APPLICATION OF COMPUTERIZED RELATIVE ALLOCATION OF FACILITIES AND ANALYTIC HIERARCHY PROCESS MODELS FOR FABRICATION YARD LAYOUT OPTIMIZATION

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Abstract

Location and layout are major operational issues that can be major threat to development. They can also threaten the survival of any business organisation. The reason is that they have a long, if not an extensive implication on cost of operations and competitiveness of any firm. Other than facilities being the major assets of an organisation, their arrangement has the tendency of improving overall operations and can significantly reduce total operating cost by as much as say 50%. The main concern of the present study is to demonstrate how Computerized Relative Allocation of Facilities (CRAFT) and Analytic Hierarch Process (AHP) can be applied to solve the problem of layout facility at Ladol Fabrication Yard in Lagos, Nigeria. To optimize the existing layout at this yard, the CRAFT algorithm is carried out by using an MS Excel add-in for generating alternatives in the Facility Layout Design (FLD). Likewise, AHP is done by using commercially available software. Super Decisions were also used to evaluate the alternatives in FLD, based on two qualitative and quantitative criteria. The secondary data mainly served as tools for computing the material handling costs and personnel flow for each alternative FLD. In all, there were 162 respondents. These generated data in the form of pairwise comparisons that is required by AHP methodologies. After this, geometric mean was used to categorise various responses for analysis. Test for consistency and sensitivity analyses were then done to ensure a deep and reliable judgment. Sensitivity analysis revealed that there are moderate changes in the weight values of the safety and flexibility criteria. The study's recommendation therefore is that AHP should be adopted by oil and gas servicing companies to evaluate alternative FLD, so as to guarantee a systematic and efficient way of solving problems associated with facility layout.

Keywords: Computerized Relative Allocation of Facilities (CRAFT), Analytic Hierarchy Process (AHP), Facility Layout Design, Optimization, Fabrication yard, Expert opinion.

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1. Introduction

The layout design adopted in any facility plays a major role in the attainment of goals and objectives set of an organisation. It goes without saying that different layouts are designed to achieve different purposes, simply because decision makers are usually faced with varying situations which require them to design and select a single layout that best suits the needs of an organisation, both in the short and long term. As such, the type of layout adopted in construction sites, production plants, and fabrication and assembly yards may be different, depending on the criteria to be satisfied. It is therefore important to clearly identify the type of layout and the criteria to be satisfied in advance, before layout design begins. This is in view of the fact that they play a central role in mapping out how efficacious is the final layout.

To Huang and Wong (2015), there is a high tendency that big construction projects would need to set up different construction site facilities – site offices, storage areas, different workshops, etc – within an area to undertake various construction activities. The number and sizes of these facilities must be determined well in advance after considering the processes they are meant to serve. Failure to properly organize these facilities could result in an inefficient layout which usually requires a lot of funding, time and human resources to modify. It then means that an efficient planning of layout of a construction site is central in achieving any successful project. It, in fact, has a significant impact on finances, safety, and other aspects, particularly for huge construction projects (Hamiani & Popescu, 1988; Jiuping & Zongmin, 2012). In the Oil and gas industry, fabrication and assembly yards are designed to handle a variety of tasks, ranging from construction activities, through fabrication of component parts of a job to assembly of large facilities. Such tasks may include: the fabrication and assembly of Floating Production Storage and Offloading (FPSO) vessels, Floating Liquefied Natural Gas (FLNG) vessels, Tension Leg Platforms (TLP), oil drilling rigs, and other facilities used in the production, processing and/or storage of crude oil and natural gas. These are very complex and high risk tasks which require heavy machinery, both of the movable and immovable types. Thus, a fabrication yard uses a combination of permanent and temporary facilities, because of the nature of activities it is designed to handle. This gives rise to a layout design problem which is both dynamic (due to the changing availability and use of space) and static (due to the requirement for permanent facilities and equipment). On the other hand, it involves satisfying multiple objectives such as personnel safety, flexibility, minimization of material handling distance (and costs), and personnel flows.

Therefore, the layout problem can be viewed as a multi-objective facility layout problem (MOFLP), which can be solved using appropriate models such as Analytic Hierarchy Process (AHP). The commonest method in selecting the layout to be implemented begins with generating viable alternatives with a set of criteria that are clearly identified. This is then closely followed by a form of analysis to determine the alternative that is most suitable. Thereafter, the process of implementing the selected layout can begin.

There are many techniques for generating facility layouts. Some are well-known computerized techniques, like Computerized Relationship Layout Planning (CORELAP) developed by Lee and Moore (1967), Automated Layout Design Program (ALDEP, developed by Seehof and Evans (1967), Plant Layout Analysis and Evaluation Technique (PLANET), Computerized Relative Allocation of Facilities (CRAFT), developed by Armour and Buffa (1963), and Multi-floor Plant Layout Evaluation (MULTIPLE). They are basically divided into two categories, known as construction and improvement algorithms. Construction algorithms are used to generate new layouts from scratch and include: CORELAP, ALDEP and PLANET. On the other hand, improvement algorithms are used to generate layouts from previously existing layouts. Thus, they are used when the focus is to make improvements on already existing layouts, and include: CRAFT and MULTIPLE.

After the alternative layouts have been generated, it then leaves decision makers with the responsibility to select the best alternative that satisfies most of the criteria in meeting up with goal. A common approach is to use the AHP technique, as developed by Saaty (1980) to modeling a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives; where the goal is at the top of the hierarchy, followed by the criteria and sub-criteria (if required), and finally, the alternatives occupy the lowest level. It uses pairwise comparison in determining the relative importance of each alternative in terms of each criterion. Using Saaty's scale of relative importance, the alternatives are compared in twos, with respect to each criterion to generate a matrix of performance values known as judgement matrix for each criterion. Similar comparisons are made for the criteria with respect to the overall goal. Finally, priority vectors from each judgement matrix are combined to form the decision matrix from which the final priority vector is obtained. The final priority vector ranks the alternatives from the most suitable alternative to the least suitable one.

Some serious studies have taken into consideration the multi-objective facility layout design problems by looking at the static and dynamic layouts, while some have applied the techniques (CRAFT and AHP) in isolation. So far, there has been no study that has combined the techniques for layout design problem, particularly in oil and gas fabrication yard. This study adds to existing literature on the subject matter, while exploring the peculiarities of oil and gas fabrication yards in Nigeria.

Ladol Fabrication Yard is a facility which was built such that fabrication and assembly of oil and gas facilities and systems can be successfully carried out. The facility covers a total floor area of one hundred and forty-two thousand (142,000) square meters, and has twenty-three (23) main activity areas and departments that are used for and support diverse aspects of fabrication and assembly processes. It is relatively smaller in size, compared to other facilities of its kind in Nigeria. As such, space management was a critical factor in its design, with the main objective of ensuring that adequate space was allocated to the twenty-three activity areas, while maintaining appropriate material handling throughout the yard.

Although, space management was a key factor in the design of the layout, the yard is currently characterized by frequent movement of materials throughout the yard. Storage areas have been relocated so many times to accommodate unforeseen space constraints , a situation that has resulted in materials being stored in multiple locations throughout the yard, making it difficult at times, to assemble tools and materials required for similar tasks. Again, because of the risks involved in the handling of materials and sub-assemblies weighing as much as 500Tons, this has given rise to increased safety concerns, high cost of material handling, increased cost of maintenance of material handling equipment (such as cranes, forklifts, and flat beds) and increased personnel flows.

In response to these problems, a layout optimization and selection procedure, which serves as a guide to making modifications on the yard to accommodate the issues raised is therefore needed. Further, one needs to identify the determinants of an efficient fabrication yard layout; so that necessary improvements can be made before a layout design is implemented, therefore making the present study stimulating and worthwhile.

2. Literature Review

2.1 Theoretical Framework of CRAFT Algorithm and AHP Model

Decision making is an integral part of any organisation that strives to survive in the business environment. It can be mono-objective or multi-objective in nature, depending on the area of application. However, Bhushan and Rai, (2004) opine that single-criterion and simple decision-making requirements of previous years have given way to today's highly complex, multi-faceted, dynamic and far-reaching business environment. An abundance of theories exist that can be used to solve such multi-criteria decision making (MCDM) problems, and these include: AHP, TOPSIS, and goal programing.

Furthermore, one key aspect of decision making which manufacturing and service companies must pay attention to is the choice of facility layout design. This is because facilities are important to organisations, since they usually represent an organisation's major asset (Mulugeta, Beshah, & Kitaw, 2013). A proper arrangement of facilities contributes to the overall efficiency of operations and can reduce the total operating expenses by as much as 50% (Drira, Pierreval, & Hajri-Gabouj, 2007). In addition, a good layout presents safe workplace for employees, and increases employees' morale, minimizes risk of injury to personnel and damage to property (Cheong, 2002). This has led to the development of a number of algorithms and computer programs to aid in the design and optimization of facility layouts. Some of the most popular of these algorithms/computer programs are: CRAFT, CORELAP and ALDEP (Cambron, & Evans, 1991).

This study involves the application of CRAFT algorithm and AHP model to optimize the layout design at Ladol Fabrication Yard, Lagos, Nigeria. The theories behind these approaches are equally discussed.

