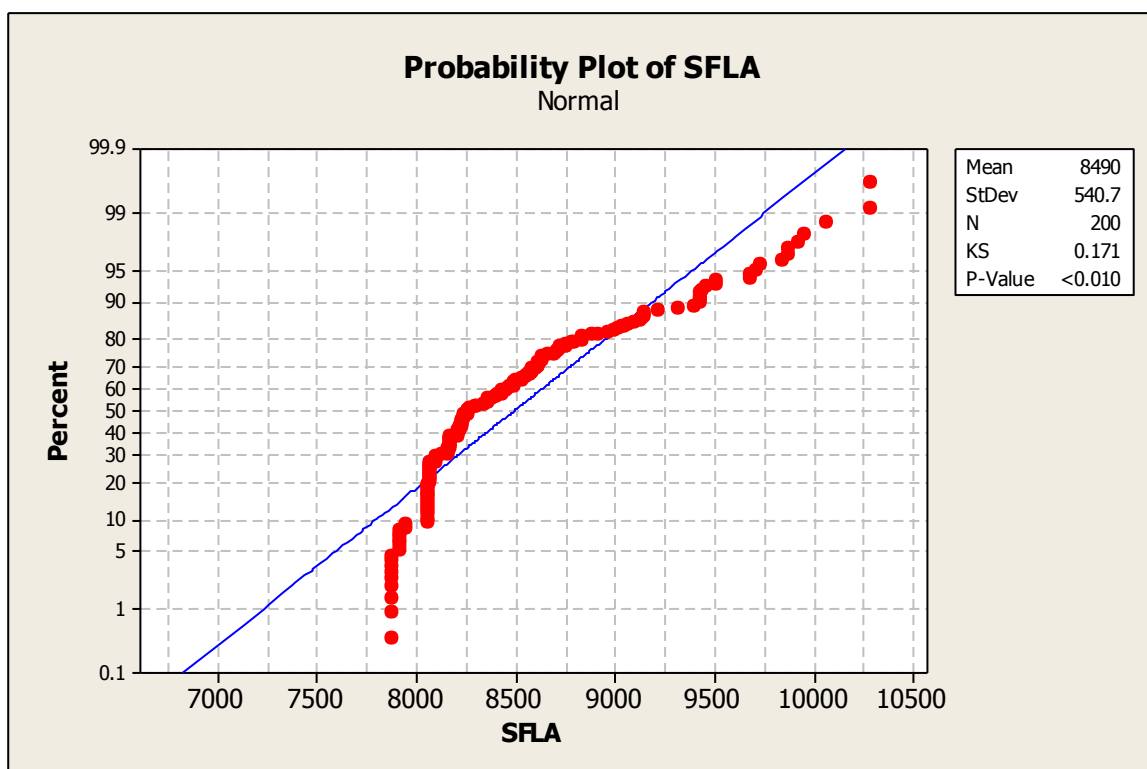


Figure 23 SFLA Result of Problem 1 (30 by 30) Bandwidth 5

