Computer Aided Plant Layout Development for an Aluminum Product Factory.

T.S. Ogedengbe, M.Sc.[*1]**; S.B. Adejuyigbe, Ph.D.**[1]**; S.O. Ismaila, Ph.D.**[1]**;
B.A. Adewumi, Ph.D.[2]**; and D.M. Ali, M Sc.**[1]

[1]Department of Mechanical Engineering, Federal University of Agriculture,
PMB 2240, Abeokuta, Ogun State, Nigeria.
[2]Department of Agricultural Engineering, Federal University of Agriculture,
PMB 2240, Abeokuta, Ogun State, Nigeria.

E-mail: temitayooged@gmail.com[*]

ABSTRACT

This study presents research into the use of computers as a tool to aid the planning of layouts in factories to reduce daily cost incurred, using developed software.

The approach involves identifying and solving plant layout problems (especially closeness relationship problems) thereby generating an ideal layout through the use of computer software which was developed using the programming language known as Visual Basic. A building products fabrication plant in Lagos, Nigeria was used as a case study in the research. It was discovered that the computer software developed (AUTO LAY 2010) could be used to generate alternative layouts which are more effective as it reduced material movement between departments and hence lowered Transportation cost, these ultimately reduces the relative cost of setting up facilities in a company.

The results derived from the application of AUTO LAY 2010 to the case study company generated a layout with a cost reduction of ₦500.00, ₦33,000.00, and ₦1,000.00 daily in the office, production, and whole plant sections of the case study factory respectively, resulting in a cost reduction of ₦34,500.00 daily and about N9 million annually. These results show that the use of computer software in modern facility design will not only save costs but also enhance production and thereby increase the profit margins in the manufacturing industry.

(Keywords: closeness relationship, plant layout, effectiveness value, relative cost)

INTRODUCTION

Plant layout is the optimum arrangement of different facilities including man, machine, equipment, and materials, showing the space allocated for material movement storage and supporting activities from the receipt of raw materials to the shipping of the finished goods for an overall economy of production (Verma, 2007). An industrial plant must fulfill its intended functions efficiently and economically. Its design must consider and account for the basic operating conditions to be served. The basic objective of plant layout is to achieve an orderly and practical arrangement of departments and work centers to minimize the movement of material and/or personnel while allowing for sufficient working space and perhaps space for future expansion within an area that may be predefined (Altamuro, 2007). This goal is kept in mind in every phase of plant development from assignment of overall areas of each of the departments to the generating of a detailed layout of each individual department within its space (Sule, 1988).

As opined by Verma (2007), a plant layout study is required to create an arrangement that will minimize unit production costs. Such a study involves a careful analysis of all factors affecting layout. It is an important decision as it represents a long term commitment. It is also important because it affects the flow of materials and processes, labor efficiency, supervision and control use of space and expansion possibilities (Adejuyigbe, 2002).

Plant layout problems are now faced by industry more frequently, owing to a change from mass production towards more flexible manufacturing. A production system must be flexible enough to

permit future changes brought about by production technology or changes in product design (Bazaraa, 1975). After the location of a new plant, the next process is the layout of production facilities and their maintenance. The manners with which materials are moved from one facility to another constitute the master plan, which co-ordinates all aspects of the production system (Ali, 2008).

James and John (1984) reported that layout problems are not peculiar to factory. A manufacturer must position machinery to achieve smooth flow of production through their factories. Whatever volume of output is selected as the most economical, production capacity in terms of sales requirement will determine the amount of investment in land, building, machinery, labor, and equipment. The optimum capacity figure also dictates the pattern of the work-in-process flow and materially affects the cost of labor, supplies, maintenance, and overhead. In short, the layout decision is the crucial point at which sales, finance, engineering, and production must be co-coordinated in order to have a physically integrated production system (Bryon and Cukosky, 1991).

Buffa et al. (1966) observed that in the past, the conventional methods have been used in solving plant layout problems. These conventional methods involve careful determination of the degree of closeness that should exist between departments and degree of closeness that exist between machine in a plant, determination of flow between each department and machine (Lee and Moore, 1967). Designers then resort to graphical technique and template manipulation to evaluate their results subjectively (Hunter, 1983). These methods however are prone to error and could be very tedious.

The crude nature of these methods, which often resulted in the development of substandard and 'expensive to run' layouts made the speedy generation of layouts very difficult if not impossible as human effort involved required a lot of time. However, with the emergence of operation research and the use of digital computers, more analytical-based procedures are now applied in layout development. This trend culminated in what is now known as computer-aided plant layout, which involves using computer programs that assist in generating layouts quickly and comparing them on an objective basis to generate an effective layout with optimum costs

(Altaf, 1995). Though a wide ground has been covered in the field of computerized Plant Layout, software that generates plant layout automatically and compares all layout on the bases of their effectiveness and cost incurred is yet to be developed. This work is therefore an attempt to bridge this gap.

MATERIALS AND METHODS

The method adopted in carrying out this research includes the use of a well-structured questionnaire for information acquisition and also by direct determination of the plant dimensional characteristics, that is, direct measurement of plant facilities, the measurement will cover the area covered by each sections/departments, this includes offices, stores, workshops, and all other work centers. Other investigations cover the degree of closeness that exists between departments/sections, degree of flow of material between departments and degree of relationship between departments, etc.

The data collected from the plant were used to develop computer software that is capable of generating various plant layouts and estimating the daily cost incurred in running the layouts generated.

The areas that were investigated include degree of closeness relationship that exist between departments and machines, degree of flow that exist between departments, area required for each work centers and some other layout planning requirements such as, number of movements, material volume and transportation time and cost.

The problem of closeness relationship was identified and software was developed to eliminate the identified problems.

Mathematical Analysis

The objective function is to minimize the effective distance between departments that have strong activity relationships with each other:

$$\min F = \sum_{i=1}^{n} \sum_{j=1}^{m} G_{ij}\, d\left(k_{i,}h_{j}\right) \tag{1}$$

where,

$-1 \leq G_{ij} \leq 4$ for all set of i relationship with j

n = m

and

i	Department on the column (i = 1…n)
j	Department on the row (j = 1… m)
k	Location of department i
h	Location of department j

$d\left(k_i, h_j\right)$ Rectilinear distance between the centers

of the kth and h^{th} locations for departments i and j (length of the shortest path or the least number of square blocks between two departments as represented in the grid)

G_{ij} Numerical activity relationship rating of

department i and j

F Layout effectiveness value (effective distance relationship between departments)

Solution Procedures

The following are the basic procedural steps that guide the software operation.

