

## MODELING OF A PLANT LAYOUT FOR A LIQUIFIED PETROLEUM GAS REFILLING PLANT

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### ABSTRACT

As a result of the volatile nature of Liquefied Petroleum Gas (LPG), the improper siting of facilities and equipment within a LPG refilling gas plant could lead to accidents with devastating effects. This study therefore seeks to lay out a LPG refilling plant such that the total risk in financial terms when the plant is exposed to an accident is minimized. This is necessary considering the conflicting objectives of reduced piping cost and increased separation distance between process units. This was achieved using the integrated approach of quantitative risk analysis and mathematical programming to the layout of a LPG refilling plant. The Dow Fire and Explosive Index was used as a quantitative risk tool to evaluate the potential hazardous units and their distances of exposure were incorporated into a Mixed Integer Linear Program (MILP). This was done to minimize the piping cost and the residual risk posed to the units in the event of an accident. It was solved using the AMPL (A Mathematical Programming Language) optimization package. The result obtained revealed a good layout characteristics such as adequate spacing between process units and good utilization of land among others. The total financial cost of USD108,640.88 which may be broken down into residual financial risk of USD106,906.08 and piping cost of USD1,734.81 was obtained for the layout.

**Keywords:** liquefied petroleum gas, modeling, industrial engineering, mathematical programming, dow fire and explosive index.

### INTRODUCTION

Energy is unarguably essential for the support of human activities. Its uses are innumerable and of huge significance to our daily activities. Cooking utilizes energy and this is a universal need for over 7 billion people worldwide. The major sources of cooking energy include electricity, biomass (firewood, charcoal, and agricultural wastes), Liquefied Petroleum Gas (LPG) and Kerosene. The major sources of cooking energy in descending order of use are biomass, kerosene, electricity and LPG in the sub-Saharan Africa as stated by Ahmed [1]. However, considering the CO<sub>2</sub> emissions, energy cost, clean burning, faster cooking and consumer health, LPG remains one of the best sources of cooking energy [2]. Liquefied

petroleum gas is one of the products of natural gas that is cleaner and it contains low carbon. It is a mixture of propane (C<sub>2</sub>H<sub>6</sub>) and butane (C<sub>4</sub>H<sub>10</sub>) for standard heating and cooking purposes. These unique properties make it very useful and versatile for cooking [3, 4]. LPG is commonly stored in steel cylinders for ease of conveyance. It has a very low flash point temperature of -104°C as well as an auto ignition temperature of 405°C. LPG has an ignition ratio of between 2.15 and 9.6 percent in open air.

Nigeria produces 2.1 million metric tonnes per annum (MTPA) of LPG and barely consumes 15 % of her production, thereby forcing her to export the rest [1]. A comparison of consumption of LPG per capita of different countries shows that Nigerians consume barely 1kg of LPG, in deep contrast to Ghana (4.7 kg), Senegal (9

kg) and Morocco (44 kg) [1, 5, 6]. However, in the face of an astronomical increase in the cost of kerosene as well as more general awareness on the dangers and health effects of using biomass as a source of cooking energy, more households are beginning to embrace LPG as a source of cooking. The demand of LPG has increased and more than doubled in Nigeria over the years [1, 7]. This surge in growth has led to the springing up of domestic LPG refilling stations across different cities in Nigeria. These refilling stations serve as the point of service to the eventual end user. In the construction of this LPG refilling station as any other facility, one of the variables to be decided upon is the layout of the facility. Plant layout as an aspect of engineering that deals with design of the arrangement of physical elements of an activity [8]. Over the years, a lot of research in the area of plant layout has been carried out with findings successfully applied and implemented in various aspects of industry including but not limited to manufacturing, banking, departmental stores, hospitals, and schools. The layout of any facility is very crucial since it is permanent in nature and poor decision making at this stage could lead to the facility operating at continuing disadvantages such as low safety, increase in maintenance time, poor utilization of space, poor expansion capabilities, high operating cost, etc.

As a result of the volatile nature of LPG, operations carried out in the station pose a significant risk to the everyday worker as well as the customers. This risk could be mitigated by the inherent design of safety in the layout of the LPG refilling station [9]. This study focuses on the layout of a LPG refilling station with the primary objectives of providing a safe environment for the operation of a LPG refilling station as well as mitigating the risk associated with the operation of a LPG refilling station. In order to integrate safety into plant layout, various approaches such as Minimum Distance Approach, Index-based Approach and Mathematical Programming Approach have been developed and established [10 - 13]. In this study, one of the approaches was explored in the design of safety in the layout. The Mathematical Programming Approach (Mixed Integer Linear Programming) adopted provides a general systematic framework for problem analysis. A variety of different problems can be formulated using the same mathematical tools for the overall optimization of the system being analyzed. Facilities involved in the handling of volatile substances

which are similar to LPG could also find the study very useful. The anticipated benefits would include reduced costs, better customer confidence, lower operational risk, increased productivity, easy expansion among others.

## EXPERIMENTAL

### Collection of data

The information required and collected include: (i) Operation and process description, which gives the general overview about the operation of LPG refilling plant; (ii) Cost parameters, which include information about the replacement cost of the facilities, cost of interconnection (piping, valves, etc.). This also includes information on the compensation of persons involved in explosive accident resulting in major injuries and death; and (iii) Safety parameters, which include information on hazardous units, as well as the distance of exposure,  $D_i^e$  of the hazardous units.