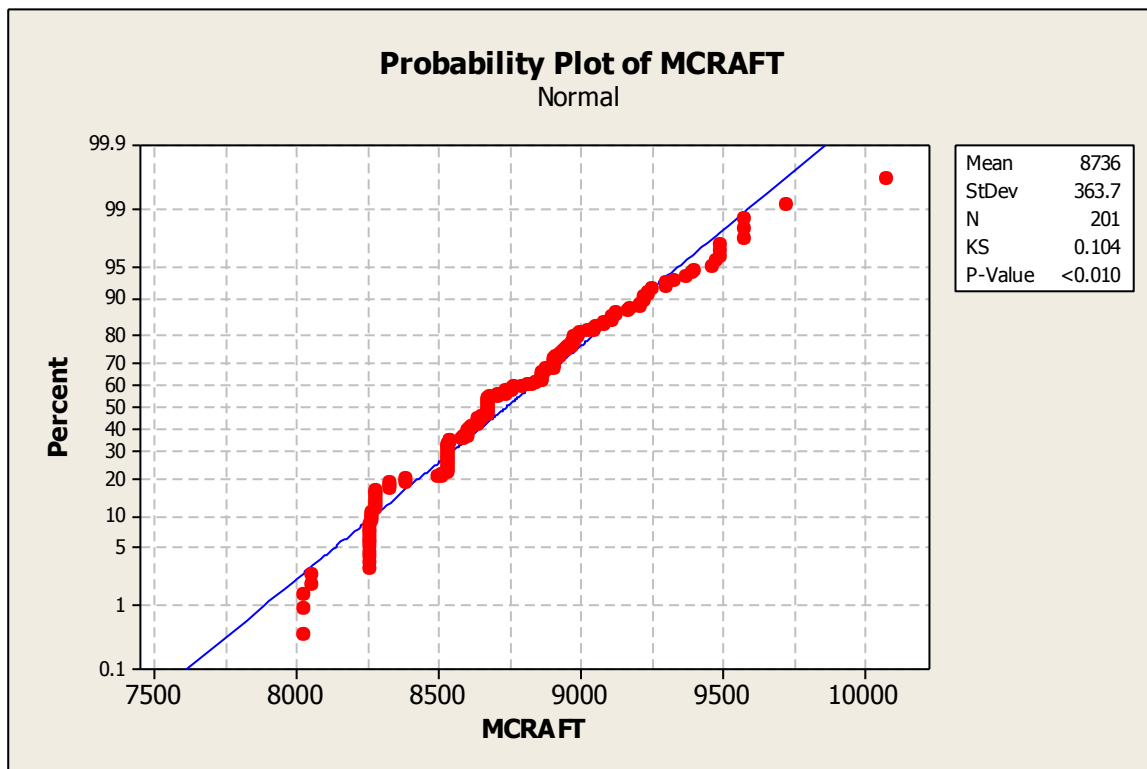


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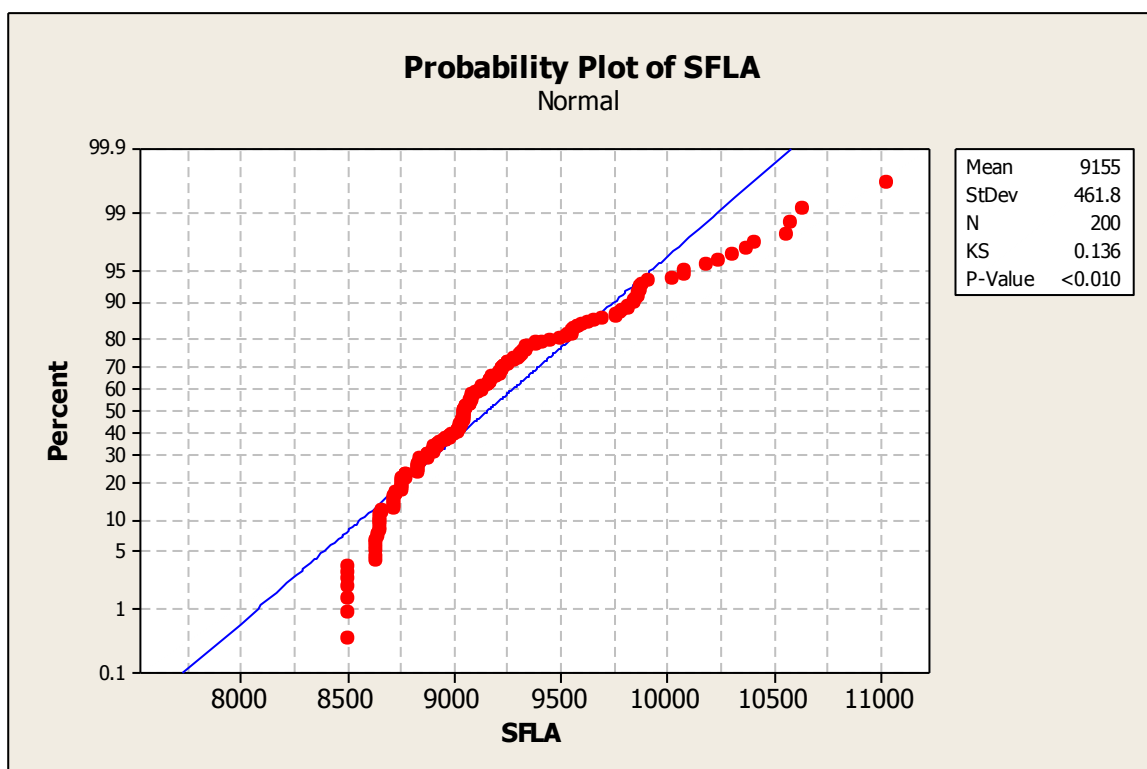