Composition of Relationship Priority Codes for $-1 \leq G_{ij} \leq 4$

$$T_{j_m} = G_{1j_m} + G_{2j_m} + G_{3j_m} + G_{4j_m} + G_{5j_m} + ... + G_{n-ij_{m-i}},$$ **(2)**

where, T_j = Total Closeness Relationship Value

for each department (section)

Construction of the Closeness Relationship Value (Activity Relationship Table)

The closeness relationship was developed as shown in Table 1 using the method proposed by Sule (1988).

Table 1: Relationship Priority Codes.

Code	Priority	Value
A	Absolutely necessary	4
E	Especially important	3
I	Important	2
O	Ordinary	1
U	Unimportant	0
X	Undesirable	-1

Generation of Square Blocks for Grid Formation of Each Department (Section)

The area of each department is converted to an approximate number of square blocks, using:

$$B = A/q^2$$ **(3)**

where B is the number of block to be generated for each department (section), A is the area of the department (section) in square meters and q is the block dimension. For the purpose of this research, q = 2, 6, and 6 for office section, production section, and the whole plant layout-generation respectively.

Construction of the Grid

The grid was made up of square blocks generated from each department and obtained from (4):

$$B_t = B_i B_j$$ **(4)**

where B_t is total number of square blocks in the grid, B_i is total number of square blocks on the grid column (length), B_j is total number of square blocks on the grid row (width), $B_t = 13 \times 14,\ 12 \times 4,\ 16 \times 4$ office section, production section, and the whole plant layout-generation, respectively.

Determination of the Layout Effectiveness Value for the Grid Arrangement

The nodal diagram and/or the grid arrangement are varied until the minimum workable effectiveness value (minimum effective distance relationship) is obtained:

$$F = \sum_{i=1}^{n}\sum_{j=1}^{m} G_{ij}d(k_i,k_j), \quad (5)$$

where

$$f_j = G_{ij}d\left(k_i,h_j\right) \quad (6)$$

f_j = distance effectiveness row value

Therefore:

$$F = \sum_{j=1}^{m-1} f_j \quad (7)$$

$$\left(j=1,2,3............................m\right)$$

where,

$$f_{j_{m-1}} = G_{in-1\,jm}d\left(k_{in-1},h_{jm}\right) \quad (8)$$

The grid with the minimum workable effectiveness value (minimum effective distance relationship) is chosen.

Determination of the Relative Cost of Layout to be Generated by the Arrangement

The cost is obtained from the product of the minimum effective distance of travel and the projected transportation cost between departments, where:

R = Relative Cost of layout arrangement
Cij = Projected Transportation cost of setting department i beside j.
$d\left(k_i,h_j\right)$ = Rectilinear distance between the centers

of the k_{th} and h_{th} locations for departments i and j (i.e., length of the shortest path or the least number of square blocks between two departments as represented in the grid).

$$R = \sum_{i=1}^{n}\sum_{j=1}^{m} C_{ij} \times d(k_ih_j) \quad (9)$$

Where $R_j = C_{ij} \times d(k_ih_j)$ (10)

$$R = \sum_{j=1}^{m-1} R_j \quad (11)$$

$$R_{j_{(m-1)}} = C_{i_{(m-1)}j_m} \times d(k_{i_{(m-1)}},h_{j_m}) \quad (12)$$

Note that all the steps above are observed in generating office segment, production segment, and the whole plant layout. A projected transportation cost of ₦100.00, ₦1000.00, and ₦500.00 was used for the office, production, and whole plant sections of the case study.

Software Algorithm

Step 1: Start
Step 2: Specify the relationship priority codes
Step 3: Compute the number of block(s) for each section
Step 4: Specify the relationship value between each section
Step 5: Compute the Total Closeness Relationship value for each section
Step 6: Generate the Nodal Diagram based on the Closeness relationship value
Step 7: Generate Grid
Step 8: Generate Effectiveness Value
Step 9: Generate Relative Cost
Step 10: Generate layout
Step 11: Stop

Flowcharts (Figures 1-6)

The flowchart in Figure 1 shows the security page which consist of the welcome screen and the password verification interface. The flowchart shows that the software is built such that it can reject incorrect password thereby denying unauthorized users access to the software.