### Sources of data

The sources of data for this study include (i) expert opinion such as cost of land, cost of construction, remuneration of workers, etc.; (ii) market survey for items readily available in the market within close ranges.

### Model assumptions

The following assumptions were made in this study.

Shapes of units and facilities are assumed to be rectangular irrespective of their actual shapes;

The available piece of land is assumed to be rectangular irrespective of its actual shape; and

The distances between facilities are assumed to be rectilinear.

Model notations

#### Indices

$i, j$  = equipment items

$I_p$  = set of pertinent process units

#### Parameters

$x_{max}$  = breadth of the available piece of land

$y_{max}$  = length of the available piece of land

$C_{ij}$  = cost of connection between items  $i$  and  $j$

$C_i^p$  = cost of purchase of item  $i$

$D_i^e$  = distance of exposure of item  $i$

DF $i$  = damage factor of item  $i$

$F1_i$  = general process hazards factor of item  $i$

$F2_i$  = special process hazards factor of item  $i$

$F3_i$  = process unit hazards factor of item  $i$

$F_i$  = fire and explosion index of item  $i$

$M$  = upper bound for total rectilinear distance

$MF_i$  = material factor for item  $i$

$\alpha_i, \beta_i$  = dimensions of item  $i$

#### Continuous variables

$l_i$  = length of item  $i$

$d_i$  = depth of item  $i$

$x_i, y_i$  = co-ordinates of the centre of item  $i$

$A_{ij}$  = relative distance in  $y$  co-ordinates between item  $i$  and  $j$  if  $i$  is above  $j$

$B_{ij}$  = relative distance in  $y$  co-ordinates between item  $i$  and  $j$  if  $i$  is below  $j$

$D_{ij}$  = total rectilinear distance between item  $i$  and  $j$

$D_{ij}^{in}$  = total rectilinear distance between item  $i$  and  $j$  if

$D_{ij}$  is smaller than  $D_i^e D_{ij}^{out}$  = total rectilinear distance between item  $i$  and  $j$  if  $D_{ij}$  is larger than  $D_i^e L_{ij}$  = relative distance in  $x$  co-ordinates between item  $i$  and  $j$  if  $i$  is to the left of  $j$

$R_{ij}$  = relative distance in  $x$  co-ordinates between item  $i$  and  $j$  if  $i$  is to the right of  $j$

$\Omega_i^0$  = base maximum probable property damage cost for pertinent process unit  $i$

$V_i^e$  = value of the area of exposure of pertinent process unit  $i$ .

#### Binary variables

$E1_{ij}$  = non-overlapping binary variables

$E2_{ij}$  = non-overlapping binary variables

$O_i$  = 1 if length of item  $i$  is equal to  $\alpha$  (i.e. parallel to  $x$ -axis); 0 otherwise

$W_{ij}^x$  = 1 if  $i$  is to the right of  $j$ ; 0 otherwise

$W_{ij}^y$  = 1 if  $i$  is above  $j$ ; 0 otherwise

$\Psi_{ij}$  = 1 if  $j$  is allocated within the area of exposure of  $i$ ; 0 otherwise

$m_{iy}$  = binary variables

$m_{ix}$  = binary variables

#### Model formulation

Mathematically, an optimization program can be constructed as given in Eqs. (1) and (2)

Maximize:

$$Z = f(x) \quad (1)$$

(Objective Function)

Subject to:

$$g_i(x) \leq b_i, \quad i = 1, 2, 3, \dots, m, \quad (\text{Constraints}) \quad (2)$$

#### Objective function

The objective function is the total sum of the costs which can be divided into interconnection cost (cost of piping, valves, etc.) and financial risk (cost of damaged facilities, loss of human life in the event of an accident etc).

Mathematically, the objective function  $Z$  becomes Eq. (3)

$$Z = \text{Interconnection cost} + \text{financial risk} \quad (3)$$

The sub-costs when broken down can be explained using Eqs. (4) and (5):

$$\text{Interconnection cost} = \sum_i \sum_{j \neq i} I_{ij} \cdot C_p \cdot D_{ij} \quad (4)$$

$$\text{Financial cost} = \sum_i \Omega_i$$

where  $I_{ij}$  = equal 1 when units  $i$  and  $j$  are connected else 0,  $C_p$  = cost of interconnection per unit length expressed in  $\mathbb{N}/m$ ,  $D_{ij}$  = distance between items  $i$  and  $j$  expressed in metres,  $\Omega_i$  = value of the area of exposure of item  $i$  expressed in  $\mathbb{N}$ .

The objective function can now be stated as Eq. (6)

Minimize

$$Z = \sum_i \sum_{j \neq i} I_{ij} \cdot C_p \cdot D_{ij} + \sum_i \Omega_i \quad (6)$$

#### Model constraints

In order to model the layout mathematically, the available piece of land was represented on the Cartesian plane, with the  $y$ -axis representing the breadth of available land, while the  $x$ -axis represents the length of available land.