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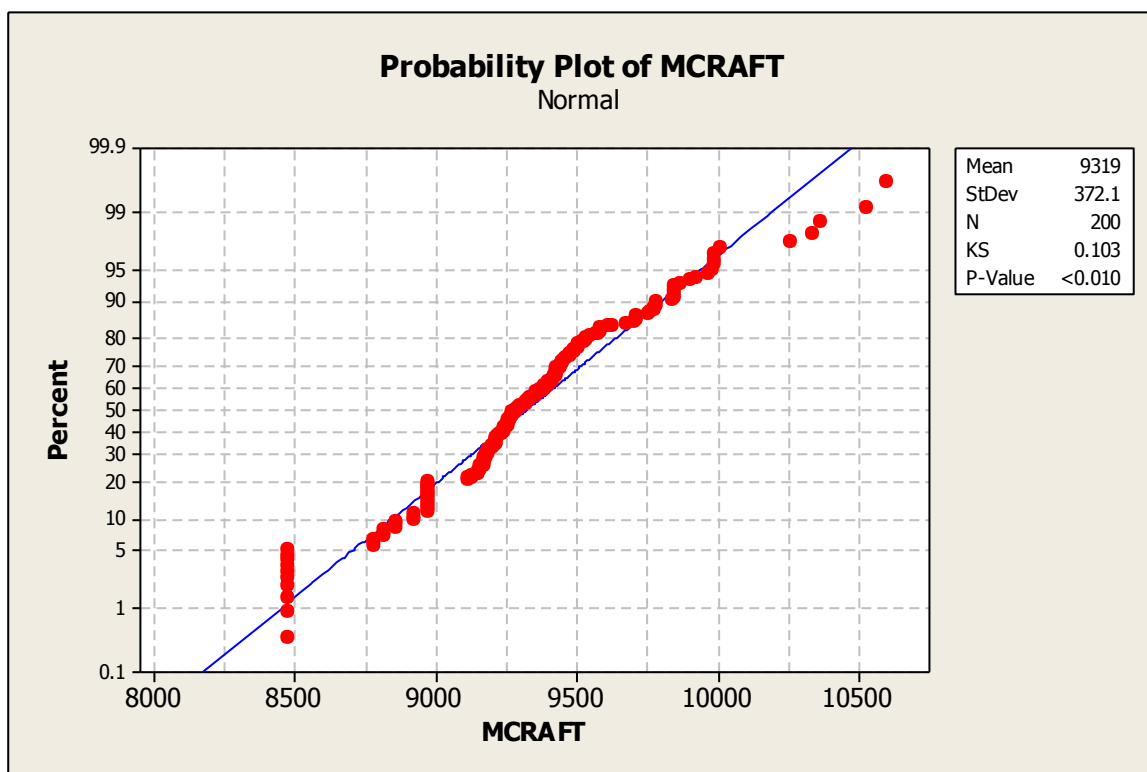


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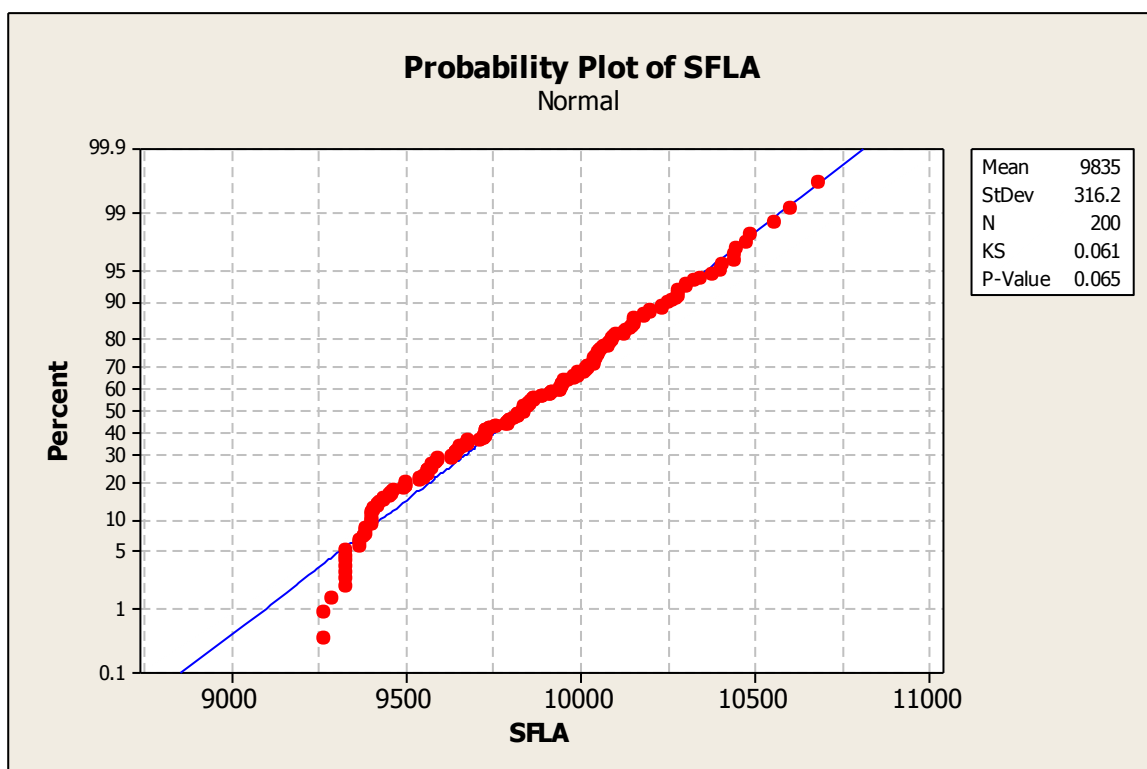