The flowchart in Figure 2 shows the display of the main menu which comprises of the set-up menu (here, the set-up information is imputed into the software) and the layout generation menu (here, the layout is generated based on the information imputed into the software).
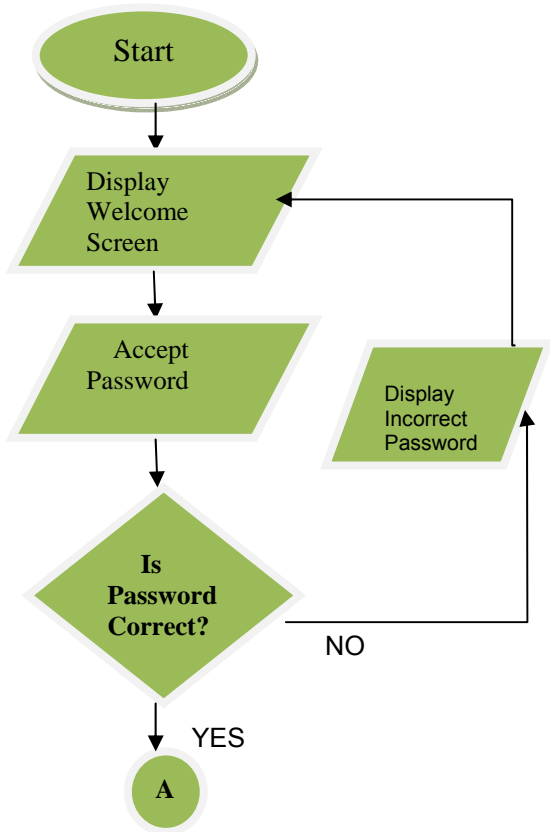
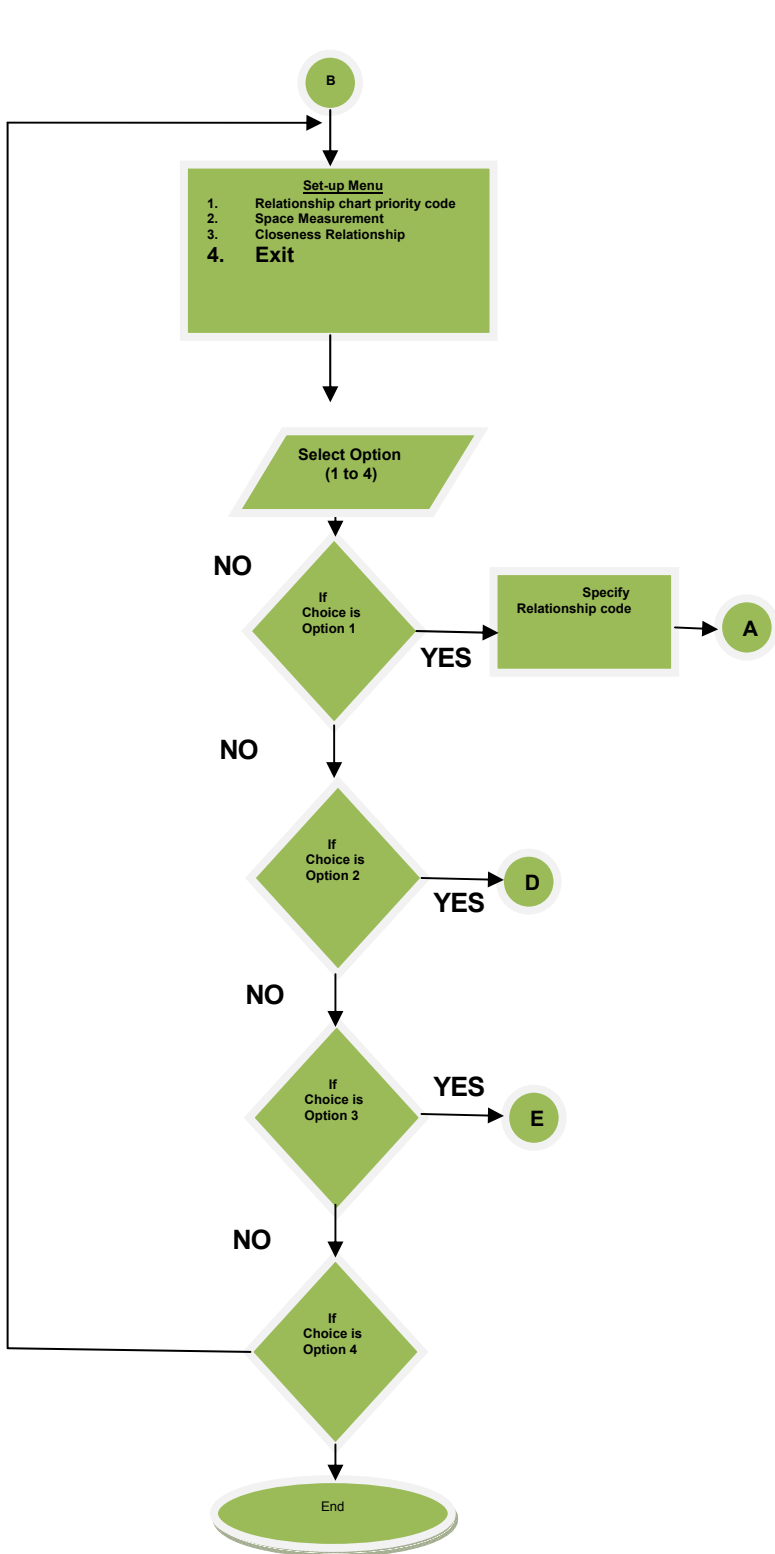**Figure 1:** The Flowchart for the Display of Welcome Screen and Password Verification.
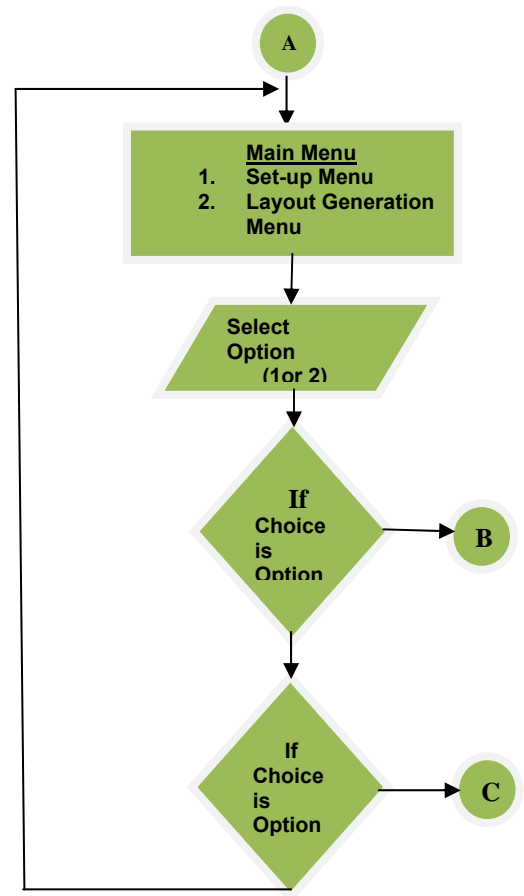
Figure 2: The Flowchart for the Display of Main Menu.

