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Decision on the selection of the best height-diameter ratio for the optimal design of 13,000 m$^3$ oil storage tank

O. O. Agboola$^{1,2,3,*}$, B. O. Akinnuli$^{2,3}$, B. Kareem$^{2,3}$ and M. A. Akintunde$^3$

Abstract: The decision on the selection of the best height-diameter ratio for the optimal design of oil storage tanks is a difficult task because there are so many criteria to be considered in selecting the most appropriate alternative. In this study, Multi-Criteria Decision Analysis (MCDA) was used by adopting Criteria Importance Through Inter-criteria Correlation (CRITIC) in determining the objective weight of the criteria. The six criteria considered in this study are: Area occupied by the tank (m$^2$), Weight (kg), Wind Moment (Nm), Seismic Ringwall Moment RWM (Nm), Base shear (N) and Estimated Cost (₦) and the objective weights assigned to them by CRITIC are 0.2356, 0.2607, 0.1238, 0.1249, 0.1196 and 0.1354, respectively. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was then used to rank each of the alternatives based on the objective weight obtained through CRITIC. The objective of obtaining an optimal design of a 13,000 m$^3$ storage tank that will occupy less space, weighty to resist wind load and seismic overturning at a moderate (low) cost was achieved by Alternatives A$_4$ and A$_5$ (height-diameter ratios of 0.8 and 0.9). To validate the ranking result obtained by the TOPSIS method, another MCDA method, VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) was employed to compare the results. Validation of the TOPSIS method by

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PUBLIC INTEREST STATEMENT

Decision making involves identifying and choosing alternatives to get the best solution from a pool of available options based on different criteria and expectations of the decision-maker. Decisions are made in every facet of life, even in oil & gas. Multi-Criteria Decision Analysis (MCDA) is a potent tool used in decision making. The decision on the selection of the best height-diameter ratio for the optimal design of 13,000 m$^3$ oil storage tanks is a difficult task because there are so many criteria to be considered in selecting the most appropriate alternative. MCDA adopted in this study was Criteria Importance Through Inter-criteria Correlation (CRITIC) to determine the objective weight of the criteria. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and VIKOR were then used to rank each alternative. The decision on designing a storage tank that will occupy less space, weighty to resist wind load and seismic overturning at a moderate cost was achieved by height-diameter ratio 0.8.
VIKOR method revealed that there was high consistency in the results obtained, with a very high Spearman’s rank correlation coefficient of 0.8727. Sensitivity analysis was also done to ascertain the robustness of the results.

Subjects: Engineering Education; Mechanical Engineering Design; Engineering Management; Production Engineering

Keywords: Storage tank; TOPSIS; CRITIC; design; oil & gas; VIKOR

1. Introduction

Upright cylindrical tanks used in oil storage are designed to conform to standard and codes such as American Petroleum Institute (API) Standards, for example, API 650, API 620, and British Standard BS EN 14015. Tank design codes and standards are the documented facts and outcomes of the decades of work experience by some dedicated professionals. The full adoption of these standards helps in ensuring that the tanks can withstand the rigours of the stress conditions subjected to (Ammar et al., 2018; Okpala & Jombo, 2012).

Storage facility such as storage tanks is a key consideration in the oil sector because crude oil is stored temporarily before it is being exported or processed into refined products. Even in both the midstream and downstream sectors of oil and gas, the importance of storage tanks cannot be over-emphasized (Enarevba et al., 2016; Agboola et al., 2019; Agboola et al., 2017). For Nigeria to attain her desire of Vision 2020, all efforts should be channeled to the attainment of self-sufficiency in meeting her petroleum products’ demands through local refining. However, refineries require a high number of storage tanks for their operations. Samuel (2013) stated that this could be realized through proper and adequate maintenance of all her local refineries and by building new ones. As a result of expansion in the oil sector, there is a need for indigenous design and installation of bulk storage tanks in refineries and depots to adequately store these petroleum products instead of depending on the turnkey design from the foreign experts to save the country’s foreign exchange.