#### Equipment orientation constraints

In order to specify the orientation of the dimensions of the facilities, the dimension of the facility  $i$  measured are specified as Eqs. (7) and (8):

$$l_i = \alpha_i \cdot O_i + \beta_i \cdot (1 - O_i) \quad \forall_i \quad (7)$$

$$d_i = \alpha_i + \beta_i - l_i \quad \forall_i \quad (8)$$

The binary variables  $O_i$  is used to specify when a specified dimension is parallel to the  $x$ -axis or  $y$ -axis. When  $O_i$  is equal to 1, the dimension  $\beta$  is parallel to

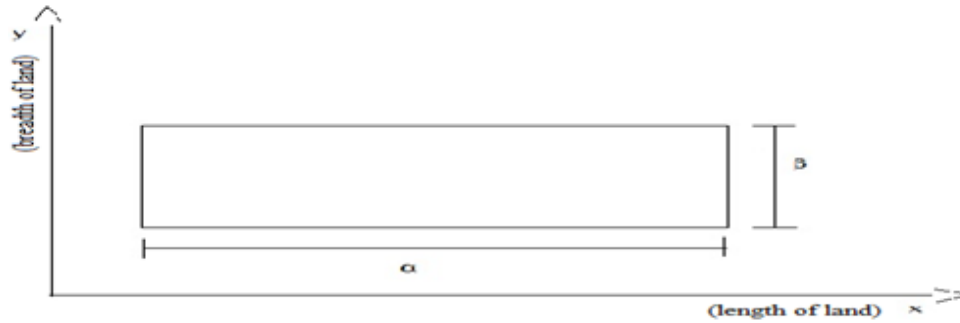


Fig. 1. Orientation of facility i with dimensions  $\alpha$  and  $\beta$ .

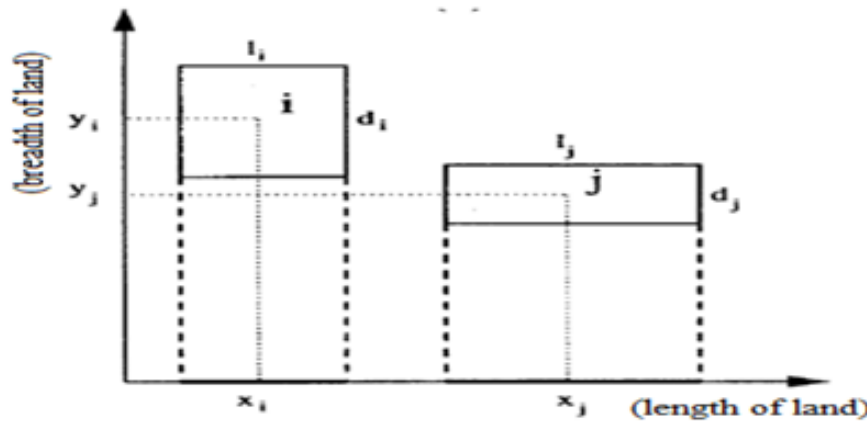


Fig. 2. Relative position of two different equipment i and j.

the y-axis, otherwise it is parallel to the x-axis. Fig. 1 shows an example of a facility with dimension  $\alpha$  and  $\beta$ , when  $O_i$  is 1.

**Non – overlapping constraints**

To ensure that no two facilities are placed on the same land area, non-overlapping constraints are introduced. Fig. 2 shows the position of two facilities relative to one another.

An analysis of Fig. 2 reveals that provided the distance between either the x- and y-coordinate of the units  $i$  and  $j$  exceeds half the sum of the dimensions of the facilities, the facilities  $i$  and  $j$  cannot overlap. Mathematically,

$$x_i - x_j \geq \frac{l_i + l_j}{2}; \quad (x_i > x_j) \tag{9}$$

$$x_j - x_i \geq \frac{l_i + l_j}{2}; \quad (x_j > x_i) \tag{10}$$

$$y_i - y_j \geq \frac{l_i + l_j}{2}; \quad (y_i > y_j) \tag{11}$$

$$y_j - y_i \geq \frac{l_i + l_j}{2}; \quad (y_j > y_i) \tag{12}$$

These separate (disjunctive) constraints in Eqs. (9)

- (12) can be integrated using the “big-M” formulation. The “big-M” formulation is a modelling technique used to convert disjunctive conditions into dependent conditions using the mixed integer linear form. This conversion is necessary as conditions in Eqs. (9) - (10) cannot simultaneously hold, just as conditions in Eqs. (11) and (12) cannot also simultaneously hold. The constraints in Eqs. (9) - (10) then become constraints in Eqs. (13) to (16), respectively.

$$x_i - x_j + M \cdot (1 - Z_{xij}) \geq \frac{l_i + l_j}{2} \tag{13}$$

$$\forall i = 1, \dots, N - 1, j = i + 1, \dots, N$$

$$x_j - x_i + M \cdot (1 - Z_{xji}) \geq \frac{l_i + l_j}{2} \tag{14}$$

$$\forall i = 1, \dots, N - 1, j = i + 1, \dots, N$$

$$y_i - y_j + M \cdot (1 - Z_{yij}) \geq \frac{d_i + d_j}{2} \tag{15}$$

$$\forall i = 1, \dots, N - 1, j = i + 1, \dots, N$$

$$y_j - y_i + M \cdot (1 - Z_{yji}) \geq \frac{d_i + d_j}{2} \tag{16}$$

$$\forall i = 1, \dots, N - 1, j = i + 1, \dots, N$$

where  $M$  is an appropriate upper bound (sufficiently large) on the dimension of the facilities, and  $Z_{xij}, Z_{xji}, Z_{yij}, Z_{yji}$  are binary variables.