The flowchart in Figure 3 shows the sequence of operations available (sub-menus) under the set-up menu. The sub-menu options available include imputing the relationship chart priority codes, space measurements (from the case study), activity rating closeness relationship (from the case study), and exit. The user can either choose the first three options depending on the information to be imputed or exit.
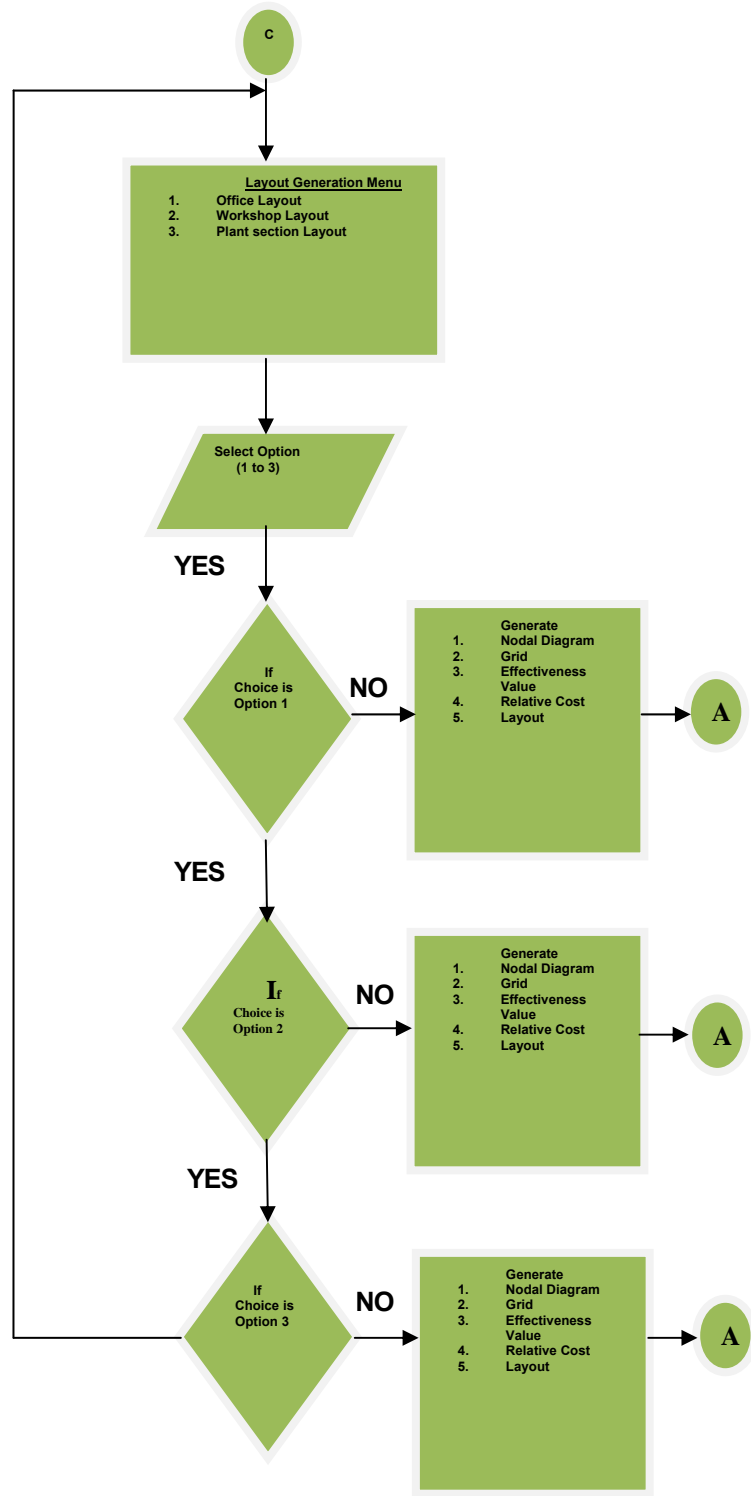
The flowchart in Figure 4 displays the layout under the layout generation menu; the user has three options to choose from as shown. The options include, the layout generation for the office, workshop section, and whole plant. The nodal diagram, grid, effectiveness value, transport cost, and final layout could be generated here.