The choice of the type of upright cylindrical tanks depends on the number of factors. These factors are the safety requirement, environmental factor, nature of the fluid to be stored, available space, height-diameter ratio and operational cost (EEMUA Publication, 2003; John, 2004). In designing an upright cylindrical storage tank, the height-diameter ratio is an important factor that should be considered to know its effects on the design output parameters such as the Area occupied by the tank (m²), Weight (kg), Wind Moment (Nm), Seismic Ringwall Moment RWM (Nm), Base shear (N) and Estimated Cost (₦). Though API 650 does not give the actual value of height-diameter ratio but tank design experts stated that the height-diameter ratio ranges from 0.5 to 1.5 (Equipment Design Lecture 11 Tanks, 2019). The aim of this study is to select the best height-diameter for the optimum design of oil storage tank using Multi-Criteria Decision Analysis (MCDA). MCDA deals with decisions involving the choice of the best alternative from several available options, subject to several criteria or attributes which may be tangible or intangible (Stanojković & Radovanović, 2017). The objective weight of each criterion is defined based on the importance of each criterion relative to other criteria. Objective weights are numbers that are either subjectively selected or objectively derived for each criterion (Madić et al., 2015). Among the subjectively selected weights are Analytic Hierarchy Process and the Analytic Network Process. These are the two traditional MCDA methods developed by Saaty (Madić & Radovanović, 2015; Milić & Župac, 2012). However, the two methods possess inherent deficiencies that affect the rankings in the real-world application (Diakoulaki et al., 1995; Naga et al., 2016). This is because they failed to relate each criterion concurrently with other criteria (Balli & Korukoglu, 2009). To improve these deficiencies, another method of determining objective weight was developed called Criteria Importance Through Inter-criteria Correlation (CRITIC). CRITIC and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) were employed by Stanojković and Radovanović (Stanojković & Radovanović, 2017) in the selection of solid carbide end mill for machining aluminum 6082-T6. An extensive review of the applications of the TOPSIS method in
various fields of technical and managerial decision-making could be found in Babatunde and Ighravwe (2019), Bagheri et al. (2018), and Tlig and Rebai (2017); Behzadian et al. (2012) (Babatunde & Ighravwe, 2019; Bagheri et al., 2018; Behzadian et al., 2012; Tlig & Rebai, 2017).

2. Materials and methods
The Storage tank considered in this study is a 13,000 m$^3$ PMS tank designed in accordance with API 650 and to be erected at Apapa, Nigeria in total compliance to the DPR guidelines. The values of design output parameters based on various height-diameter ratios (Alternatives) are tabulated and presented in Table 1. The criteria considered were space occupied, the overall weight of the tank, resistance to wind load, resistance to seismic ringwall moment, base shear and estimated fabrication cost. Then, the CRITIC was used to determine the objective weight of each criterion. Thereafter, the ranking of each alternative was achieved by both the TOPSIS and VIKOR (VISeKriterijumska Optimizacija I Kompromisno Resenje) methods. The two results (ranks) obtained from both the TOPSIS and VIKOR methods were compared. VIKOR and TOPSIS methods were used because they are based on an aggregating function representing “closeness to the ideal solution” which originates in the compromise programming method (San Cristóbal, 2011).

The six (6) criteria used in evaluating the alternatives were determined from the standardized Equations (1–6)

Area occupied by the tank (m$^2$) = $\frac{\pi d^2}{4}$

Weight of the tank (kg) = $\left[\left(\frac{\pi d^2 t_b \rho_b}{4}\right) + \left(\pi d p_s \sum h_i t_i\right) + \left(\frac{\pi d p_l t_c (4r_i^2 + D^2)}{8}\right)\right]$

Wind moment (Nm) = $(w_r H r_h) + (w_i H)$

Seismic Ringwall moment (Nm) = $\sqrt{[A_i (w_r X_i + w_c t_i + w_i l_i)]^2 + [A_c (w_c X_c)]^2}$