To ensure that both conditions in Eqs. (13) and (14) do not simultaneously hold, Eq. (17) was generated

$$Z_{xij} + Z_{xji} \leq 1 \quad (17)$$

Also, to ensure conditions in Eqs. (15) and (16) do not simultaneously hold, Eq. (18) was generated

$$Z_{yij} + Z_{yji} \leq 1 \quad (18)$$

Eq. (19) is generated in order to ensure that at least one of the conditions in Eqs. (13) - (16) holds

$$Z_{xij} + Z_{xji} + Z_{yij} + Z_{yji} \geq 1 \quad (19)$$

It should be noted that the above formulation requires seven (7) constraints and four (4) binary variables per pair of unit  $i$  and  $j$ . An alternative formulation requiring only two (2) binary variables and four (4) constraints is possible,

$$x_i - x_j + M \cdot (E1_{ij} + E2_{ij}) \geq \frac{l_i + l_j}{2} \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (20)$$

$$x_j - x_i + M \cdot (1 - E1_{ij} + E2_{ij}) \geq \frac{l_i + l_j}{2} \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (21)$$

$$y_i - y_j + M \cdot (1 + E1_{ij} - E2_{ij}) \geq \frac{d_i + d_j}{2} \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (22)$$

$$y_j - y_i + M \cdot (2 - E1_{ij} - E2_{ij}) \geq \frac{d_i + d_j}{2} \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (23)$$

The binary variables  $E1_{ij}$  and  $E2_{ij}$  are introduced in Eqs. (20 - 23) to reduce the number of constraints needed to enforce the non-overlap condition. When the binary variables  $E1_{ij}$  and  $E2_{ij}$  assume different states, the following conditions ensue,

When,  $E1_{ij}$  equals 0 and  $E2_{ij}$  equals 0, constraints (20) is active

$E1_{ij}$  equals 1 and  $E2_{ij}$  equals 0, constraints (21) is active

$E1_{ij}$  equals 0 and  $E2_{ij}$  equals 1, constraints (22) is active

$E1_{ij}$  equals 1 and  $E2_{ij}$  equals 1, constraints (23) is active.

### Distance constraints

It is often desirable to use rectilinear distances as against straight line distance as they provide a more realistic estimate of piping cost [9]. Therefore the distance between items  $i$  and  $j$  which is the sum of the distance between the x coordinates and the distance between the y coordinates, is specified as shown in Eqs. (24) - (25).

$$R_{ij} - L_{ij} = x_i - x_j \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (24)$$

$$A_{ij} - B_{ij} = y_i - y_j \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (25)$$

where,

$R_{ij}$  = distance between the x co-ordinates of facilities  $i$  and  $j$  when  $i$  is to the right of  $j$ .

$L_{ij}$  = distance between the x co-ordinates of facilities  $i$  and  $j$  when  $i$  is to the left of  $j$ .

$A_{ij}$  = distance between the y co-ordinates of facilities  $i$  and  $j$  when  $i$  is to the top of  $j$ .

$B_{ij}$  = distance between the y co-ordinates of facilities  $i$  and  $j$  when  $i$  is to the bottom of  $j$ .

Fig. 3 shows  $L_{ij}$  and  $B_{ij}$  for a given position of units  $i$  and  $j$ .

In order to prevent the variables,  $R_{ij}$  and  $L_{ij}$  from being present at the same time, as an item  $i$  cannot be to the left and to the right of item  $j$  simultaneously, we use the "big-M" formulation used earlier by introducing the binary variable  $W_{ij}^x$  (Eq. (26)), ostensibly when  $W_{ij}^x$  equals 1, the item  $j$  is to the left of item  $i$ , and constraint (27) is not active. The same pattern of reasoning holds with constraints (28) and (29) in the vertical Y-Axis.

$$R_{ij} \leq M \cdot W_{ij}^x \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (26)$$

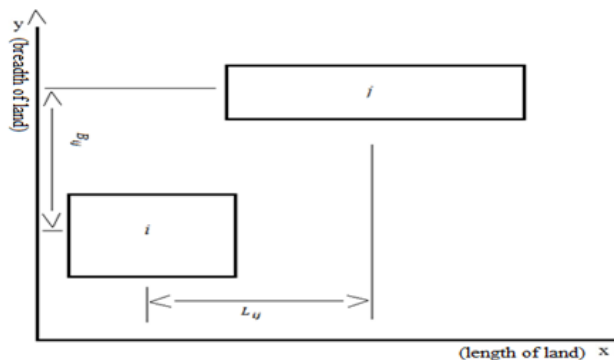


Fig. 3.  $L_{ij}$  and  $B_{ij}$  for units  $i$  and  $j$  as positioned.

$$L_{ij} \leq M \cdot (1 - W_{ij}^x) \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (27)$$

$$A_{ij} \leq M \cdot W_{ij}^y \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (28)$$

$$B_{ij} \leq M \cdot (1 - W_{ij}^y) \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (29)$$

The total rectilinear distance is given as shown in Eqs. (30) - (31).

$$D_{ij} = R_{ij} + L_{ij} + A_{ij} + B_{ij} \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (30)$$

$$D_{ij} = D_{ji} \quad \forall_i = 1, \dots, N - 1, j = i + 1, \dots, N \quad (31)$$

**Available land constraint**

All facilities and equipment must stay on available land, therefore Eq. (32) - (33) hold to ensure that all facilities and equipment find places on the land.

$$x_i + \frac{l_i}{2} \leq x_{max} \quad \forall_i \quad (32)$$

$$y_i + \frac{d_i}{2} \leq y_{max} \quad \forall_i \quad (33)$$

In order to forestall the co-incidence items with the axes origin of items, the following constraints in Eqs. (34) - (35) are introduced.

$$x_i \geq \frac{l_i}{2} \quad \forall_i \quad (34)$$

$$y_i \geq \frac{d_i}{2} \quad \forall_i \quad (35)$$

where  $x_{max}$  and  $y_{max}$  refer to the dimensions of the available piece of land.