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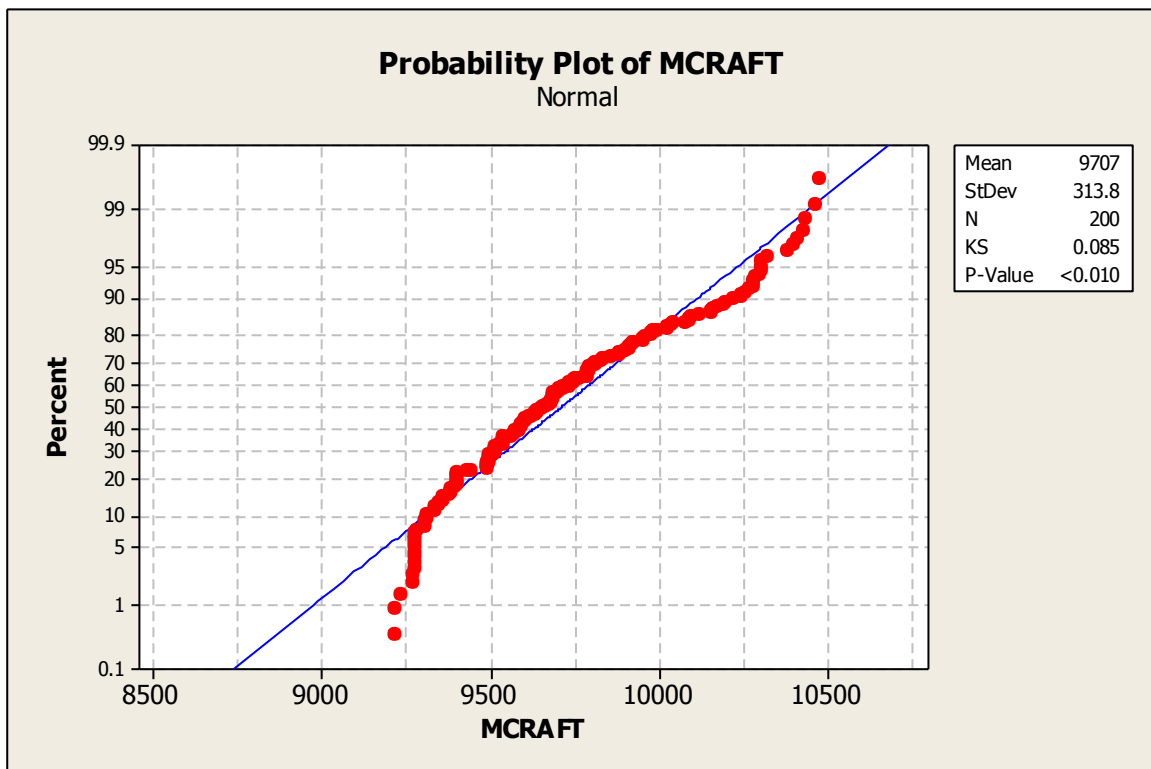


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