Base Shear (N) = $\sqrt{V_r^2 + V_c^2}$

Estimated cost (N) = $\left[\left(\frac{\pi d^2 t_b \rho_b}{4}\right) + \left(\pi d p_s \sum h_i t_i\right) + \left(\frac{\pi d p_l t_c (4r_i^2 + D^2)}{8}\right)\right] \times C_u$

where $d$ is the nominal diameter of the tank, $t_b$ is the thickness of bottom plate, $\rho_b$ is the density of bottom plate, $p_s$ is the density of shell plate, $p_l$ is the density of roof plate, $h_i$ is the height of each course plate, $t_i$ is the thickness of each plate, $r_i$ is the roof height, $H$ is the nominal tank height, $w_r$ is the wind load on the roof, $w_c$ is the wind load on the shell, $V_i$ is the impulsive shear force, $V_c$ is the convective shear force, $A_i$ is the impulsive acceleration, $A_c$ is the convective acceleration, $w_i$ is the impulsive wind load, $w_c$ is the impulsive wind load, $w_i$ is the wind load on the roof, $X_i$ is the impulsive centre of action, $X_c$ is the convective centre of action, $l_i$ is the moment arm of the shell, $l_r$ is the moment arm of the roof.

3. CRITIC
Determining the objective weights using the CRITIC method was done by adopting these six steps (Madić et al., 2015; Madić & Radovanović, 2015).

$$r_{ij} = \frac{x_{ij} - x_{ij}^{worst}}{x_{ij}^{best} - x_{ij}^{worst}}$$

1. Determination of the elements of normalized decision matrix $r_{ij}$ using Equation 7.
| Height-Diameter ratio | Area occupied (m²) | Weight of tank (kg) | Wind moment (Nm) | Seismic Ringwall moment (Nm) | Base shear (N) | Estimated cost (₦) |
|----------------------|-------------------|--------------------|-----------------|-----------------------------|---------------|-------------------|
| 0.5                  | 773.61            | 271,213.25        | 7,398,007.96    | 138,941,492.16              | 20,392,184.87 | 171,271,170       |
| 0.6                  | 687.66            | 271,748.34        | 8,778,819.38    | 173,832,828.30              | 22,877,103.97 | 171,609,076       |
| 0.7                  | 618.89            | 272,649.99        | 10,236,850.57   | 209,646,707.96              | 24,986,591.72 | 172,178,470       |
| 0.8                  | 562.63            | 276,305.28        | 11,768,181.85   | 251,334,864.56              | 26,299,403.95 | 174,486,783       |
| 0.9                  | 562.63            | 276,305.28        | 11,768,181.85   | 251,334,864.56              | 26,299,403.95 | 174,486,783       |
| 1.0                  | 515.74            | 284,786.45        | 13,369,439.65   | 293,779,079.78              | 27,365,058.39 | 179,842,644       |
| 1.1                  | 476.07            | 287,172.24        | 15,037,679.73   | 335,676,349.98              | 28,216,805.15 | 181,349,272       |
| 1.2                  | 442.06            | 295,094.48        | 16,770,302.75   | 377,968,944.07              | 28,940,257.82 | 186,352,795       |
| 1.3                  | 412.59            | 306,716.21        | 18,564,991.54   | 40,561,372.12               | 29,562,710.73 | 193,691,284       |
| 1.4                  | 412.59            | 306,716.21        | 18,564,991.54   | 40,561,372.12               | 29,562,710.73 | 193,691,284       |
| 1.5                  | 386.81            | 317,033.32        | 20,419,663.25   | 462,973,356.98              | 30,091,816.42 | 200,206,539       |
where $x_{j}^{\text{worst}}$ = maximum of non-beneficial criteria and minimum of beneficial criteria ($x_{ij}$, $i = 1$, ..., $m$) and $x_{j}^{\text{best}}$ = minimum of non-beneficial criteria and maximum of beneficial criteria ($x_{ij}$, $i = 1$, ..., $m$)

$$\sigma_j = \sqrt{\frac{1}{n} \left( \sum_{i=1}^{m} \left( x_{ij} - \bar{r} \right)^2 \right)} \quad (8)$$

2. Based on the value $r_{ij}$ a vector of criteria was formed, each vector has a standard deviation $\sigma_j$, which represents the degree of deviation of alternatives for a given criterion. Standard deviation is calculated using Equation (8) where: $n$ is a number of elements and $\bar{r}$ is an arithmetic mean.