2.1.1 Computerized Relative Allocation of Facilities Technique (CRAFT)

Developed by Armour and Buffa (1963), CRAFT is a heuristic model for minimizing transportation costs when presented with flow data. According to them, the main aim of CRAFT is to determine a choice of departments' locations within the facility. This minimizes incremental costs that are affected with changes in location patterns such as material handling costs. To this end, departments with high interaction should be located close to each other, while those with fewer interactions should be placed farther apart. However, it is important to note that material handling cost is not just a function of distance and number of trips between departments alone. Other factors that influence handling cost include: the cost of moving the material handling equipment per unit distance, the number of personnel involved during such movements, and the availability of appropriate material handling way throughout the facility.

Cambron and Evans (1991) note that CRAFT accepts as input an initial layout, a from-to chart containing the projected number of loads per unit time to be moved between each pair of departments, and the cost per unit of distance moved. With this in place, the algorithm attempts to reduce the projected material movement costs by two-way or three-way exchanges among department locations with the objective of minimizing the material flow costs. For each departmental interchange, it calculates the total material flow cost and compares it to the total costs of the previous layout. If the cost of the new layout is greater than the previous one, it will not accept the new layout, but will continue the iteration process until a layout with the least material flow cost is generated. CRAFT has as its basis a Quadratic Assignment Problem (QAP) formulation of the block layout design problem.

Amour and Buffer (1963) conceptualized the CRAFT theory using mathematical notations. They considered a problem of assigning location to departments in a manufacturing plant in such a manner that an objective function (total materials flow costs) is minimized.

Let: n = the number of departments

v_{ij} = the number of unit loads moving between department i and j

u_{ij} = the cost to move a unit load a unit distance between departments i and j

l_{ij} = the distance between the centroids of departments i and j

y_{ij} = the cost to move the total load flow between departments i and j a unit distance between the two departments

As long as all $u_{ij} \in U$, $v_{ij} \in V$, and $y_{ij} \in Y$ are known and constant with changes in locations, we can say that:

$$y_{ij} = u_{ij} \times v_{ij} \quad \ldots\ldots\ldots\ldots\ldots \quad 2.1$$

In matrix form, this is:

$$Y = \begin{pmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ y_{n1} & y_{n2} & \cdot\ \cdot & y_{nn} \end{pmatrix}$$

In the same vein, a matrix of the distance between departmental centroids is:

$$L = \begin{pmatrix} l_{11} & l_{12} & \ldots & l_{1n} \\ l_{21} & l_{22} & \ldots & l_{2n} \\ . & . & & . \\ . & . & & . \\ . & . & & . \\ l_{n1} & l_{n2} & \ldots & l_{nn} \end{pmatrix}$$

The cost of any particular relative location pattern or layout is:

$TC_o = TC/2$, where

$$TC = \sum_{i=1}^{n} \sum_{j=1}^{n} y_{ij}\, l_{ij} \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.2$$

Subject to $l_{ij} = 0$ and $y_{ij} = 0$, where i = j. This is equivalent to saying that all main diagonal elements of the symmetric L and Y matrices are zero.

Equation (2.2) is the objective function which the layout algorithm seeks to minimize. The CRAFT algorithm accomplishes this by following a six step iteration process which can be described as follows:

1. Compute a matrix, L, of distances between computed department centroids for the first feasible initial layout
2. Compute the Y matrix
3. Evaluate changes in TC, ΔTC, which would occur if each department was exchanged with all other departments in location. Find the largest ΔTC.
4. If no positive ΔTC_{ij} exists, go to step 6. If a positive ΔTC_{ij} exists, make the exchange corresponding to the largest positive ΔTC_{ij} found during step 3. Re-compute L. Print the new location pattern and associated cost and move identifying information.
5. Go to step 3.
6. Stop. The sub-optimum has been reached.

The CRAFT algorithm is used in this study to optimize the existing layout at Ladol Fabrication yard, Lagos, Nigeria; a process that yields alternative layouts from which the most suitable one is selected and proposed for implementation.

2.1.2 Analytic Hierarchy Process (AHP)

The AHP is a decision support tool which was developed by Saaty (1980) to aid in solving complex decision problems. Adebiyi, Oyatoye, and Kuye (2015) described it as multi-criteria decision analysis methodology that allows both objective and subjective factors to be considered in the decision-making process. That is, it makes it possible to incorporate qualitative attributes (which are based on human judgement) with quantitative attributes (which can be measured, counted, etc.) in one decision making model, and thus presents the decision maker with a holistic view of the problem at hand.

AHP is based on a mathematical framework formed by matrix and vector algebra that can easily be performed in Microsoft Excel (Kizil, Abdalla, & Canbulat, 2014). For more complex analysis, software packages such as Expert Choice and Super Decisions have been developed to assist in handling the mathematical analysis. In using the AHP to model a problem, it is essential to follow the basic guidelines which are captured in the following steps (Saaty, 1987; Fariborz, Partovi, & Burton, 1992):

1. Describe the complex decision problem as a hierarchic structure. This is an application of the principle of decomposition.
2. Use pairwise comparisons to estimate the relative importance of the various elements on each level of the hierarchy. A process that applies the principle of comparative judgement.
3. Integrate the pairwise comparisons to develop an overall evaluation of decision alternatives. This step is the principle of synthesis of priorities.

The first step involves building a structure that starts with the goal or main objective of the decision making process at the top of the hierarchy which could be seen as Level 1. The main criteria and sub-criteria (if required) are placed at the lower consecutive levels (Level 2, 3…), with the alternatives at the lowest level of the hierarchy. The second step involves comparing two lower level elements of the hierarchy at a time with respect to their importance to the next and higher element. This process starts from the top where the main criteria are compared in twos against the main goal, to the bottom of the hierarchy where the alternatives are compared against the criteria (sub-criteria if present in the structure). Finally, the last step involves deriving relative weights for the various elements and determining the composite weights of the decision alternatives. This results in a normalized vector of the overall weights of the options, which represents a ranking of the alternatives from the most suitable to the least suitable.

2.2.2 Layout Optimization Techniques

Optimization refers to the process of finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones (Business Dictionary, n.d.). In FLP, the expected outcome of layout optimization is an improved layout in terms of the objectives being optimized. It is a process that can run either during the planning phases or the modification phase of the FLP. Some layout optimization techniques that have been used by various scholars include: Binary-Mixed-Integer-Linear Programme (BMILP) optimization technique (Huang & Wong, 2015; Patsiatzis & Papageorgiou, 2002); SLP (Chen, Liu, Huang, Lai & Li, 2016; Shahin & Poormostafa, 2011), Multi-Objective Particle Swarm Optimization (MOPSO) algorithm (Xu & Li, 2012), Goal Programming (Osman & Georgy, 2005), Genetic Algorithm (GA) technique (Azadivar & Wang, 2010; Aiello, La Scalia, & Enea, 2012) and CRAFT (Hedau & Sharma, 2016; Cambron & Evans, 1991; Mulugeta *et al*, 2013).

2.2.3 Computerized Layout Techniques

Plant layout design and optimization requires diverse field of knowledge such as architecture, safety, mathematical modelling and use of computers. Thankfully, the advent of computerized layout techniques has helped to make the process both faster and easier, because the computer can perform tedious computations and generate several alternative solutions much more rapidly and effectively than manual procedures (Mulugeta *et al*, 2013). The available computerized layout techniques are heuristic models and include: Computerized Relative Allocation of Facilities Technique (CRAFT), Computerized Relationship Layout Planning (CORELAP), Automated Layout Design Program (ALDEP), Computerized Facilities Design (COFAD), Multi-floor Plant Layout Evaluation (MULTIPLE), BLOCPLAN, Layout Optimization with Guillotine Induced Cuts (LOGIC) and Plant Layout Analysis and Evaluation Techniques (PLANET).

These algorithms are generally split into the construction and improvement types. The construction type layout routines generate a block layout based on the relationship between different departments and include CORELAP, ALDEP and COFAD (Mulugeta *et al*, 2013). On the other hand, improvement-type routines require an input of a pre-existing block layout and aim to reduce material handling cost by attempting simultaneous pair-wise position exchanging among the departments. CRAFT and MULTIPLE are examples of this type. Yet, a third kind of algorithm exists which incorporates both the features of the construction type and the improvement type such as BLOCPLAN and LOGIC.

2.2.4 Fabrication and Assembly Yards

In the oil and gas industry, a fabrication yard refers to any facility that can handle large scale fabrication of component parts for oil and gas facilities such as refineries, Floating Production Storage and Offloading (FPSO) vessels, Tension Leg Platforms (TLP), drill rigs, ships, etc. Beyond fabricating these component parts, a fabrication yard should also be able to handle integration (also known as assembly) of large numbers of these parts either in modules or as a complete facility built from ground-up. This is why they are mostly referred to as fabrication and assembly yards.

The FLP in fabrication yards combines the characteristics of static and dynamic construction site layout problems. In static construction site layout problems, the facilities serviced in the different construction phases in accordance with the requirements of the construction work during the whole progress of a construction project are assumed to be the same (Xu & Li, 2012). The reverse is the case in the dynamic construction site layout problems. The static nature of the fabrication yard is reflected by the requirement for workshops in the yard which require installation of permanent and immovable equipment like lathe machines, drilling and boring machines, cutting machines, and overhead cranes; and permanent facilities such as blasting and painting workshops, assembly shops, gas stations and radiation bunkers. Construction site nature of the yard is reflected by the need for movable cranes, assembly of large blocks weighing as much as 500Tons, heavy lifting activities, and need for temporary storage and/or quarantine areas; all creating a changing availability and use of floor space. Thus, the FLP in a fabrication yard is partly dynamic and partly static in nature.