The flowchart in Figure 5 displays the space measurement, a sub-menu under the set-up menu; the user has three options to select as shown. The options include the space measurement of the office section, workshop section and the whole plant. The figures here can be varied.
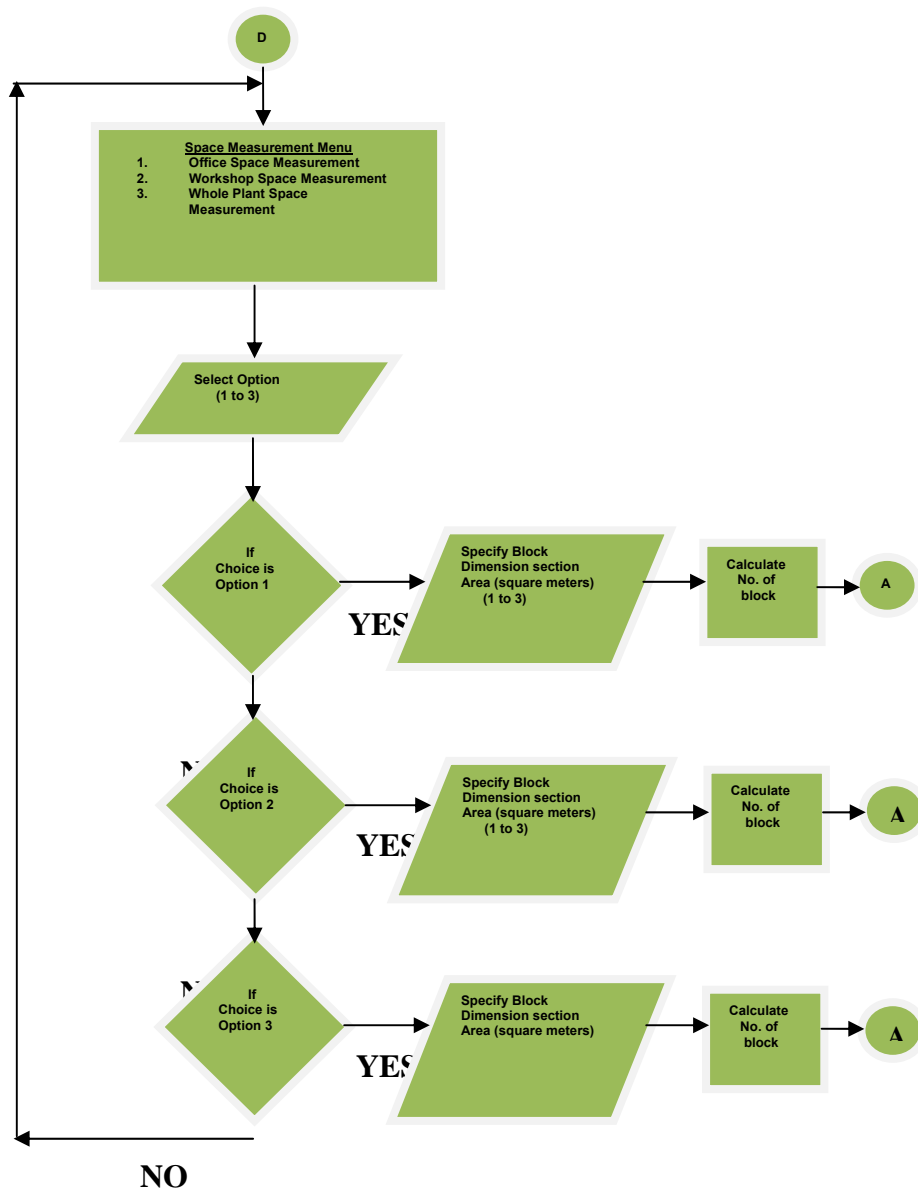
The flowchart in Figure 6 displays the closeness relationship sub-menu, which is under the set-up menu. This contains the closeness relationship values of the office sections, workshop section and the whole plant.
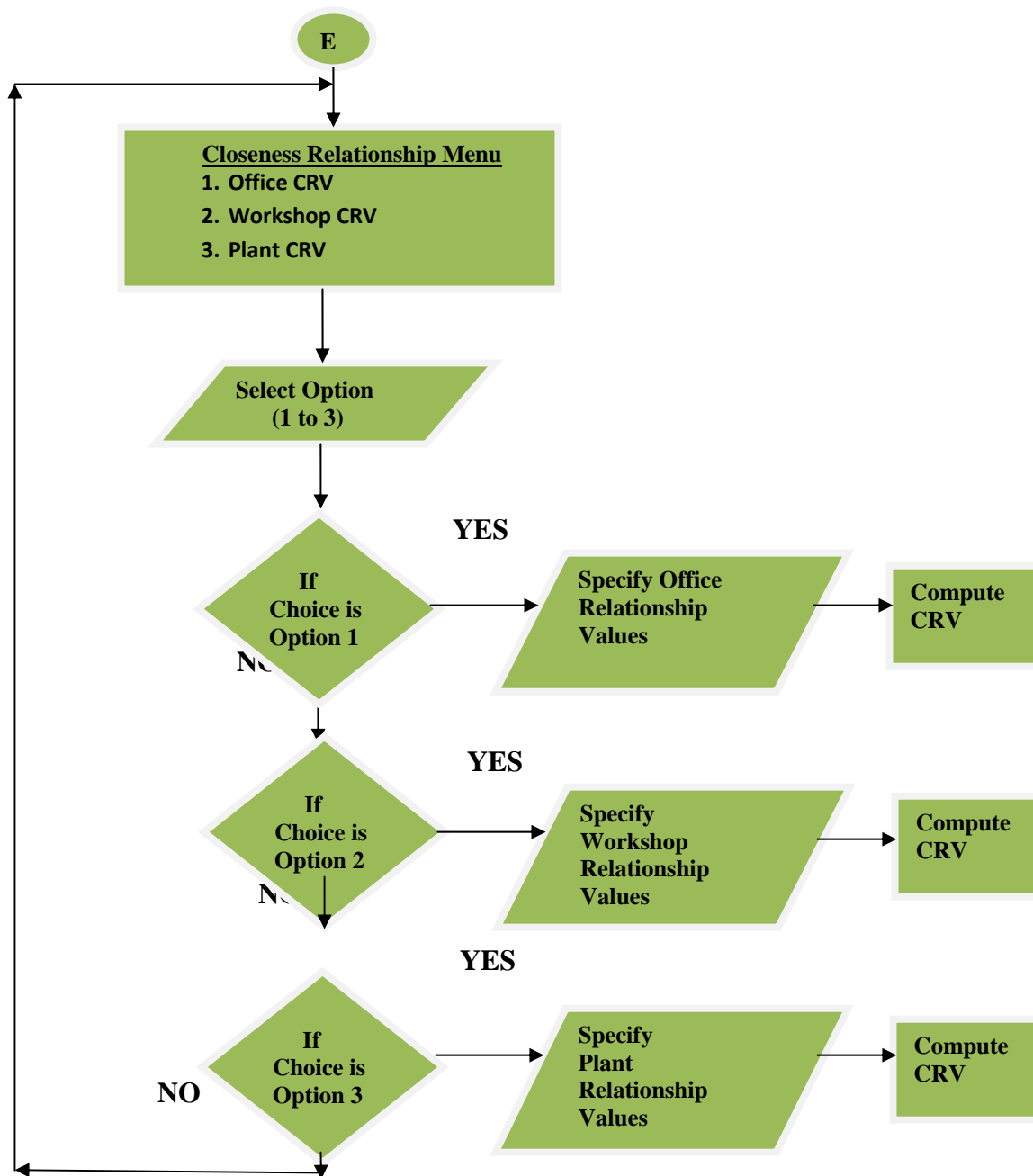
Figure 3

B

Set-up Menu
1. Relationship chart priority code
2. Space Measurement
3. Closeness Relationship
4. **Exit**

Select Option (1 to 4)

NO

If Choice is Option 1 — **YES** → Specify Relationship code → **A**

NO

If Choice is Option 2 — **YES** → **D**

NO

If Choice is Option 3 — **YES** → **E**

NO

If Choice is Option 4

End

Figure 3: The Flowchart for the Display of the Set-up Menu.

Figure 4

C

Layout Generation Menu
1. Office Layout
2. Workshop Layout
3. Plant section Layout

Select Option (1 to 3)

YES

If Choice is Option 1 — **NO** →
1. Generate Nodal Diagram
2. Grid
3. Effectiveness Value
4. Relative Cost
5. Layout
→ **A**

YES

If Choice is Option 2 — **NO** →
1. Generate Nodal Diagram
2. Grid
3. Effectiveness Value
4. Relative Cost
5. Layout
→ **A**

YES

If Choice is Option 3 — **NO** →
1. Generate Nodal Diagram
2. Grid
3. Effectiveness Value
4. Relative Cost
5. Layout
→ **A**

Figure 4: The Flowchart for the Display of the Layout Generation Menu.

Figure 5: The Flowchart for the Display of the Space Measurement Menu.

Figure 6: The Flowchart for the Display of the Closeness Relationship Menu.

RESULTS AND DISCUSSION

The software was run as illustrated by the flowcharts above and the following plate's displays some of the outputs generated by the software. Plate 1 displays the interface for the verification of password.


Plate 1: Password Verification Module.

After the software generates the closeness relationship rating, the software divides the entire departments that makes up the section (office) into nodes and forms a diagram called a nodal diagram and a grid is formed.