3. Formation of a symmetric matrix $n \times n$ with elements $R_{jk}$, which represent linear correlation coefficients $r_{jk}$, and $n$ represents the number of alternatives, using Equation (9). When there is a large discrepancy between the values of attributes for criteria $j$ and $k$, it is the lower value of the coefficient $R_{ij}$ that is considered (Madić & Radovanović, 2015; Milić & Župac, 2012).

$$R_{ij} = \frac{n \sum_{k=1}^{n} r_{jk} - \sum_{j}^{n} \sum_{k}^{n} r_{jk}}{\sqrt{n \sum_{j=1}^{n} (\sum_{k=1}^{n} r_{jk})^2} \sqrt{n \sum_{k=1}^{n} (\sum_{j=1}^{n} r_{jk})^2}} \quad (9)$$

4. Determination of the rates of the conflict criteria (Diakoulaki et al., 1995) using Equation (10) $R = 1 - r_{jk}$

5. Establishing the quantity of the information in relation to each criterion using Equation (11)

$$C_j = \sigma_j \sum_{k=1}^{n} (1 - R_{jk}) \quad (11)$$

6. Normalization of the value of $C_j$ using Equation (12) to obtain the objective weight.

$$w_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \quad (12)$$

4. TOPSIS

1. Determining the objective, alternatives and criteria.

The objective is to evaluate the eleven (11) alternatives (height-diameter ratio in designing oil storage tanks) based on the criteria [Area Occupied (m$^2$), Weight (kg), Wind Moment (Nm), Seismic Ringwall moment (Nm), Base shear (N), Estimated Cost (₦)].

2. Based on the given values, the decision matrix $X$ is defined by Equation (13)

$$X = [x_{ij}] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (13)$$

3. Normalization of the decision matrix is done by adopting Equation 14 (Balli & Korukoglu, 2009; Naga et al., 2016).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \quad (14)$$

4. Calculate the values of the objective weight coefficients with Equation (15)
\[ \sum_{j} w_j = 1 \]  

5. Determine the weighted decision-making matrix using Equation (16), which represents the multiplication of elements of a column of the normalized matrix with appropriate objective weight coefficients obtained from Equation (12).

\[ v_{ij} = r_{ij} w_j \]  

(16)

6. Identify the positive and negative ideal solution based on Equations (17) and (18)

\[ V^+ = \{ \max_{j, i} (v_{ij}) \}, \text{subject to } v_{ij} = 1 \} = \{ V_1^+, V_2^+, \ldots, V_n^+ \} \]  

(17)

\[ V^- = \{ \min_{j, i} (v_{ij}) \}, \text{subject to } v_{ij} = 1 \} = \{ V_1^-, V_2^-, \ldots, V_n^- \} \]  

(18)

7. Calculate the Euclidean separation distance of each competitive alternative from the positive and negative solution using Equations (19) and (20)

\[ S^+_i = \sqrt{\sum_{j=1}^{n} (v_{ij} - V_{ij}^+)^2} \]  

(19)

\[ S^-_i = \sqrt{\sum_{j=1}^{n} (v_{ij} - V_{ij}^-)^2} \]  

(20)

8. Measure the relative closeness of each location of the ideal solution \( P_i \). For each competitive alternative the relative closeness of the potential location with respect to the ideal solution is calculated by using Equation (21)

\[ P_i = \frac{S^-_i}{S^-_i + S^+_i} \]  

(21)

9. The order of the alternatives is done according to the value of \( P_i \) obtained in Equation (21)

5. VIKOR

VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) is a Serbian language which means Multicriteria Optimization and Compromise Solution was practically applied in 1998 (Opricovic, 1998). The procedures for VIKOR are as itemized in Equations (22–26)

1. Establishment of a decision matrix as shown in Equation (22)

\[ I = [I_{ij}] = \begin{bmatrix} I_{11} & I_{12} & I_{1n} \\ I_{21} & I_{22} & I_{2n} \\ I_{m1} & I_{m2} & I_{mn} \end{bmatrix} \]  

(22)

2. Normalization of decision matrix using Equation (23)

\[ f_{ij} = \frac{I_{ij}}{\sqrt{\sum_{j=1}^{n} (I_{ij})^2}} \]  

(23)

3. Calculate utility measure \( S_j \) and Regret measure \( R_j \) using Equations (24a,b), (25a,b)

\[ s_j = \sum_{i=1}^{n} w_i \left[ \frac{(f_{ij})_{\max} - (f_{ij})}{(f_{ij})_{\max} - (f_{ij})_{\min}} \right] \text{ Beneficial criteria} \]  