On the other hand, a lot of factors are considered in the design, implementation, use and modification of fabrication yards. Beyond costs, material handling, equipment and personnel flow mentioned earlier, two very important factors that decision makers have to take note of are safety and flexibility. Others include good space utilization, effective supervision, security, aesthetics and noise control (Cambron & Evans, 1991; Shang, 1991; Singh & Singh, 2011).

Therefore, the layout problem in a fabrication yard can be treated as a multi-objective facility layout problem (MOFLP) which is partly dynamic and partly static in nature.

3. Research Methods

3.1 Research Design

A case-based research methodology was chosen for this study. The aim is to provide an example of practice. It is also to test the proposition that the combination of CRAFT algorithm and AHP model is an appropriate technique to solve layout optimization and decision making problems in oil and gas fabrication yards in Nigeria. The case-based research method is an empirical inquiry that investigates a contemporary phenomenon within its real life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used (Soy, 1997; Yin, 1984). This method involves focusing on a single case, and has been criticized frequently because it has been found to be incapable of providing general conclusion to similar scenarios (Tellis, 1997). However, it continues to thrive in many disciplines through carefully planned and crafted studies of real-life situations, issues, and problems. The case study adopted in this research is not representative, but exemplary. The researcher does not need to assume that what is observed is truly representative of all similar situations (Stuart, McCutcheon, Handfield, McLachlin & Samson, 2002).

The case study selected to show the applicability of the CRAFT-AHP technique to the FLP is the facility layout design at Ladol Fabrication Yard, Lagos, Nigeria. Twenty three (23) activity areas and departments make up the yard along with the necessary material handling ways throughout the facility. The fabrication yard covers a total floor space of one hundred and forty-two thousand, (142,000) square meters. It has an L-shaped layout, and includes a quay wall where large vessels can berth. This information has been sourced from the company documents database and is used in this work to achieve the set objectives. However, for easy optimization, the layout has been presented in a block form in such a way that material handling ways throughout the fabrication yard has been assigned to individual activity areas. For example, the material handling way between Contractor Office and Piping Shop was assigned to the Contractor Office in the block layout. This block layout serves as the first alternative in the selection process adopted in this study and is designated “Layout Design 1”.

Upon collection of relevant data, CRAFT algorithm is employed to optimize the existing layout, in a bid to minimize the material handling cost on the yard. To achieve this, the algorithm requires as input the flow and cost matrices. The flow matrix shows the number of trips between each pair of departments, while the cost matrix shows the unit cost of transporting materials in the yard per unit distance. The algorithm is implemented with the aid of a Microsoft Excel add-in developed by Jensen and Bard (2004). The program assigns the number of cells for each activity area in the MS Excel spread sheet according to the scale selected. A scale of 'one cell represents $100m^2$' has been chosen to represent the total floor space on the yard. Therefore, we have a total of 1,452 cells depicting the entire floor space available in the facility. The existing arrangement is fed manually into the add-in mimicking the actual relative positioning of the activity areas. The algorithm determines the centroids of the activity areas and calculates the total material handling cost automatically using the formulas:

$$y_{ij} = u_{ij} \times v_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.1$$

$$TC = \sum_{i=1}^{n} \sum_{j=1}^{n} y_{ij}\, l_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where:

v_{ij} = the number of unit loads moving between department i and j. That is, the load flow matrix.

u_{ij} = the cost to move a unit load a unit distance between departments i and j

y_{ij} = the cost to move the total load flow between departments i and j a unit distance between the two departments;

l_{ij} = the rectilinear distance between the centroids of departments i and j; and

TC = Total material handling cost

To generate improved layout designs, the algorithm runs a series of iterations, which involves swapping departments of identical sizes or two adjacent departments. It calculates the total handling cost for each iteration output and compares it to the previous output to determine how much cost is reduced. This process continues until the algorithm can no longer find iterations that result in further transportation cost savings; after which it stops and yields an output layout design. The layout design generated solely by the CRAFT algorithm is designated as "Layout Design 2". After performing the optimization process with the CRAFT algorithm, the output layout design from the algorithm is further modified manually to cover other issues such as safety requirements, shape of the departments, and process flow requirement which the algorithm cannot explicitly handle. The alternative layout design resulting from this modification is designated "Layout Design 3".

Further, the MS Excel add-in is used to calculate the total personnel flow for each alternative layout design. Personnel flow is total distance travelled by personnel on the yard. The flow matrix in this case represents the number of interdepartmental trips made by personnel in the facility, and is referred to as the personnel flow matrix. The total personnel travel distance for each layout design is calculated using variations of Equations 3.1 and 3.2, and are given by:

$p_{ij} = q_{ij} \times r_{ij}$ ……………………..…3.3

$$TD = \sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij}\, l_{ij} \quad \text{……………………} \ 3.4$$

Where:

q_{ij} = the number of personnel trips between department i and j. That is, the personnel flow matrix;

r_{ij} = the cost for one person to travel a unit distance between departments i and j

p_{ij} = the cost for personnel to travel between departments i and j a unit distance between the two departments;

l_{ij} = the rectilinear distance between the centroids of departments i and j; and

TD = Total distance covered by personnel

However, the unit transportation cost (r_{ij}) between pairs of departments is set to unity with the assumption that it costs ₦1 for each worker to walk 1 meter between departments i and j. This was done to ensure that the unit transportation cost has negligible impact on the value obtained for the total distance travelled. Therefore, for every q_{ij}; with $r_{ij} = 1$;

$p_{ij} = q_{ij} * 1 = q_{ij}$

$p_{ij} = q_{ij}$

The next step of the technique proposed in this study involves the application of AHP model as a decision making tool to select from among the available alternative layout deigns. AHP is implemented with the aid of a commercial software tool, Super Decisions, developed by William, Adams and Saaty in 1999 (Saaty, 2016). A hierarchical structure of three levels is developed to model the decision making problem. This structure consists of the overall goal at the top of the hierarchy, the set of criteria at the second level, with the alternatives at the third and lowest level of the hierarchy. The criteria are safety, flexibility, personnel flow and equipment flow. The alternatives are compared in pairs with respect to each criterion, while the criteria are compared and ranked with respect to the overall goal. The result of these comparisons is presented in matrix form known in AHP as pairwise comparison matrix.

In order to generate the pairwise comparison matrices (PCM) required by the process, an AHP-based questionnaire is administered to a sample of the entire company workforce who are deemed to be knowledgeable in the subject area and were involved in different capacities during the design and construction of the fabrication yard. Each respondent is given a number for easy identification and reference. Their responses are then used to generate PCM's with the weights they provided. Next, all PCM's for each level of the model hierarchy are grouped into one PCM per hierarchy to yield the grouped PCM's. The responses elicited through this medium serves as input to the qualitative aspects of the decision making process which involves the criteria safety and flexibility, and the overall goal.

The quantitative aspect of the AHP process involves two criteria which are material handling and personnel flow. The material handling cost and personnel flow for each alternative are estimated with the aid of the MS Excel add-in mentioned earlier and compared in a ratio form to generate the comparison matrices. This is followed by the integration of the PCM's generated from both the qualitative and quantitative processes. Finally, the three alternatives are evaluated using the AHP model and the most suitable one is selected and proposed for implementation.

3.2 Population of the Study

The population of the study consists of personnel at Ladol Fabrication Yard, Lagos, Nigeria. There are two hundred and seventy-three (273) individuals in the Yard, and are grouped with respect to their professional qualifications and hierarchies. The groups are referred here as disciplines or teams within the organisation and there exist nine (9) of such teams comprising: the Management, Project Control, Procurement, Quality Assurance, Civil Engineering, Electrical Engineering, Piping Engineering, Lifting and Health, Safety and Environment (HSE) teams. Table 3.1 shows the number of personnel in each team.

Table 3.1: Number of Personnel in the Teams

S/N	Discipline / Team	Number of Personnel
1	Management	8
2	Project Control	22
3	Procurement	3
4	Quality Assurance	25
5	Civil Engineering	65
6	Electrical Engineering	31
7	Piping Engineering	36
8	Lifting	29
9	HSE	54
Total		**273**

3.3 Sample Size and Sampling Technique

The sample size for the study is calculated using the formula for proportions as provided by Yamane (1967). It is represented in equation 3.5 below.

$$n = \frac{N}{1 + N(e^2)} \quad \ldots\ldots\ldots\ldots 3.5$$

Where n is the sample size, N is the population size, and e is the level of precision. Assuming a 95% confidence level and a precision level of ±5%; with a population size of 273, the sample size is calculated as follows:

$$n = \frac{273}{1 + 273(0.05^2)}$$

$$= 162 \text{ samples}$$

The stratified random sampling technique is adopted in this study, due to the heterogeneous nature of the population. This method requires that the entire heterogeneous population be divided into a number of homogeneous groups (known as strata) and each of these groups is homogeneous within itself; and then units are sampled at random from each of these stratums (Singh & Masuku, 2014). This is achieved in the case study as the personnel have been grouped into teams with respect to their job positions and technical qualifications as already described in section 3.2 of this work.

Stratified sampling is thereafter applied to determine the number of samples needed from each group to arrive at the Yamane figure of 162. The samples are chosen randomly within each team until the number of samples required from that team is complete; thus, giving every member of the teams equal chance of being selected.