**Area of exposure constraints**

In order to determine whether an item  $i$  lies within the area of exposure of item  $j$ , the Dow Fire and Explosive Index (DFEI) defines the variable  $D_i^e$  as the distance of exposure of item  $j$  from item  $i$  which is a measure of the state of safety of item  $j$  given an expo-

sion of item  $i$ . Items contained within the distance of exposure  $D_i^e$  of item  $i$  are considered at risk of damage while items  $j$  out of the range are considered not at risk. Let  $D_{ij}^{in}$  represent a state when the unit  $j$  is within the distance of exposure of unit  $i$  and  $D_{ij}^{out}$  represent a state where the unit  $j$  is out of the distance of exposure of item  $i$ . The distance between them  $D_{ij}$  can therefore be perceived as either of both states  $D_{ij}^{in}$  and  $D_{ij}^{out}$  as shown mathematically in Eq. (36).

$$D_{ij} = D_{ij}^{in} + D_{ij}^{out} \quad \forall_i \in I_p, j \neq i \quad (36)$$

To model this two disjunctive states, we use the “big-M” formulation, to ensure that  $D_{ij}$  does not assume the simultaneous states of being at risk and not being at risk, as shown in Eqs. (37) - (39).

$$D_{ij}^{in} \leq D_i^e \cdot \Psi_{ij} \quad \forall_i \in I_p, j \neq i \quad (37)$$

$$D_{ij}^{out} \geq D_i^e \cdot (1 - \Psi_{ij}) \quad \forall_i \in I_p, j \neq i \quad (38)$$

$$D_{ij}^{out} \leq M \cdot (1 - \Psi_{ij}) \quad \forall_i \in I_p, j \neq i \quad (39)$$

where  $\Psi_{ij}$  is a binary variable. When  $\Psi_{ij}$  equals 1, constraint (36) is active, and  $D_{ij}$  equals  $D_{ij}^{in}$ , otherwise constraint (37) is active when  $\Psi_{ij}$  equals 0.

Assuming there is a linear relationship between the total cost of damage  $C_i^p$  of item  $i$  and cost of damage  $C_j^p$  of item  $j$ , as a function of the distance  $D_{ij}$  between items  $i$  and  $j$ , as suggested by Floudas (1995), the value (financial) of the area of exposure  $V_i^e$  can now be computed as,

$$V_i^e = C_i^p + \sum_{j \neq i} (C_j^p \cdot \Psi_{ij} - \frac{C_j^p}{D_i^e} \cdot D_{ij}^{in}) \quad \forall_i \in I_p \quad (40)$$

where  $I_p$  is the set of potentially hazardous facilities  $i$  such as LPG storage tanks, delivery truck etc. An investigation into Eq. (40) reveals that the cost  $C_i^p$  of the pertinent unit  $i$ , remains constant, while the other part of the expression,  $\sum_{j \neq i} (C_j^p \cdot \Psi_{ij} - \frac{C_j^p}{D_i^e} \cdot D_{ij}^{in})$

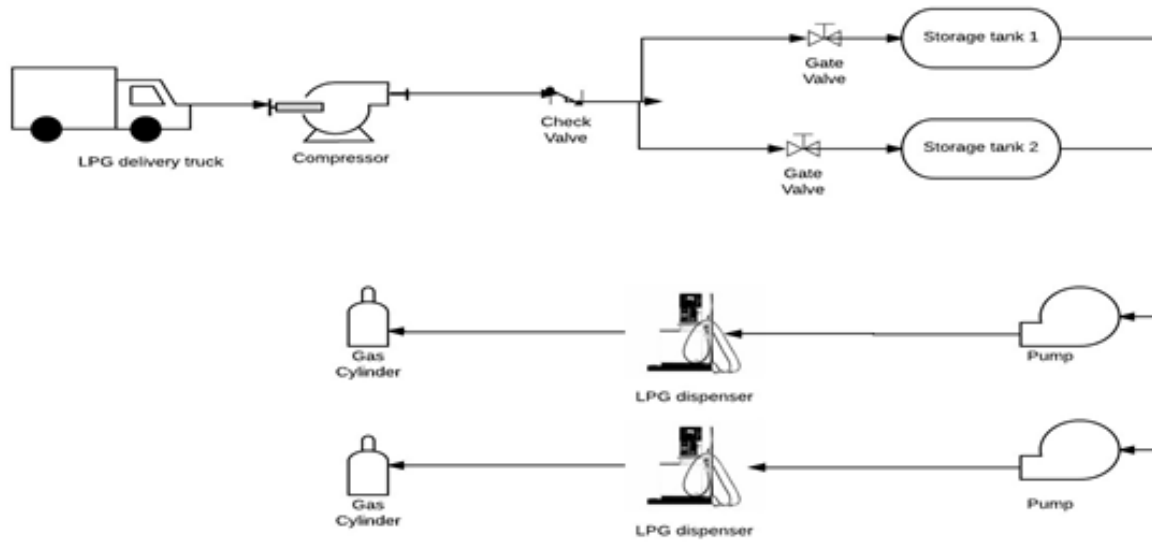


Fig. 4. Schematic showing the overview of the processes of an LPG refilling station. (Note: Compressor and Pump are located in the pumping unit).

reveals a inversely proportional relationship between the distance  $D_{ij}^{in}$  and the cost  $C_j^p$  of target item  $j$  in the event of an explosion of pertinent unit  $i$ . The expression simply reduces to the cost  $C_i^p$  of item  $i$  when  $\Psi_{ij}$  equals 0 i.e  $D_{ij}^{in}$  equals 0.