(24a)
\[ S_i = \sum_{j=1}^{n} w_i \left( \frac{(f_{ij}) - (f_{ij})_{\text{min}}}{(f_{ij})_{\text{max}} - (f_{ij})_{\text{min}}} \right) \text{ Non beneficial criteria} \quad (24b) \]

\[ R_i = \text{maximum} \left\{ w_i \left[ \frac{(f_{ij})_{\text{max}} - (f_{ij})}{(f_{ij})_{\text{max}} - (f_{ij})_{\text{min}}} \right] \right\} \text{ Beneficial} \quad (25a) \]

\[ R_i = \text{maximum} \left\{ w_i \left[ \frac{(f_{ij}) - (f_{ij})_{\text{min}}}{(f_{ij})_{\text{max}} - (f_{ij})_{\text{min}}} \right] \right\} \text{ Non beneficial} \quad (25a) \]

4. Calculate the value of \( Q_i \) using Equation 26

\[ Q_i = v \left[ \frac{S_i - (S_i)_{\text{min}}}{(S_i)_{\text{max}} - (S_i)_{\text{min}}} \right] + (1 - v) \left[ \frac{R_i - (R_i)_{\text{min}}}{(R_i)_{\text{max}} - (R_i)_{\text{min}}} \right] \quad (26) \]

where \( f_{ij} \) is the normalized decision matrix; \( S_i \) is the utility measure, \( R_i \) is the regret measure, \( w_i \) is the objective weight of each criterion as obtained from CRITIC, \( v \) (compromised strategy) = 0.6; \( Q_i \) is the ranking index.

6. Results and discussion

Table 1 shows that as the value of the Height-Diameter ratio increases, the area occupied by the storage tank decreases while other output parameters such as weight, wind moment, seismic RWM (Ringwall moment), base shear and cost increase. The increase in cost is attributed to the increase in the weight because the cost of tank fabrication depends majorly on the weight of the metal plate used (API Standard 650, 2012; Enarevba et al., 2016).

Tables 2–5 are the Element of Normalized decision matrix and Standard deviation, 6 × 6 Matrix for the Criteria, Quantity of Information in relation to each criterion and Coefficient of Objective weight, respectively.

where, \( A_1 = 0.5, A_2 = 0.6, A_3 = 0.7, A_4 = 0.8, A_5 = 0.9, A_6 = 1.0, A_7 = 1.1, A_8 = 1.2, A_9 = 1.3, A_{10} = 1.4, A_{11} = 1.5, C_1 \) = Area, \( C_2 \) = Weight, \( C_3 \) = Wind Moment, \( C_4 \) = Seismic RWM, \( C_5 \) = Base Shear, \( C_6 \) = Estimated Cost

The weight (kg) of the tank has the highest coefficient of objective weight among other criteria while the Base shear (N) has the least coefficient as could be seen in Table 5. This implies that the weight of

| Alternatives | \( C_1 \) | \( C_2 \) | \( C_3 \) | \( C_4 \) | \( C_5 \) | \( C_6 \) |
|--------------|---------|---------|---------|---------|---------|---------|
| \( A_1 \)    | 0.0000  | 0.0000  | 1.0000  | 1.0000  | 1.0000  | 1.00    |
| \( A_2 \)    | 0.2222  | 0.0117  | 0.8940  | 0.8923  | 0.7438  | 0.99    |
| \( A_3 \)    | 0.4000  | 0.0314  | 0.7820  | 0.7818  | 0.5263  | 0.97    |
| \( A_4 \)    | 0.5454  | 0.1111  | 0.6644  | 0.6531  | 0.3910  | 0.89    |
| \( A_5 \)    | 0.5454  | 0.1111  | 0.6644  | 0.6531  | 0.3910  | 0.89    |
| \( A_6 \)    | 0.6667  | 0.2962  | 0.5414  | 0.5222  | 0.2811  | 0.70    |
| \( A_7 \)    | 0.7692  | 0.3483  | 0.4133  | 0.3929  | 0.1933  | 0.65    |
| \( A_8 \)    | 0.8572  | 0.5212  | 0.2803  | 0.2623  | 0.1187  | 0.48    |
| \( A_9 \)    | 0.9334  | 0.7748  | 0.1424  | 0.1309  | 0.0545  | 0.23    |
| \( A_{10} \) | 0.9334  | 0.7748  | 0.1424  | 0.1309  | 0.0545  | 0.23    |
| \( A_{11} \) | 1.0000  | 1.0000  | 0.0000  | 0.0000  | 0.0000  | 0.00    |
| Standard deviation | 0.3199 | 0.3559 | 0.3320 | 0.3348 | 0.3148 | 0.3559 |
The tank (kg) has more contribution to the overall objective weight while the base shear has the least contribution.