3.4 Data Collection Method

The type of data collected in the study is a hybrid of primary and secondary data. Secondary data collected for the study include: size, shape and dimensions of the initial facility layout design, number of departments/activity areas with their space requirements, cost matrix, and equipment and personnel flow matrices, all required by the CRAFT procedure. They were obtained from the case study company's documents database. Primary data collection involves generating pairwise comparison matrices (PCM) required as input by the AHP model. The PCM's are generated by administering an AHP-based questionnaire which the experts complete, indicating their preferences for each pair of alternatives and criteria. Their preferences are determined in terms of relative weights using Saaty's scale of relative importance, as shown in Table 3.2. The scale is represented in a number line form, as shown in fig. 3.1. Each question in the questionnaire is answered by indicating a point on the scale (such as by circling the number on the line) that best reflects the preferences of the decision makers. The number line approach enables the respondents to make finer compromises between two numbers on the line, a feature which can hardly be achieved in other formats. Therefore, decimal entries (e.g. 3.5, 6.5. 2.3, etc.) can be made to indicate a more accurate preference of one item over the other. The questions take the form: "Which criterion is more important with respect to the goal and by how much?"

Table 3.2: Fundamental scale for making judgments

Intensity of Importance or Preference	Definition	Explanation
1	Equal	Two criteria/alternatives have equal importance or preference
3	Weak	A criteria/alternative is slightly more important or preferred than the other
5	Strong	A criteria/alternative is strongly more important or preferred than the other
7	Very strong	A criteria/alternative is almost absolutely more important or preferred than the other
9	Absolute	A criteria/alternative is absolutely more important or preferred than the other
2,4,6,8	Intermediate values between two adjacent judgments	Used when compromise is required

Source: Adapted from Saaty (1987)

3.5 Model Building

A hierarchical structure is developed for the decision making problem in the case study as depicted in fig 3.2. The elements of the hierarchy are known as nodes in the environment of the Super Decisions software, while the levels are recognized as clusters. The first level contains the Goal node alone in the Goal cluster; and as already defined, the goal is to select the best facility layout design. The second level contains the Criteria cluster which contains the criteria nodes – safety, flexibility, personnel flow and material handling. The third level cluster contains the Alternatives nodes which represent the alternative layout designs.

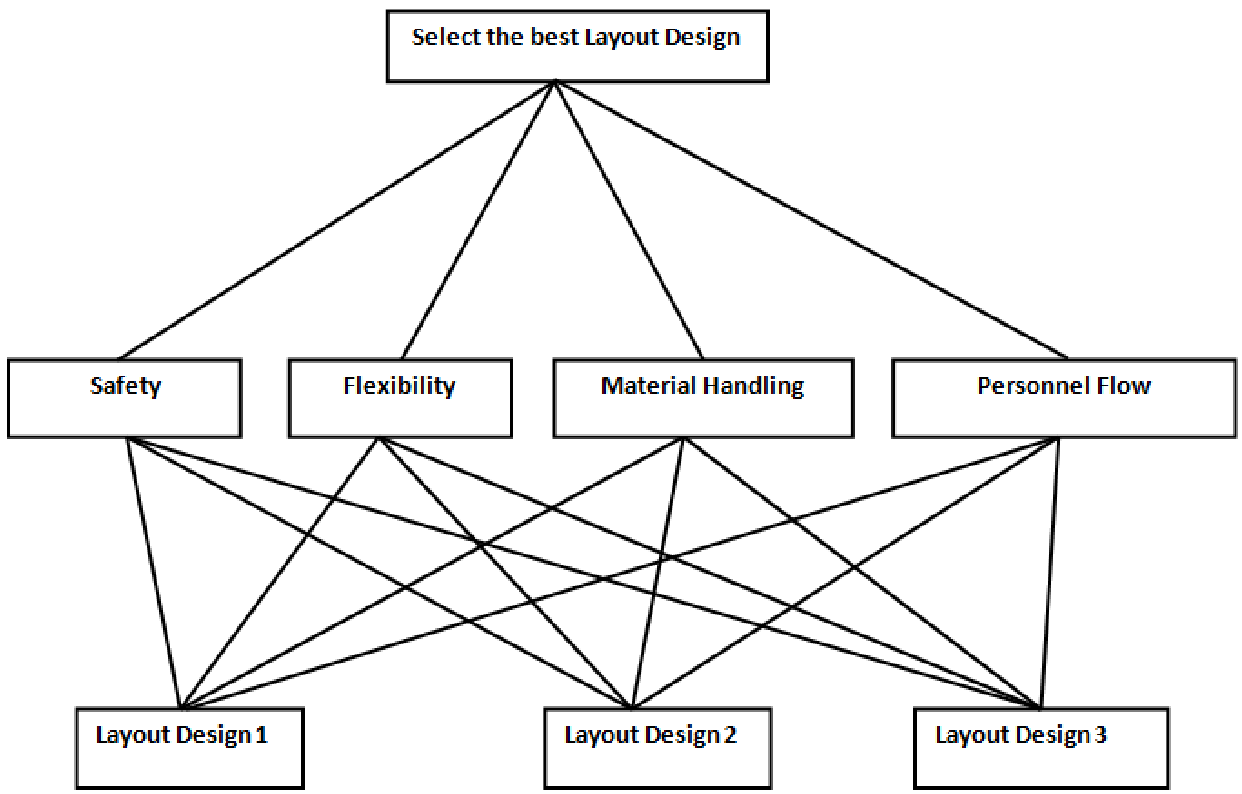

Fig 3.2: A hierarchical structure of AHP for the facility layout problem

3.6 Method of Data Analysis

Analysis of the data obtained as described earlier is carried out with the aid of the available commercial AHP-based software, Super Decisions. The individual judgments made by experts are combined into a group judgement by taking a geometric mean of the individual judgments to obtain a matrix of relative weights. This has been proven to be adequate by Aczél and Saaty (1983).

The relative weights obtained are keyed into the software using the matrix mode. For every judgement matrix generated, the program is used to automatically calculate the consistency index and ratio, since the decision makers may be uncertain or make negative judgments when comparing some of the elements. It also provides a method for improving the consistency ratio to a much better value (even if it is below 10%). Next, the program is used to automatically generate the priority matrix for each pairwise comparison matrix, after which it is used to synthesize to obtain the overall results of the decision problem. Upon generation of the overall results, the AHP-based the software is used to perform sensitivity analysis to test the responsiveness or sensitivity of the outcome of the final decision to changes in the priorities of the criteria of the facility layout problem.

In the AHP model, sensitivity analysis is performed to determine the impact a change in the weight of one or more criteria has on the ranking of the alternatives. Mu and Pereyra-Rojas (2017) noted that the overall priorities are heavily influenced by the weights given to the respective criteria; and as such, it is useful to perform a "what-if" analysis to see how the final results would have changed if the weights of the criteria were different. They further stated that sensitivity analysis allows the researcher to understand how robust the original decision is and to identify the criteria that most influenced the original results obtained. Besides, applying sensitivity analysis to such decision making processes is essential to ensure the consistency of final decision (Syamsuddin, 2013).

4. Results and Discussion

4.1 Demographic Data

The demographic data of respondent was determined. It is observed that of the 162 respondents, 130 were male, while 32 were female, representing 80.25% and 19.75% respectively. Age distribution of respondents shows that 27, representing 16.67% were below 30 years, 72, representing 44.44% were between 30 and 40 years old, 48 representing, 29.63% were between ages 41 to 50 years and 15, representing 9.26% were 51 years old and above. Concerning the marital status of the respondents, 60 (37.04%) of the total respondents were single, while 102 (62.96%) were married. Professional grouping in the organisation, in terms of the teams the respondents belong to, indicates that most of the respondents are in the Civil Engineering team, with 39 (24.07%) respondents belonging to this team. This is closely followed by HSE and Piping Engineering teams with values of 32 (19.75%) and 21 (12.96%) in respectively. Next in the frequency distribution are the Electrical Engineering, Lifting, Quality Assurance, Project Control, Management and Procurement teams in that order. They respectively had 18 (11.11%), 17 (10.49%), 15 (9.26%), 13 (8.02%), 5 (3.09%) and 2 (1.23%) respondents in the study. The highest years of experience accumulated by the respondents at the time of this study is between 5 to 15 years, with 87 respondents representing 53.70% in this category. Others include: 33 (20.37%) respondents, with years of experience between 16 to 25 years, 24 (14.81%) respondents having below 5 years' experience and 18 (11.11%) respondents acquiring total work experience of 26 years and above.

4.2 Layout Optimization using CRAFT Algorithm

The CRAFT algorithm used for the layout optimization problem requires some input data as described here. Table 4.2 shows the activity areas on the fabrication yard along with their area or space requirements. It can be observed that the Quay wall is part of the layout data displayed, although it is not relocated in the optimization process due to the strategic benefits of its current location to the company. Further, a 24^{th} 'false' area identified as "Frozen Area" is added to the list because of the limitations of the CRAFT-based MS Excel add-in used to perform the layout optimization. This add-in can only handle rectangular layout shapes; therefore, this area was added to transform the L-shaped layout into a rectangular layout. However, this additional activity area is frozen and is not relocated during the optimization process in order to retain the shape of the total floor space.

Other data required by the algorithm are the personnel flow matrix, equipment flow matrix and the cost matrix.