### Maximum probable damage constraints

The maximum probable damage constraints are introduced in accordance with the guidelines on the usage of DFEI. The constraint provides a realistic insight into the damage cost of an explosion of item  $i$ . The base maximum probable damage  $\Omega_i^0$  can be calculated using Eq. (41).

$$\Omega_i^0 = DF_i \cdot V_i^e \quad \forall_i \in I_p \quad (41)$$

### Model translation

This is the translation of the model into programming language so that the model can be solved using an appropriate solver. For this study, IBM AMPL Optimization program was utilized to solve the model.

### Interpretation of result

The results obtained from the solution of the model are then analyzed and the parameter adjusted if need be. The result can then be used in the design layout of the refilling plant.

### Process and operations description

The operations of a LPG refilling plant can be broadly divided into primary activities such as the ac-

tual refilling of empty cylinders, purchasing of refilling gas by customers, discharging of LPG from the supply trucks; and support activities which include administrative functions, maintenance of LPG cylinders for customers, security functions, parking space for customers, e and so on.

The LPG refilling process can be described as shown in Fig. 4 starting with the delivery of LPG to the storage tanks using LPG bobtail trucks. The LPG is transferred from the trucks using compressors; that are usually attached to the chassis of the truck; through series of valves and pipes into the LPG bullet storage tanks (Fig. 5). From the tanks, connections are made to the pumps which then transfers the LPG to the dispensers located in the refilling area where cylinders are refilled in the presence of customers in order to ensure that the correct volume is dispensed.

In order to carry out the primary and secondary activities, the following plant configurations provided in Table 1 were considered in this study.

## RESULTS AND DISCUSSION

### Dimension and cost data

This section present the information on the parameters used in the layout of the refilling plant. Table 2 displays the description and dimension of units of the plant layout.

In order to determine the compensation in the event of an explosive accident leading to death and major

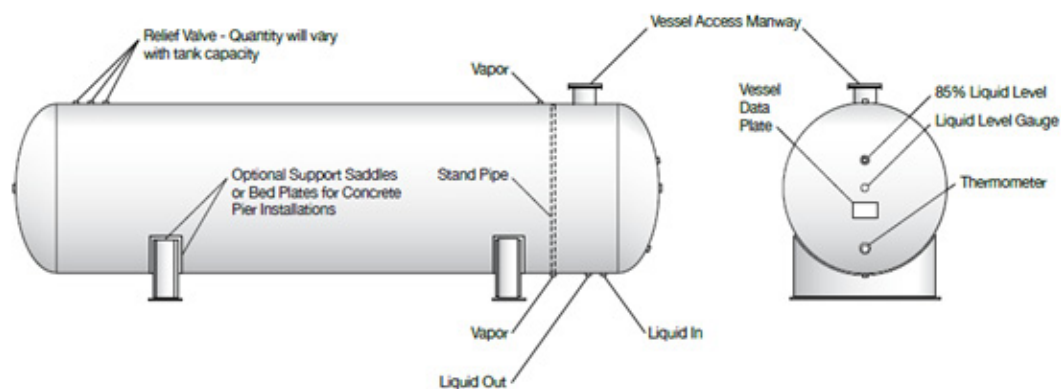


Fig. 5. LPG bulk storage “bullet” tank.

Table 1. Description of the units in the LPG refilling plant.

S/N	Unit	Description
1.	LPG storage tank 1	100m <sup>3</sup> / 50 Metric Tonnes capacity bullet tank
2.	LPG storage tank 2	100m <sup>3</sup> / 50 Metric Tonnes capacity bullet tank
3.	LPG discharge truck	25 m <sup>3</sup> /12.5 Metric Tonnes Capacity LPG delivery truck.
4.	Refilling Unit	LPG refilling area, open shed construction in order to aid easy dissipation of any leaked gases.
5.	Pumping and Compression unit	Area containing the pump and compressors.
6.	Administrative Unit	Area where administrative function such as management are located. e.g. offices
7.	Maintenance Unit	Area where maintenance function are carried out such as cylinder maintenance, facilities maintenance etc.

Table 2. Dimensions of the units.

S/N	Description of Unit	$\alpha$ (m)	$\beta$ (m)
1	Refilling Unit	15	6
2	LPG Storage Tank 1	20	2.7
3	LPG Storage Tank 2	20	2.7
4	Pumping & Compression Unit	2	2
5	LPG discharge Truck	9	4
6	Administrative Unit	6	9
7	Maintenance Unit	6	4

injury, the computed present worth of an annualized payment of 90% of the employees’ last wage for an estimated period of 21 years was used, as stipulated by the Employees Compensation Act of Nigeria (ECA) [14].