Users have the opportunity to interchange nodes as they deem fit if the automatically generated arrangement is not favorable (Plate 3). A click on the next effectiveness value button displays a diagram of the effectiveness value rating of the departmental arrangement (Layout) shown in Plate 2 and the relative cost of this layout (Plate 4).
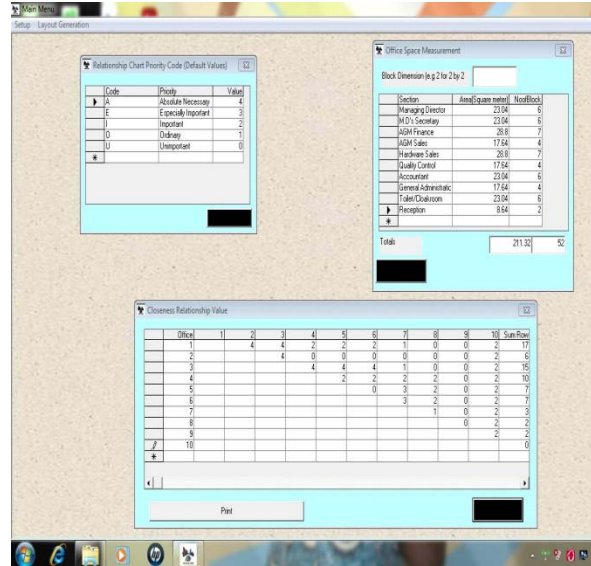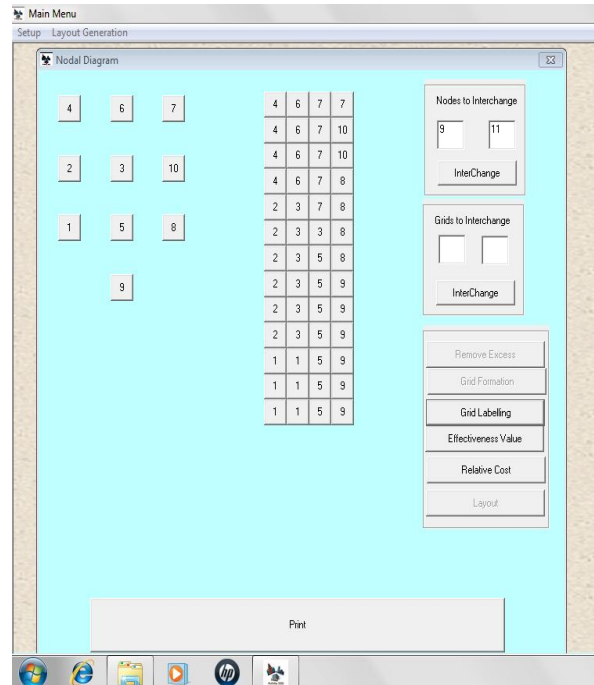

Plate 2: Display of Relationship Priority Codes, Space Dimension, and Closeness Relationship Value for Office Section.
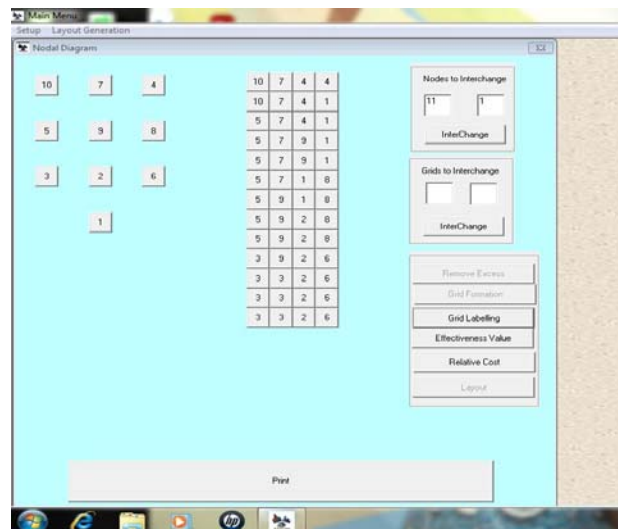
Plate 3: Nodal Arrangement and Grid formation for the layout
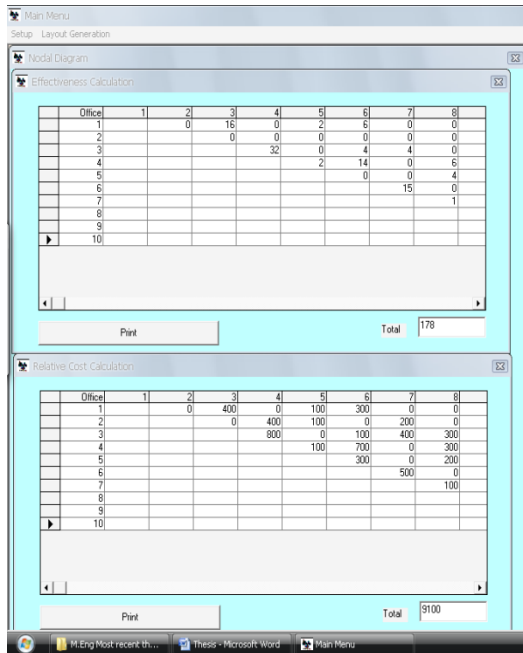
Plate 4: Effectiveness Value and Relative Cost for the Layout of the Case Study (office section) the Case Study (office section).


Plate 5: Nodal Arrangement and Grid Formation for the Alternative Layout Derived by the Software (office section).

The software thereafter generates (suggests) an array of alternative layouts which have different nodal arrangements (layout) and effectiveness/ relative cost values till an optimum effectiveness value/ relative cost combination (which is subjective) is gotten. Plates 5 and 6 illustrate an example.

The software is run in the same format for the production sections and the whole plant layout until an optimum layout is generated.

By comparing the results gotten from the initial layout and the alternative layouts, the results show that the closeness relationship strength has been tremendously improved upon for each case as the transportation costs between from one department to another was greatly reduced in the alternative layout generated.
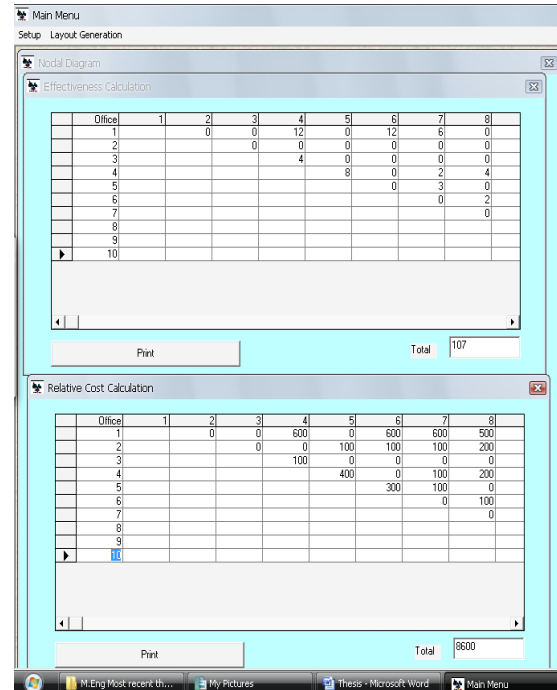
Plate 6: Effectiveness Value and Relative Cost for the Layout of the Alternative Layout Derived by Software (office section).