Table 4.2: Activity areas and their area requirements

Department Code	Department Number	Department / Activity Area	Fixed/ Variable	Area (m^2)
ASA	1	Assembly Area	V	10,500
ASH	2	Assembly shop	V	10,500
BSH	4	Blasting shop	V	4,200
CAN	10	Canteen	V	1,500
EIW	22	E&I workshop and storage area	V	4,900
GST	8	Gas station	V	3,600
MCE	18	Medical Center - Site Clinic and Emergency response office	V	900
OFA	11	Outfitting Area	V	10,500
OFF 1	6	Contractor Office 1	V	2,000
OFF 2	9	Client Office	V	1,200
OFF 3	17	Sub-contractor Office	V	3,000
OFF 4	23	Contractor Office 2	V	2,100
PEA	15	Pre-Erection Area	F	32,500
PPS	13	Piping shop	V	1,500
PSH	3	Painting shop	V	6,600
QUA	20	Quarantine Area	V	7,800
QWA	16	Quay wall Area	F	15,300
RMB	14	Radioactive materials bunker	V	1,800
SME	19	Security office and Main Entrance	F	1,500
TSA	21	Temporary Materials Storage Area	V	11,900
WHS	5	Ware house	V	5,500
WTC	12	Welders Training Center	V	1,200
WTP	7	Water treatment plant	V	1,500
		Total		**142,000**
FRZ	24	Frozen Area	F	46,200
		Grand Total		**188,200**

There is original facility layout design adopted for the study in which a block layout drawn from this original detailed layout is designated “Layout Design 1” (see fig 4.1) for reference purposes. Upon optimizing the initial layout using the CRAFT algorithm, a second alternative layout design is generated. This is designated as “Layout Design 2” and is as shown in fig 4.2. In order to generate this second layout design, the CRAFT algorithm implemented by the MS Excel add-in performs a series of iterations, the results of which are shown in table 4.3.

It can be observed that the algorithm made a total of six (6) interdepartmental switches. However, the last iteration did not yield a further reduction in the material handling cost of the layout. Thus, the algorithm terminates at this point, while the result of the sixth iteration is discarded, since it does not satisfy the objective of the optimization process. Therefore, only iterations 1 to 5 are useful as the total material handling cost is reduced from ₦87,755,600.00 to ₦80,322,228.00, yielding a total cost reduction of ₦7,433,312.00.

Table 4.3: Result of iterations by CRAFT algorithm

Iteration	**Type**	**Action**	**Material Handling Cost**	**Cost Reduction**
1	Switch PEA and TSA	15 and 21	84,502,448.00	3,253,152.00
2	Switch WHS and CAN	5 and 10	83,732,936.00	769,512.00
3	Switch TSA and EIW	21 and 23	83,656,576.00	76,360.00
4	Switch GST and OFF 3	8 and 17	82,467,360.00	1,189,216.00
5	Switch QUA and MCE	20 and 8	80,322,288.00	2,145,072.00
6	Switch ASH and WTC	2 and 12	80,637,720.00	– 315,432.00

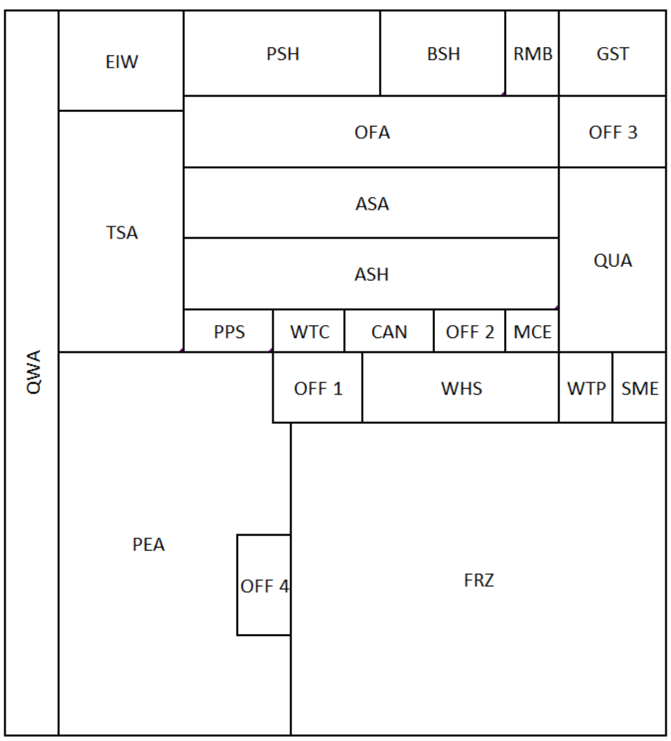

Fig 4.1: Layout Design 1

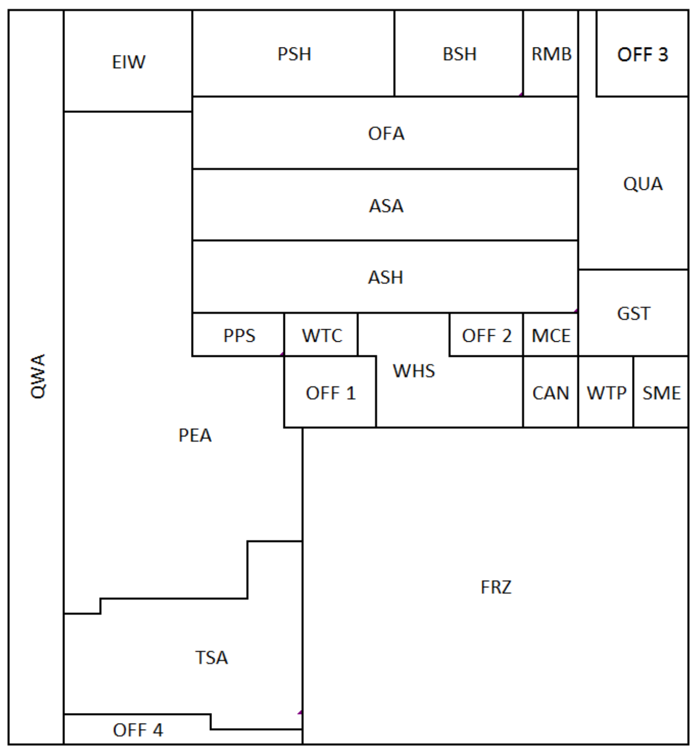

Fig 4.2: Layout Design 2

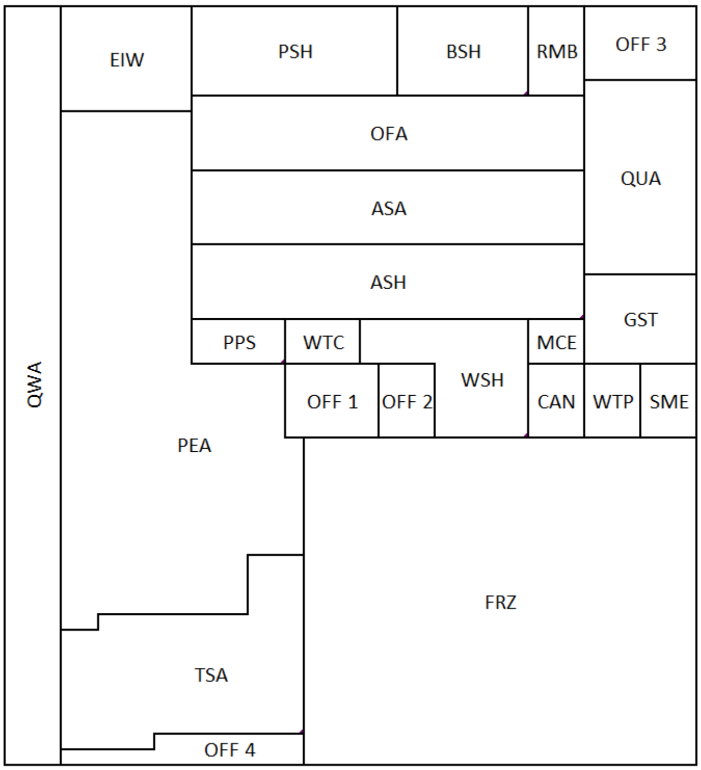

Fig 4.3: Layout Design 3

Department Code	Department Number	Department / Activity Area
ASA	1	Assembly Area
ASH	2	Assembly shop
BSH	4	Blasting shop
CAN	10	Canteen
EIW	22	E&I workshop and storage area
GST	8	Gas station
MCE	18	Medical Center - Site Clinic and Emergency response office
OFA	11	Outfitting Area
OFF 1	6	Contractor Office 1
OFF 2	9	Client Office
OFF 3	17	Sub-contractor Office
OFF 4	23	Contractor Office 2
PEA	15	Pre-Erection Area
PPS	13	Piping shop
PSH	3	Painting shop
QUA	20	Quarantine Area
QWA	16	Quay wall Area
RMB	14	Radioactive materials bunker
SME	19	Security office and Main Entrance
TSA	21	Temporary Materials Storage Area
WHS	5	Ware house
WTC	12	Welders Training Center
WTP	7	Water treatment plant
		Total
FRZ	24	Frozen Area
		Grand Total

Fig 4.4: Legend of Activity Areas

Further, the third layout design is obtained from manually modifying the second alternative to accommodate issues such as shape of departments and safety requirements which the CRAFT algorithm cannot handle explicitly. This third alternative is designated “Layout Design 3” and is shown in fig 4.3. To generate this third layout, the Client office (OFF 2) is positioned next to the Contractor Office (OFF 1) to provide for better interaction between client and contractor personnel, thus reducing the need for walk ways and increasing safety requirements. Further, the third layout design is obtained from manually modifying the second alternative to accommodate issues such as shape of departments and safety requirements which the CRAFT algorithm cannot handle explicitly. This third alternative is designated “Layout Design 3” and is shown in fig 4.3. To generate this third layout, the Client office (OFF 2) is positioned next to the Contractor Office (OFF 1) to provide for better interaction between client and contractor personnel, thus reducing the need for walk ways and increasing safety requirements. Next, the Quarantine Area (QUA) is modified from an L-shape to a rectangular shape layout to reduce its interaction with the Radiation Materials Bunker (RMB), and also to eliminate possible blockage of access between Sub-contractor office (OFF 3) and RMB. It is observed that these manual changes resulted in a further material handling cost reduction of ₦245,024.00.