Having determined the coefficient of the objective weight of each criterion, then the ranking of each alternative (Height-Diameter) was done using TOPSIS.

7. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)
The result of normalizing Table 1 using TOPSIS is shown in Table 6. Thereafter, Table 6 is multiplied by the coefficient of objective weight of each criterion to obtain the weightage normalized decision matrix shown in Table 7.

From the ideal best and ideal worst values obtained in Table 7, Euclidean distances of each competitive alternative from the positive $S^+$ and negative $S^-$ solutions were calculated for ranking as displayed in Table 8.

8. VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje)
The result of normalizing Table 1 using VIKOR is shown in Table 9. Then, Table 9 is multiplied by the coefficient of objective weight of each criterion as obtained from CRITIC to get the weightage normalized decision matrix shown in Table 10.

From Table 10, Measure of Utility $S_i$ and Measure of Regret $R_i$ and final Ranking index $Q_i$ were computed as shown in Table 11.

Spearman’s rank correlation coefficient $r$ for Table 12 is 0.8727.
Table 6. Normalized decision using TOPSIS

| Alternatives | C₁   | C₂   | C₃   | C₄   | C₅   | C₆   |
|--------------|------|------|------|------|------|------|
| A₁           | 0.4281 | 0.2837 | 0.1541 | 0.1307 | 0.2282 | 0.2837 |
| A₂           | 0.3805 | 0.2843 | 0.1828 | 0.1615 | 0.2560 | 0.2843 |
| A₃           | 0.3425 | 0.2852 | 0.2132 | 0.1972 | 0.2797 | 0.2852 |
| A₄           | 0.3113 | 0.2891 | 0.2451 | 0.2365 | 0.2944 | 0.2891 |
| A₅           | 0.3113 | 0.2891 | 0.2451 | 0.2365 | 0.2944 | 0.2891 |
| A₆           | 0.2854 | 0.2979 | 0.2784 | 0.2764 | 0.3063 | 0.2979 |
| A₇           | 0.2634 | 0.3004 | 0.3132 | 0.3158 | 0.3158 | 0.3004 |
| A₈           | 0.2446 | 0.3087 | 0.3492 | 0.3556 | 0.3239 | 0.3087 |
| A₉           | 0.2283 | 0.3209 | 0.3866 | 0.3957 | 0.3309 | 0.3209 |
| A₁₀          | 0.2283 | 0.3209 | 0.3866 | 0.3957 | 0.3309 | 0.3209 |
| A₁₁          | 0.2141 | 0.3317 | 0.4252 | 0.4356 | 0.3368 | 0.3317 |

Table 7. Weightage normalized decision matrix for TOPSIS

| Alternatives | C₁   | C₂   | C₃   | C₄   | C₅   | C₆   |
|--------------|------|------|------|------|------|------|
| A₁           | 0.1009 | 0.0740 | 0.0191 | 0.0163 | 0.0273 | 0.0384 |
| A₂           | 0.0897 | 0.0741 | 0.0226 | 0.0204 | 0.0306 | 0.0385 |
| A₃           | 0.0807 | 0.0744 | 0.0264 | 0.0246 | 0.0334 | 0.0386 |
| A₄           | 0.0734 | 0.0754 | 0.0303 | 0.0295 | 0.0352 | 0.0391 |
| A₅           | 0.0734 | 0.0754 | 0.0303 | 0.0295 | 0.0352 | 0.0391 |
| A₆           | 0.0672 | 0.0777 | 0.0345 | 0.0345 | 0.0366 | 0.0404 |
| A₇           | 0.0621 | 0.0783 | 0.0338 | 0.0394 | 0.0378 | 0.0407 |
| A₈           | 0.0576 | 0.0805 | 0.0432 | 0.0444 | 0.0387 | 0.0418 |
| A₉           | 0.0538 | 0.0836 | 0.0479 | 0.0494 | 0.0396 | 0.0435 |
| A₁₀          | 0.0538 | 0.0836 | 0.0479 | 0.0494 | 0.0396 | 0.0435 |
| A₁₁          | 0.0504 | 0.0865 | 0.0527 | 0.0544 | 0.0403 | 0.0449 |
| Ideal Best   | 0.1009 | 0.0740 | 0.0191 | 0.0163 | 0.0273 | 0.0384 |
| Ideal Worst  | 0.1009 | 0.0740 | 0.0191 | 0.0163 | 0.0273 | 0.0384 |