Tables 2 and 3 show that by adopting the new layout suggested by the software, the effectiveness value for the office section of the case study layout, which was initially 178, can be improved to a new effectiveness value of 107. The relative or movement cost incurred daily in the office section of the case study layout that was initially ₦9,100.00 also can be reduced to ₦8,600.00 thereby saving approximately ₦500.00 daily if the alternative layout arrangement suggested by the software is adopted. In addition, the effectiveness value for the production section of the case study layout, which was initially 138 can, improved to a new effectiveness value of 50 if the alternate layout suggested by the software is adopted.

The relative or movement cost incurred daily in the production section of the case study layout, which was initially ₦65,000.00 also, can be reduced to ₦32,000.00 thereby saving ₦33,000.00 daily if the alternative layout arrangement suggested by the software is adopted. The effectiveness value for the whole plant section of the case study layout, which was initially 32 can improved to better effectiveness values for layout arrangements as suggested by the software. However, a layout arrangement of effectiveness value of 32 is selected because this layout arrangement will save more costs as the relative cost will reduce from a value of ₦16,500.00 to ₦15,500 thereby saving ₦1,000.00 daily should the alternate layout suggested by the software be adopted.
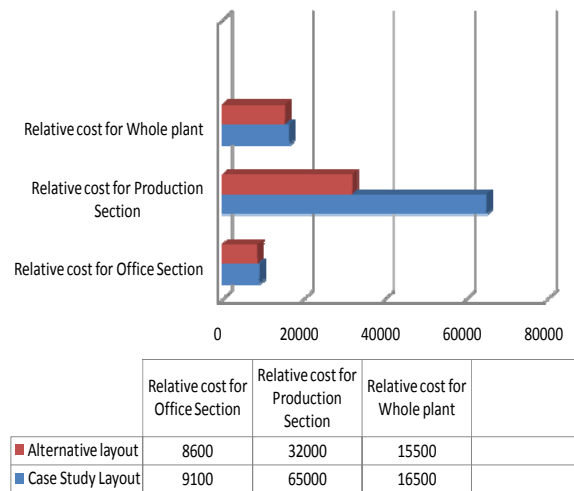
Table 2: Comparison of the Effectiveness of the Case Study Layout with that of the Alternative Layout Generated by the Software.

Section	Effectiveness Value	
	Case study layout	Alternative layout generated from software
Office	178	107
Production	138	50
Whole plant	32	32

Table 3: Comparison of the Relative Cost of Case Study Layout with that of the Alternative Layout Generated by the Software.

Section	Relative Cost Value	
	Case study layout	Alternative layout generated from software
Office	=N= 9,100.00	=N= 8,600.00
Production	=N= 65,000.00	=N= 32,000.00
Whole plant	=N= 16,500.00	=N= 15,500.00

Figure 7 further describes graphically the reduction in costs possible if the alternate layout arrangements suggested by the software are adopted. Though not much difference is seen in the office and whole plant sections of the factory, a significant cost is saved in the production section of the factory. Summarily, it can be seen as shown in Table 4 that about ₦500.00, ₦33,000.00 and ₦1,000.00 can be saved in the office, production, and whole plant sections respectively on a daily basis. When summed, about ₦34,500.00 can be saved daily which results in about ₦9,108,000.00 being saved annually if the alternate layout arrangements suggested by the software is adopted.

	Relative cost for Office Section	Relative cost for Production Section	Relative cost for Whole plant	
Alternative layout	8600	32000	15500	
Case Study Layout	9100	65000	16500	

Figure 7: Chart Showing Initial Costs and Final Costs Incurred by using Alternative Layout from Software.

From the results obtained from the study, the distance effectiveness value and relative cost for the alternative layout generated, compared to that of the case study were reduced. This implies that the rectilinear distance between departments having higher activity relationship, in each case had been reduced. Generally, the results shows that cost can be reduced relatively using the software to generate alternative layouts that maximizes closeness between departments. The software is able to identify the inherent closeness relationship problem in the layout of the case study and eliminate such problems in the alternative layouts it generates by minimizing the rectilinear distances between departments having higher activity relationships. The alternative layout generated by the software is therefore more efficient and cost effective than the case study layout since material movement and personnel movement reduced.

Table 4: Costs Comparison Table.

Section	Cost saved per day (₦)	Cost saved per month (₦)	Cost saved per annum (₦)
Office	500.00	11,000.00	132,000.00
Production	33,000.00	726,000.00	8,712,000.00
Whole Plant	1,000.00	22,000.00	264,000.00
TOTAL	34,000.00	759,000.00	9,108,000.00