Finally, the personnel flow for each layout design generated is automatically computed with the aid of the algorithm using equation 3.4. The results obtained are shown in Table 4.4.

Table 4.4: Material handling cost and personnel flow for each alternative FLD

Alternative FLD	**Material Handling Cost (₦)**	**Personnel Flow (* 10m)**
Layout Design 1	87,755,600.00	187,394
Layout Design 2	80,322,288.00	173,483
Layout Design 3	80,077,264.00	172,887

4.3 Hierarchical Model and Pairwise Comparison Matrices

A snapshot of the AHP model developed for the FLP in the study and designed in the Super Decisions software environment is shown in fig 4.5. It has three levels as follows:
Level 1: The goal – Selection of the best facility layout design
Level 2: The criteria – Safety, Flexibility, Material Handling and Personnel Flow
Level 3: The Alternatives – Layout Design 1 (LD1), Layout Design 2 (LD2) and Layout Design 3 (LD3)

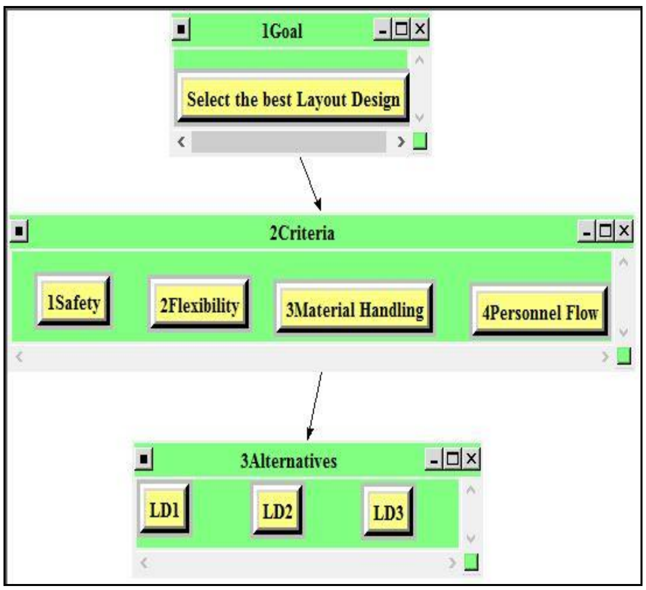

Fig 4.5: The hierarchical model for the study

Pairwise comparison matrices are generated from the responses provided by the respondents in the AHP questionnaire. The overall PCM's for each level of the hierarchy are obtained by taking a geometric mean of all judgement weights in that level. Further, the PCM's for comparison of alternatives with respect to material handling and personnel flow criteria are generated quantitatively using the information provided by the CRAFT algorithm (see in table 4.4). The weights are obtained by taking a ratio of the values in Table 4.4 for each comparison of alternatives. Tables 4.8 and 4.9 display the PCM's for these comparisons respectively. In total, this study involves the generation of 491 pairwise comparison matrices.

4.3.1 Comparison of Criteria with respect to the Goal

The pairwise comparison matrix is for the goal of selecting the most appropriate layout design is represented in Table 4.5 below. The consistency ratio and the maximum lambda (λ_{max}) are displayed at the top left corner of the table. The CR was as estimated by the Super Decisions software. Additionally, fig 4.6 is a snapshot from the software environment that indicates the ideal mode relative priority of the criteria with respect to the goal of selecting the best FLD. It can be observed that Safety criterion ranks highest followed by Personnel Flow, Material Handling and Flexibility criteria in that order. Again, since C.R < 0.1, the decision makers' judgments are considered to be consistent.

Table 4.5: Pairwise Comparison Matrix for the goal of selecting the best FLD

Selection of the Best Facility Layout Design	**Safety**	**Flexibility**	**Material Handling**	**Personnel Flow**	**Priority Vector**
Safety	1.000	0.574	2.885	1.000	0.35169
Flexibility	1.742	1.000	2.395	1.777	0.09888
Material Handling	0.347	0.417	1.000	1.736	0.21806
Personnel Flow	1.000	0.563	0.576	1.000	0.33137

λ_{max} = 4.06456; CI = 0.02152; CR = 0.02416

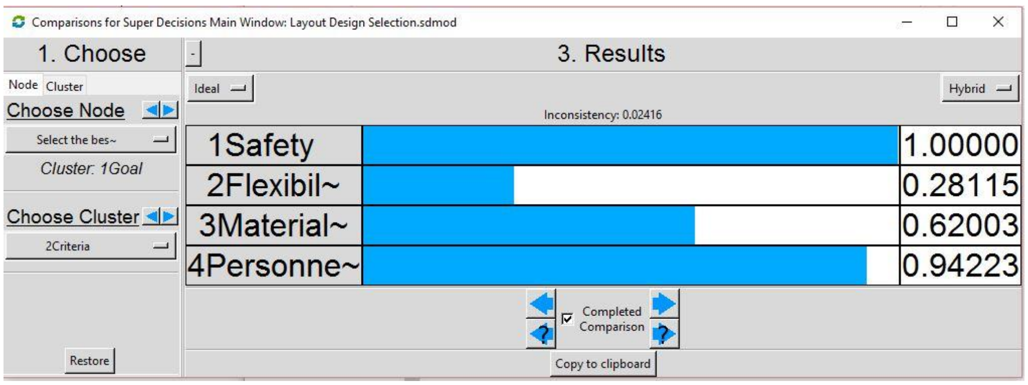

Fig 4.6: Priority results for the goal of selecting the best FLD

4.3.2 Comparison of Alternatives with respect to Safety Criterion

Table 4.6 below depicts the pairwise comparison matrix generated with regard to the Safety criterion, while fig 4.7 shows the snap shop from the Super Decisions software. The decision makers' judgments are considered to be consistent since the CR < 0.1. Under this criterion, Layout Design 3 (LD3) ranks highest, followed by Layout Design 1 (LD1) and Layout Design 2 (LD2) in that order. The maximum lambda is also estimated with the aid of the software.

Table 4.6: Pairwise Comparison Matrix for the Safety criterion

Safety	**Layout Design 1**	**Layout Design 2**	**Layout Design 3**	**Priority Vector**
Layout Design 1	1.000	1.111	0.858	0.32740
Layout Design 2	0.900	1.000	0.898	0.30989
Layout Design 3	1.165	1.113	1.000	0.36271

λ_{max} = 3.00255; CI = 0.00128; CR = 0.00243

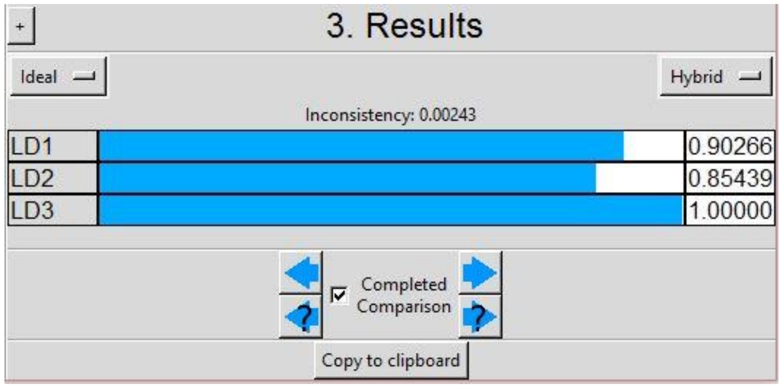

Fig 4.7: Priority results for the Safety criterion

4.3.3 Comparison of Alternatives with respect to Flexibility criterion

On comparing the alternative facility layout drawing with respect to the Flexibility criterion, the PCM shown in Table 4.7 and the relative priority ranking of the alternatives is shown in fig 4.8 below. Here, Layout Design 3 ranks best; then Layout Design 2 and finally, Layout Design 1.