Mathematically,

$$\text{Annual Wage} = \$193.37 / \text{Month} \times 12 \text{ Months} = \$ 2320.44$$

$$\text{Annual Compensation (AV)} = \$2320.44 \times 0.9 = \$ 2088.40$$

$$\text{Period of payment (T)} = 21 \text{ years}$$

$$\text{Interest rate (i)} = 10\%$$

Table 3. Cost of the units.

S/N	Description	Cost (₦)	Source
1.	Refilling Unit	30,000,000	Expert opinion
2.	LPG Storage Tank 1	26,000,000	Market Survey
3.	LPG Storage Tank 2	26,000,000	Market Survey
4.	Pumping & Compression Unit	1,500,000	Market Survey
5.	LPG delivery truck	15,000,000	Market Survey
6.	Administrative Unit	26,000,000	Expert opinion
7.	Maintenance Unit	14,000,000	Expert opinion
8.	Cost of Piping/Meter	5,000	Market Survey
9.	Compensation per person in the event of death from an explosion	6,500,000	Estimate

Using the Present worth formula (Eq. (42)),

$$PV = AV \text{ multiplied by } \frac{(1+i)^n - 1}{i(1+i)^n} \quad (42)$$

$$PV = \$2088.40 \times 8.64 = \$18043.78.$$

This value will also be applied to the compensation of customers (non-staff) in the plant area.

The cost of the units of the plant is shown in Table 3.

*Cost Breakdown*

*Refilling Unit*

- = Cost of Open Shed = \$2762.43
- + Compensation for 2 Attendants = \$35911.60
- + Compensation for 2 Customers = \$35911.60
- + Cost of Two LPG Dispensers = \$8287.29
- \$82872.93

*LPG Storage tanks*

- = Cost of Tanks = \$44198.90
- + Cost of Stored LPG (₦ 200,000/MT) = \$27624.31
- \$71823.20

*Administrative Unit*

- = Cost of Building = \$13812.15
- + Compensation for 3 Staff = \$53867.40
- + Cost of computers, furniture, etc = \$4143.65
- \$71823.20

*Pumping & Compression Unit*

- = Cost of 2 Pumps (\$1381.22 each) = \$2762.43
- + Cost of offloading compressor = \$1657.46
- \$4419.89

*Maintenance Unit*

- = Cost of construction = \$2762.43
- + Compensation for 2 Staff = \$35911.60
- \$38674.03
- LPG delivery truck
- = Cost of truck = \$27624.31
- + Cost of stored LPG (₦ 200,000/MT) = \$13812.15
- \$41436.46

These costs are conveniently presented in Table 3.

***Safety parameters***

Based on the examination of historical data, the hazardous operations were identified to be the storage of LPG and the transfer of LPG from the delivery truck. The hazardous units therefore are the LPG storage tank 1, LPG storage tank 2, and LPG delivery truck.

Using the Dow Fire and Explosive Index, the necessary safety parameters were calculated as follows;

***Material factor (MFi)***

The Dow Fire and Explosion Index lists LPG (Propane and Butane) with a Material Factor of 21.

***General process factor (F1i)***

The Dow Fire and Explosive Index specifies a base penalty of 1.

The Dow Fire and Explosive Index specifies a penalty of 0.5 for the storage of the LPG.

The Dow Fire and Explosive Index specifies a penalty of 0.85 for the offloading and loading of LPG.

***Special process factor (F2i)***

The Dow Fire and Explosive Index specifies a base penalty of 1.

Table 4. Safety parameters.

$I_p$	$MF_i$	$F1_i$	$F2_i$	$UF_i$	$Fi$	$Di$	$DF_i$
Delivery truck	21	1.5	1.5	2.25	47.25	12.1	0.5
Storage Tank 1	21	1.5	3.65	5.48	114.98	29.434	0.6
Storage Tank 2	21	1.5	3.65	5.48	114.98	29.434	0.6

Table 5. Breakdown of the objective value.

S/N	Description	Sub- Cost (₦)	Cost(₦)	Total Cost (₦)
1.	Risk due to LPG Storage Tank 1	15,600,000		
2.	Risk due to LPG Storage Tank 2	15,600,000		
3.	Risk due to LPG discharge Truck	7,500,000		
4.	Total Residual Financial Risk	6	38,700,000	
5.	Total piping cost		628,000	
6.	Total Cost (₦)			39, 328,000

The Dow Fire and Explosion Index also specifies a penalty of 0.5 where the ingress of air could cause a hazard. The Dow Fire and Explosion Index specifies a bulk storage penalty which can be deduced from a graph showing the relationship between the total amount of energy in storage and the associated penalty (**Appendix 1**)

Given that the total energy stored measure in Btu (British thermal unit) is given as;

$$\begin{aligned} \text{Total Energy (50MT)} &= \\ \text{Heat of Combustion} \times \text{Total Amount of Material} \\ &= 19.9 \times 1000 \times 50000 \times 2.2 \\ &= 2.189 \times 10^9 \text{ Btu} \end{aligned}$$

$$\begin{aligned} \text{Total Energy (12.5MT)} &= \\ \text{Heat of Combustion} \times \text{Total Amount of Material} \\ &= 4.975 \times 1000 \times 50000 \times 2.2 = \\ &= 0.547 \times 10^9 \text{ Btu} \end{aligned}$$

The associated bulk storage penalty is deduced from the graph to be 2 for 50MT and 1 for 12.5MT

### 3.2.4. Damage factor ( $DF_i$ )

The Damage Factor ( $DF_i$ ) is also deduced using a graph showing the relationship between the Material Factor ( $MF_i$ ), General Process Factor ( $F1_i$ ) and the Special Process Factor ( $F2_i$ ) (**Appendix 2**)

Table 4 shows the safety parameters for the pertinent process units.