Table 8. Euclidean distances and ranking

| Alternatives | S⁺ | S⁻ | S⁺⁺S⁻ | Pᵢ | Rank position |
|--------------|----|----|-------|----|---------------|
| A₁           | 0.0520 | 0.0528 | 0.1048 | 0.5040 | 10 |
| A₂           | 0.0416 | 0.0481 | 0.0897 | 0.5362 | 6 |
| A₃           | 0.0350 | 0.0455 | 0.0804 | 0.5653 | 4 |
| A₄           | 0.0318 | 0.0440 | 0.0758 | 0.5801 | 1 |
| A₅           | 0.0318 | 0.0440 | 0.0758 | 0.5801 | 1 |
| A₆           | 0.0319 | 0.0436 | 0.0755 | 0.5775 | 3 |
| A₇           | 0.0352 | 0.0443 | 0.0795 | 0.5574 | 5 |
| A₈           | 0.0400 | 0.0460 | 0.0860 | 0.5344 | 7 |
| A₉           | 0.0460 | 0.0486 | 0.0946 | 0.5135 | 8 |
| A₁₀          | 0.0460 | 0.0486 | 0.0946 | 0.5135 | 8 |
| A₁₁          | 0.0528 | 0.0520 | 0.1048 | 0.4960 | 11 |
### Table 9. Normalized decision matrix using VIKOR

| Alternatives | C_1    | C_2    | C_3    | C_4    | C_5    | C_6    |
|--------------|--------|--------|--------|--------|--------|--------|
| A_1          | 0.4281 | 0.2837 | 0.1541 | 0.1307 | 0.2282 | 0.2837 |
| A_2          | 0.3805 | 0.2843 | 0.1828 | 0.1635 | 0.2560 | 0.2843 |
| A_3          | 0.3425 | 0.2852 | 0.2132 | 0.1972 | 0.2944 | 0.2891 |
| A_4          | 0.3113 | 0.2891 | 0.2451 | 0.2365 | 0.2944 | 0.2891 |
| A_5          | 0.3113 | 0.2891 | 0.2451 | 0.2365 | 0.2944 | 0.2891 |
| A_6          | 0.2854 | 0.2979 | 0.2784 | 0.3063 | 0.2979 |        |
| A_7          | 0.2634 | 0.3004 | 0.3132 | 0.3158 | 0.3158 | 0.3004 |
| A_8          | 0.2446 | 0.3087 | 0.3492 | 0.3566 | 0.3239 | 0.3087 |
| A_9          | 0.2283 | 0.3209 | 0.3866 | 0.3957 | 0.3309 | 0.3209 |
| A_{10}       | 0.2283 | 0.3209 | 0.3866 | 0.3957 | 0.3309 | 0.3209 |
| A_{11}       | 0.2141 | 0.3317 | 0.4252 | 0.4356 | 0.3368 | 0.3317 |
| Max          | 0.4281 | 0.3317 | 0.4252 | 0.3317 |        |        |
| Min          | 0.2141 | 0.2837 | 0.1541 | 0.2837 |        |        |