Plates 7 and 8 show the initial layout of the case study and alternative layout which when adopted saves the above mentioned costs.
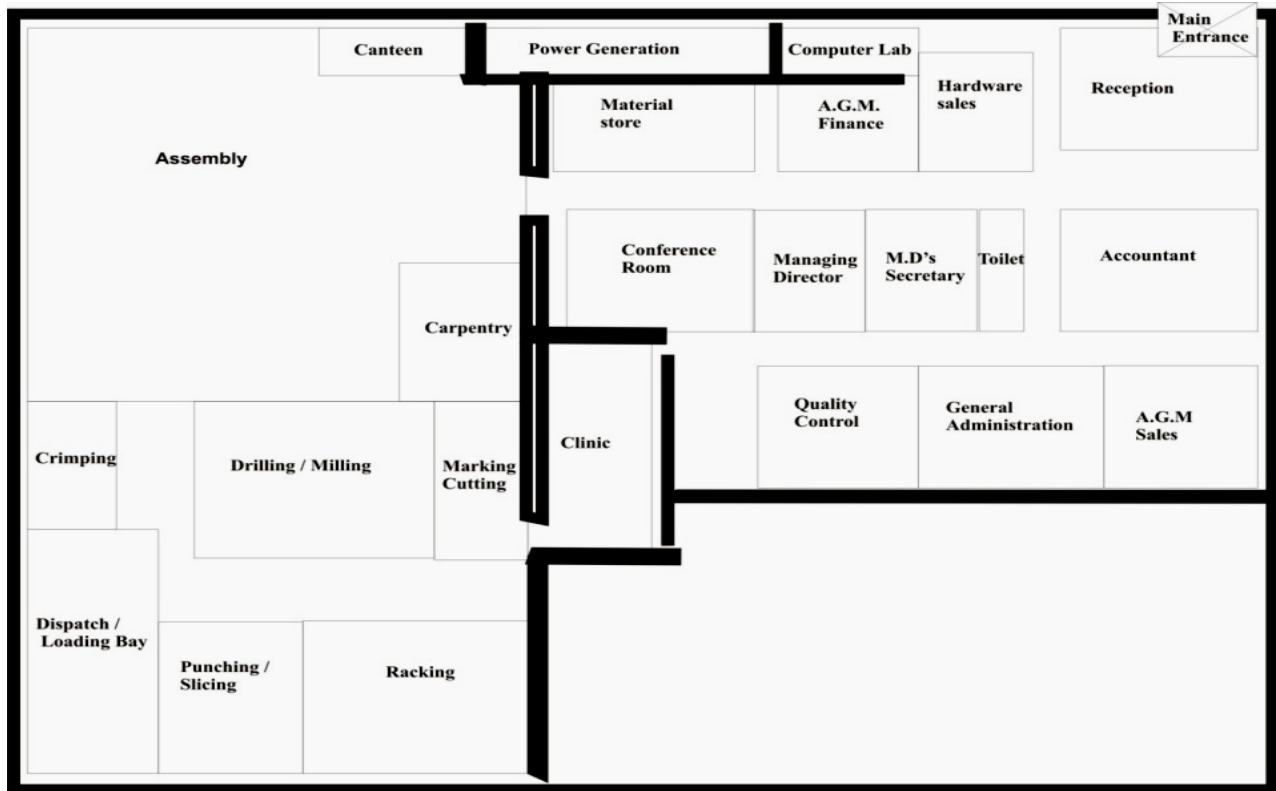
Plate 7: Initial Layout of the Company.
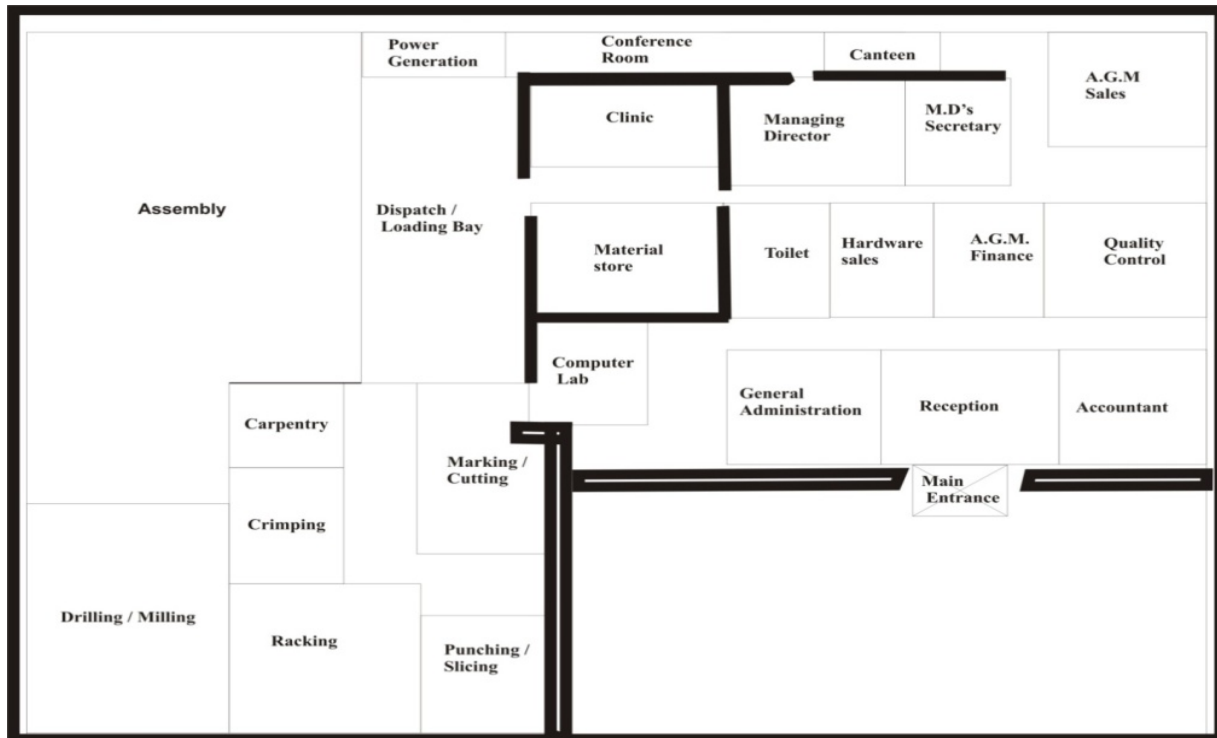
Plate 8: Proposed Layout for the Company.

CONCLUSION

The results gotten from the application of the software "AUTOLAY 2010" developed during this research work clearly shows that the use of computer-programmed software in aiding plant layout planning is the best tool for achieving the objectives of plant layout. The use of the software developed during this research work also helps ensure better working environment, reduces lost hours due to unnecessary transportation within work centres, maximize communication, and most importantly ensure high work efficiency and productivity by the reduction of costs. It is recommended that the procedures adopted in the software "AUTO LAY 2010" be used in aiding plant-layout planning in the manufacturing sector of the country as this will enhance productivity and thus bring about technological advancements in the nation.

It is also recommended that this software be made readily available to manufacturing industries especially small and medium scale enterprises as this will bring about increased production and thus greatly improve the economic situation of the nation.

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ABOUT THE AUTHORS

T.S. Ogedengbe, was a Masters Degree student in the Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta. He graduated with a Bachelors Degree in Mechanical Engineering. His research interests are in industrial engineering.

Dr. S.O. Ismaila, is a Senior Lecturer in the Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta. He holds a Ph.D. degree in Industrial Engineering and currently serves as the Deputy Dean of College of Engineering. His research interests are in the areas of ergonomics, safety engineering, operations research and industrial engineering.

Dr. S.B. Adejuyigbe, is a Professor of Mechanical Engineering with specialization in Computer Aided Design. He is a Lecturer in the Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta. He is currently the Dean of College of Engineering, Federal University of Agriculture, Abeokuta.

Dr. B.A. Adewumi, is a Professor of Agricultural Engineering and a Lecturer in the Department of Agricultural Engineering, Federal University of Agriculture, Abeokuta. He is currently the Head of Department.

D.M. Ali, is a Ph.D. student in the Department of Mechanical Engineering, Federal University of Agriculture, Abeokuta.

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