Table 4.7: Pairwise Comparison Matrix for the Flexibility criterion

Flexibility	Layout Design 1	Layout Design 2	Layout Design 3	Priority Vector
Layout Design 1	1.000	0.863	0.730	0.28401
Layout Design 2	1.159	1.000	1.175	0.36726
Layout Design 3	1.370	0.851	1.000	0.34873

$\lambda_{max} = 3.01197$; CI = 0.00399; CR = 0.01154;

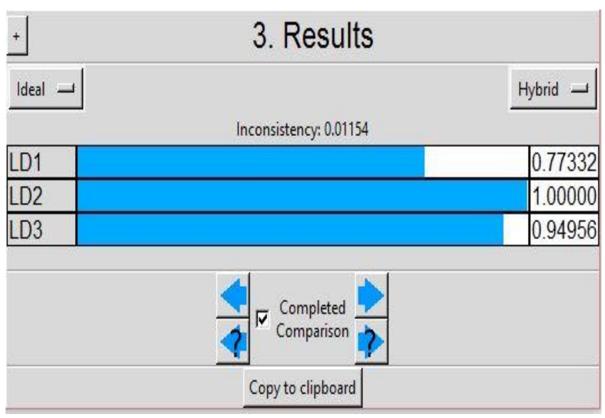

Fig 4.8: Priority results for the Flexibility criterion

4.3.4 Comparison of alternatives with respect to Material Handling criterion

The PCM generated by comparing the alternatives with regards to the Material Handling criterion is depicted in Table 4.8, while the ranking of the performance of the alternatives under this criterion is shown in figure 4.9 in ideal mode. Layout Design 3 ranks the highest, followed by Layout Design 2 and Layout Design 1 in that order. The consistency is evaluated to be zero (0) for this PCM because of the objective nature of the comparisons.

Table 4.8: Pairwise Comparison Matrix for the Material Handling criterion

Material Handling	Layout Design 1	Layout Design 2	Layout Design 3	Priority Vector
Layout Design 1	1.000	1.093	1.096	0.31358
Layout Design 2	0.915	1.000	1.003	0.34271
Layout Design 3	0.913	0.997	1.000	0.34371

$\lambda_{max} = 3.00000$; CI = 0.00000; CR = 0.00000

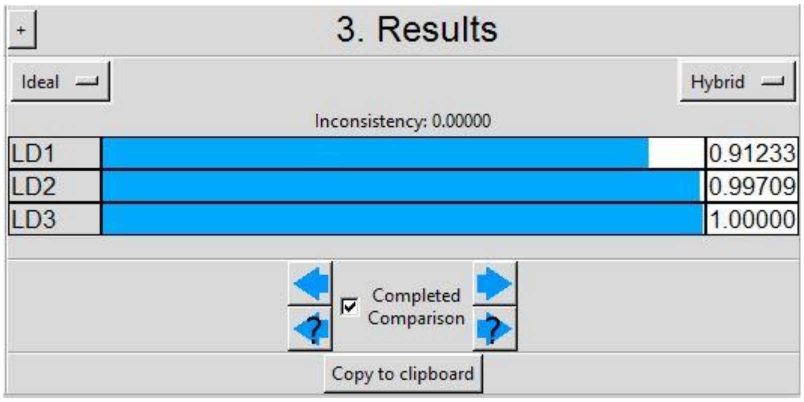

Fig 4.9: Priority results for the Material Handling criterion

4.3.5 Comparison of alternatives with respect to Personnel Flow criterion

Table 4.9 depicts the PCM obtained for the Personnel flow criterion, while figure 4.10 shows the ideal mode ranking of alternatives with respect to this criterion. As shown, Layout Design 3 has the highest ranking, then Layout Design 2 and finally Layout Design 3. Again, the consistency is not evaluated here because of the objective nature of the comparisons. Although, the Super Decisions software shows that its consistency ratio is zero.

Table 4.9: Pairwise Comparison Matrix for the Personnel Flow criterion

Personnel Flow	Layout Design 1	Layout Design 2	Layout Design 3	Priority Vector
Layout Design 1	1.000	1.080	1.084	0.31606
Layout Design 2	0.926	1.000	1.003	0.34142
Layout Design 3	0.923	1.000	1.000	0.34252

$\lambda_{max} = 3.00000$; CI = 0.00000; CR = 0.00000

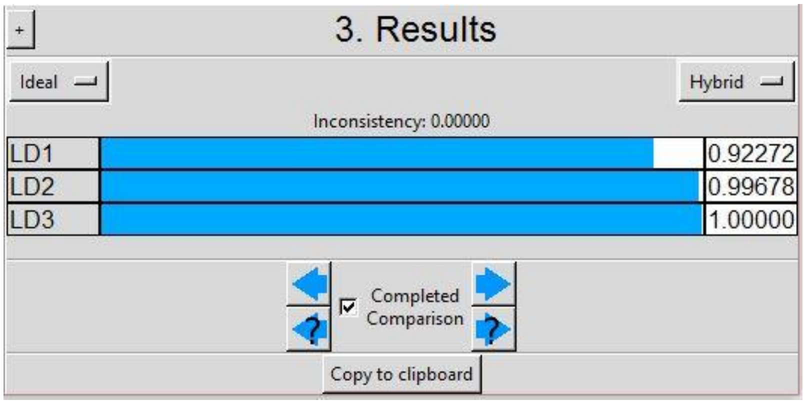

Figure 4.10: Priority results for the Personnel Flow criterion

4.3.6 Synthesis of Priorities to Generate Overall Results

The overall results obtained are as depicted in Table 4.10 and figure 4.11. It reveals that Layout Design 3 is the alternative that best satisfies the criteria behind the selection of the best facility layout design for the fabrication yard. Layout Design 2 ranks next, followed by Layout Design 1.

Table 4.10: Composite priorities of the alternatives with regard to the selection of the best FLD

Selection of the Best Facility Layout Design	**Layout Design 1**	**Layout Design 2**	**Layout Design 3**
Pooled Average	0.316336	0.333169	0.350495
Relative Preference Ranking	3	2	1

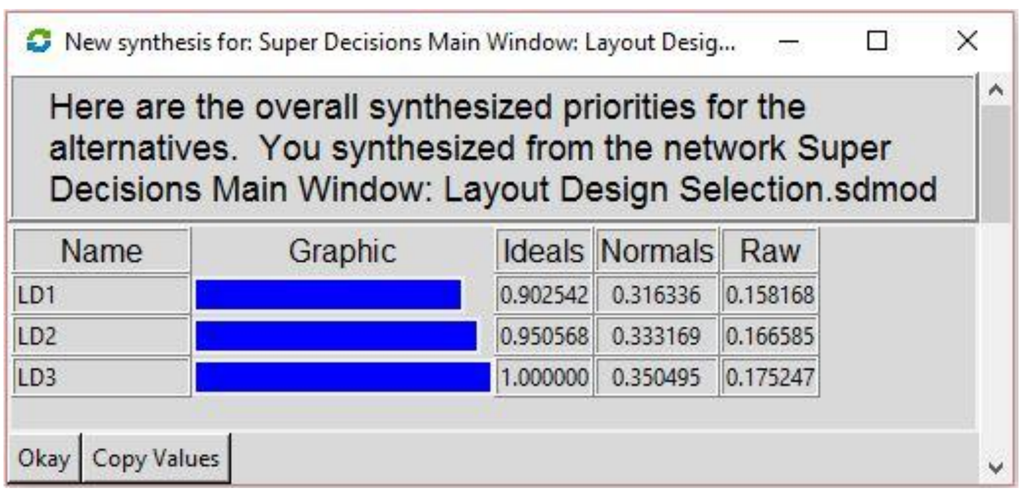

Figure 4.11: Overall priority results for the FLP

4.4 Results of Sensitivity Analysis

To test the robustness of the decision, a sensitivity analysis is performed, and the results are presented. For this study, graphical analysis is adopted because it is easier to observe the changes in priority rankings, when the weight of a criterion is varied. Firstly, sensitivity of the ranking of the alternatives is tested for the Safety criterion. The result is displayed in the graph shown in figure 4.12.

It can be observed that Layout Design 3 remains the best alternative when the weight of the Safety criterion is varied from 0 to 1. However, at 0.6789 (67.89%) of the Safety criterion's weight, rank reversal occurs between Layout Design 1 and 2, as Layout Design 1 overtakes Layout Design 2 to occupy the position of the second best alternative in the ranking. Since Layout Design 3 remains at the top of the ranking for all weight variations, it can be inferred that the overall decision with respect to the Safety criterion is robust, and therefore reasonably consistent. The intersection of the vertical line and the x-axis shows the point at which rank reversal occurs.

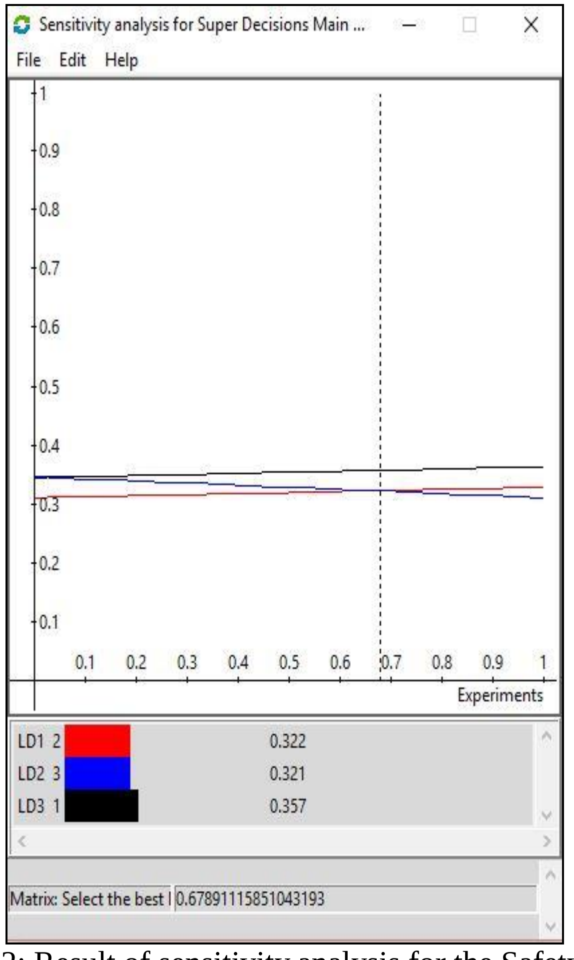

Figure 4.12: Result of sensitivity analysis for the Safety criterion

Further, the result of sensitivity analysis performed for the Flexibility criterion is shown in figure 4.13. In this graph, it can be observed that Layout Design 1 remains the least in the ranking for all weight variations of the Flexibility criterion from 0 to 1. Rank reversal occurs between Layout Design 2 and 3 at 0.5579 (55.79%) of the weight of the Flexibility criterion. At this point, Layout Design 2 overtakes Layout Design 3 to occupy the first position in the ranking. The intersection of the vertical line and the x-axis shows the point at which rank reversal occurs.