Using AMPL Optimization Package (with CPLEX

solver) to solve the resulting model with the necessary parameters, the following results were obtained.

The financial objective value was obtained to be \$108,640.88 with the breakdown given in Table 5.

Other optimal values of decision variables such as co-ordinates, orientation and so on are provided in the Table 6.

### Layout of the LPG refilling plant

The layout obtained shows the optimal position of the several units in the refilling plant (Fig. 6). The layout as expected positions the administrative and maintenance units furthest from the LPG storage tanks so as to prevent the loss of lives in the event of an explosive accident. The LPG delivery truck is also situated at a corner of the piece of land in order to prevent damage to other units in the event of an accident. Although the Dow Fire and Explosive Index was designed and intended for radial distances, its usage in the rectilinear distance provides a good estimate of the distance of exposure in any case.

An examination of the financial objective value reveals that besides from the loss of the pertinent units in the event of an accident, no other unit was expected to be at risk in the event of an explosion as they fall outside the Distance of Exposure,  $Di$ , of the pertinent units. The pertinent units were also out of the distance

Table 6. Co-ordinate and orientation of the units.

S/N	Description of Unit	X	Y	L	D
1	LPG Storage Tank 1	18.4	10	6	15
2	LPG Storage Tank 2	35	26.6	2.7	20
3	LPG discharge Truck	71.2	10	20	2.7
4	Refilling Unit	3	28	2	2
5	Pumping & Compression Unit	7	28	4	9
6	Administrative Unit	66.2	26.6	6	9
7	Maintenance Unit	61.2	17.5	4	6

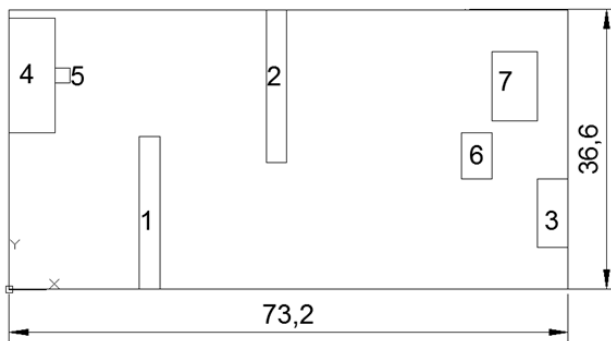
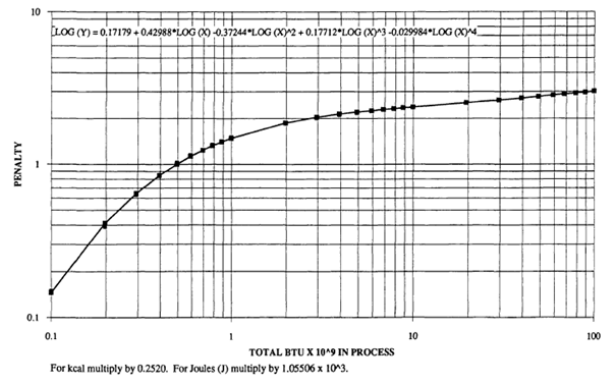


Fig. 6. Proposed Layout of the LPG refilling plant (1-LPG Storage tank 1, 2-LPG Storage tank 2, 3-LPG refilling truck, 4-Refiling Area, 5-Pumping Unit, 6-Maintenance Unit, 7-Administrative Unit).

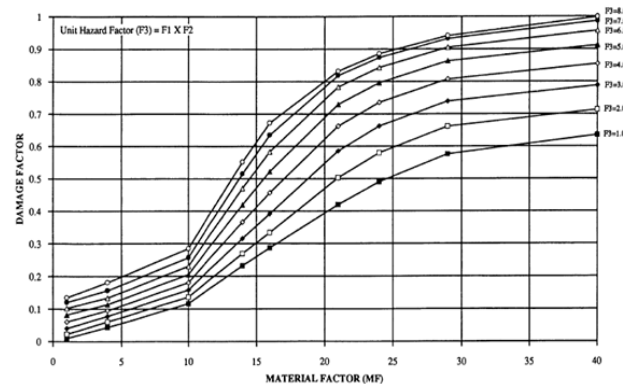
of exposure  $D_i$  to each other, effectively reducing the risk in the event of an accident. The layout also features good spacing characteristics which is integrally good for vehicular movement and quick dissipation of material in the event of a leak.

### CONCLUSIONS

The systematic layout of the LPG refilling plant using an integrated quantitative risk assessment with mathematical programming techniques afford the user the opportunity to approach the plant layout problem and obtain optimal solution to the problem. This is an invaluable attribute to the user who is conscious of the judicious use of resources. It also allows the user to access a wide range of option; given different parameter as it requires only subtle changes to the model. This is also of immense importance to the engineer who may



Appendix A. Graph showing the relationship between total energy and the associated penalty.



Appendix B: Graph showing the relationship between damage factor, material factor and Unit hazard factor.

like to test a wide range of parameters before selecting the most suitable. The final resulting layout features the characteristics of good spacing, efficient use of land, good cost, and lower financial risk amongst others. It is also important to note at this junction that the use of good layout does not preclude the use of modern safety

tools such as a safety program, as well as gadgets like gas detector, fire extinguishers and so on.

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