Sensitivity analysis is not carried out for the Material Handling and Personnel Flow criteria because of their quantitative nature.

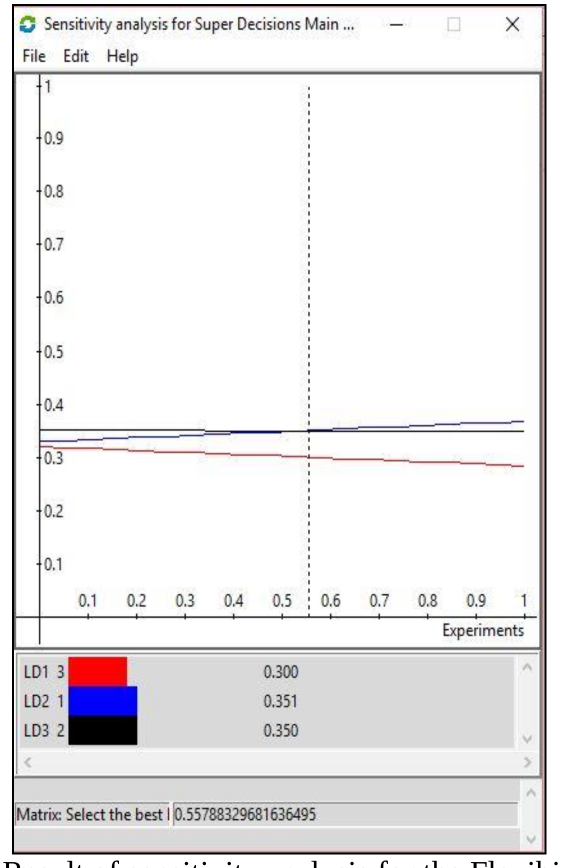

Figure 4.13: Result of sensitivity analysis for the Flexibility criterion

4.5 Discussion of Findings

This study has attempted to answer the questions raised at the beginning of this work. Firstly, the determinant factors in the selection of efficient fabrication and assembly yards have been ascertained through a combination of interaction with experts in the case study and review of relevant literature in the area of facility layout planning with regards to static and dynamic construction sites. These factors have been recognized and categorized as safety, flexibility, material handling and personnel flow and found to be applicable in oil and gas fabrication yards in Nigeria. In this regard, this study agrees with the work of many scholars like Shang (1991), Abdi (2005), Osman and Georgy (2005), Hadi-Vencheha and Mohamadghasemi (2013), and Phruksaphanrat (2016) who are of the view that the facility layout problem is multi-objective in nature. The safety factor encompasses issues such as noise pollution, relative positioning of departments and activity areas so as to minimize the escalation of incidents, minimal exposure of personnel to possible sources of harm and adequate escape and evacuation routes out of the facility. Further, the flexibility criteria address issues relating to ease of expansion of the yard and the ability to use one area or space for multiple tasks at different times. The material handling factor involves the ease and cost of moving materials and equipment throughout the yard as well as the total handling distance between each department. Again, the personnel flow factor determines the extent to which personnel can move freely from one point in the yard to another point as well as providing routes with shortest distance between two areas. It also accounts for how close departments with high personnel interactions are or should be to reduce unnecessary movement of people which could lead to avoidable loss of man-hour. Therefore, the first objective of ascertaining the determinants of efficient fabrication yard layout has been addressed thus far.

Secondly, as shown in section 4.2 of this work, CRAFT algorithm has been employed to optimize the facility layout design of the chosen case study. The objective was to design improvements into the yard layout in a systematic manner taking into consideration the available space and shape of the overall layout, and the need to generate alternative FLD’s that addressed the problems of high material handling cost and personnel flow raised earlier. This algorithm, implemented using an MS Excel add-in, attempted to reduce the total material handling cost by considering the centroidal distances between pairs of activity areas. In total, five (5) cost-reducing iterations were made which involved switching departments of similar sizes and/or adjacent boundaries while monitoring the total cost, a process that yielded a material handling cost saving of ₦7,433,312.00 (reducing the total cost by 8.47% of the initial cost). Again, the MS Excel add-in was also used to estimate the total personnel travelling distance for each of the alternatives compared in this work by replacing the equipment flow matrix with the personnel flow matrix and setting the cost per trip to unity (see formulas 3.3 and 3.4). It was found that the CRAFT algorithm yielded a layout that reduced the personnel flow on the yard by 7.42% (139,110m). Thus, this study shows that CRAFT algorithm can be easily implemented in MS Excel using the add-in function of the program. Therefore, the second objective of optimizing the facility layout design in Ladol Fabrication Yard, Lagos, Nigeria has been achieved.

Thirdly, due to the inability of the CRAFT procedure to address other important and qualitative factors such as safety, flexibility and shape of departments, a manual modification of Layout Design 2 (the output of the CRAFT procedure) was carried out. This resulted in the generation of a third alternative FLD. Thus, the third objective of generating alternative facility layout using a combination of CRAFT and manual method is achieved. Again, it is important to note that the generation of this third layout design further reduced the material handling cost by ₦245,024.00 and the personnel travel distance by 5960m.

Fourthly, AHP model, implemented by the Super Decisions software, was used to evaluate the alternatives generated in a bid to select the best one. Results from comparing the criteria for selecting the best alternative showed that the Safety criterion ranked highest, then Personnel Flow, Material Handling, with Flexibility at the bottom of the ranking. In summary, the Safety criterion was preferred to the Flexibility criterion by a factor 3.56. It was just slightly more important than the Personnel Flow criterion (a factor of 1.06), and was 1.61 times preferred to the Material Handling criterion. The implication of this in this study is that alternatives that scored highest with regards to the Safety criterion were 3.56 times more likely to be selected as the overall best alternative than those that scored least under this criterion. To this end, the Safety criterion had the highest influence in the decision making process.

On evaluation of the available alternatives, Layout Design 3 was selected as the best alternative FLD. Sensitivity analysis carried out to test the stability of this decision showed it to be robust and therefore, consistent. Similar results have been obtained in the past by Cambron and Evans (1991) who used AHP to select from alternative facility layout plans, the most suitable one to implement.

Finally, considering that the chosen layout design has the least total material handling cost and personnel flow; and that it ranked highest with respect to three out of the four decision criteria (it ranked second with regard to Flexibility criterion), it is obviously a more efficient layout than the case study layout. Moreover, it is an improvement on the layout design at Ladol Fabrication Yard, Lagos, Nigeria. Therefore, this study shows that the CRAFT-AHP technique to solving facility layout problems can yield improved fabrication yard layout design for the Nigeria oil and gas industry.

5. **Conclusion and Recommendations**

The CRAFT-AHP technique has been employed to solve the facility layout problem at the chosen case study fabrication yard. By selecting Layout Design 3 as the best layout design, the total material handling cost is reduced by ₦7,678,336.00 (8.75%), while the total personnel flow is reduced by 145,070m (7.74%). Therefore, the methodology adopted resulted in the generation and selection of a more suitable layout design which had lower material handling cost and personnel flow, while improving on the safety requirement for an oil and gas fabrication and assembly yard in Nigeria. In line with the results obtained in this study, the following recommendations are made.

(i) Firms in the oil and gas industry should ensure that fabrication yard layout designs are thoroughly examined to determine if they serve their short and long term goals in an efficient manner before implementation.

(ii) Key decision makers in the oil and gas industry should ensure and encourage optimization of layout designs in their organisations to reveal possible gains that can be adopted in the designs as early as possible, preferable in the planning phase of the facility layout.

(iii) The use of CRAFT algorithm for the optimization of fabrication yard layout designs should be employed as soon as the size and shape of the available floor space is defined and split into blocks of activity areas, just before the detailed layout designs are generated.

(iv) The use of AHP model as a tool for decision making should be adopted by oil and gas servicing companies to evaluate alternatives with respect to both objective and subjective criteria. This ensures that problems are solved in a systematic and efficient manner.

(v) Government agencies involved in the approval of oil and gas fabrication yard layout designs should ensure that adequate evaluation of possible alternative layout designs be carried out in order to determine the most suitable one in terms of safety of lives and assets on the yard.

This study has investigated the applicability of the CRAFT-AHP technique to solving facility layout problems in an oil and gas fabrication yard. It has highlighted the important factors and peculiarities in the design of efficient oil and gas fabrication yard layouts. Further, it has showed that the AHP model is a very useful decision making tool which can be used to examine the multiple objective nature of facility layout planning. Finally, it has deepened the understanding of the subject of layout planning in a facility that is partly static and partly dynamic.

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