### Table 10. Weightage normalized decision matrix for VIKOR method

| Alternatives | C_1    | C_2    | C_3    | C_4    | C_5    | C_6    |
|--------------|--------|--------|--------|--------|--------|--------|
| A_1          | 0.2356 | 0.2607 |        |        |        |        |
| A_2          | 0.1832 | 0.2577 | 0.0131 | 0.0134 | 0.0306 | 0.0016 |
| A_3          | 0.1414 | 0.2525 | 0.0270 | 0.0273 | 0.0567 | 0.0042 |
| A_4          | 0.1071 | 0.2317 | 0.0415 | 0.0433 | 0.0728 | 0.0150 |
| A_5          | 0.1071 | 0.2317 | 0.0415 | 0.0433 | 0.0728 | 0.0150 |
| A_6          | 0.0785 | 0.1835 | 0.0568 | 0.0597 | 0.0860 | 0.0401 |
| A_7          | 0.0544 | 0.1699 | 0.0726 | 0.0758 | 0.0965 | 0.0472 |
| A_8          | 0.0337 | 0.1248 | 0.0891 | 0.0921 | 0.1054 | 0.0706 |
| A_9          | 0.0157 | 0.0587 | 0.1062 | 0.1086 | 0.1131 | 0.1049 |
| A_{10}       | 0.0157 | 0.0587 | 0.1062 | 0.1086 | 0.1131 | 0.1049 |
| A_{11}       | 0.0000 | 0.0000 | 0.1238 | 0.1249 | 0.1196 | 0.1354 |

### Table 11. Values of measure of utility, measure of regret and ranking index

| Alternatives | S_i    | R_i    | Q_i    | Rank |
|--------------|--------|--------|--------|------|
| A_1          | 0.4963 | 0.2607 | 0.5000 | 8    |
| A_2          | 0.4997 | 0.2577 | 0.6000 | 6    |
| A_3          | 0.5090 | 0.2525 | 0.7000 | 3    |
| A_4          | 0.5116 | 0.2317 | 0.8000 | 1    |
| A_5          | 0.5116 | 0.2317 | 0.9000 | 1    |
| A_6          | 0.5045 | 0.1835 | 1.0000 | 7    |
| A_7          | 0.5164 | 0.1699 | 1.1000 | 4    |
| A_8          | 0.5157 | 0.1248 | 1.2000 | 5    |
| A_9          | 0.5071 | 0.1131 | 1.3000 | 9    |
| A_{10}       | 0.5071 | 0.1131 | 1.4000 | 9    |
| A_{11}       | 0.5037 | 0.1354 | 1.5000 | 11   |
The alternatives $A_4$ and $A_5$ (height-diameter ratios, 0.8 and 0.9) were considered to be the ideal best alternatives because they have the highest ranking with the value of 0.5801. However, the alternative $A_{11}$ (height-diameter ratio 1.5) was considered as the worst alternative with a value of 0.4960. Since all the alternatives (0.5–1.4) have their ranks above 0.4999, these alternatives could also be chosen but the alternative(s) with the highest-rank was termed the best alternative. Terming the highest ranked alternative(s) as the best alternative aligns with the study of Stanojković and Radovanović (Stanojković & Radovanović, 2017). Any rank value from 0.50 and above could be regarded as a good alternative. However, the best choice of alternatives is the one with the highest-rank value. Based on this statement, alternatives 0.8 and 0.9 were given priority over the other alternatives in this study because they have the highest ranking value of 0.5801.

More so, comparing the ranking results of alternatives using the TOPSIS method against the VIKOR method, it could be deduced that both methods ranked alternatives $A_4$ and $A_5$ as the best alternatives, while alternative $A_{11}$ was least ranked. Few discrepancies observed when comparing the ranking value in Table 12 were due to the value of $v$ chosen (Manoj & Sagar, 2018). The effect of these discrepancies was quantified using Spearman’s correlation coefficient. Spearman’s correlation coefficient of 0.8727 shows that there is a strong positive correlation between the two MCDA methods (Prasenjit & Shankar, 2016).

### Table 12. Comparison of ranking by TOPSIS and VIKOR

| Alternatives | TOPSIS | VIKOR |
|--------------|--------|-------|
| $A_1$        | 10     | 8     |
| $A_2$        | 6      | 6     |
| $A_3$        | 4      | 3     |
| $A_4$        | 1      | 1     |
| $A_5$        | 1      | 1     |
| $A_{11}$     | 3      | 7     |
| $A_{12}$     | 5      | 4     |
| $A_8$        | 7      | 5     |
| $A_9$        | 8      | 9     |
| $A_{10}$     | 8      | 11    |
| $A_{11}$     | 11     | 11    |

### Table 13. Scenarios with varying criteria weights

| Scenarios                  | Criteria weight |
|----------------------------|-----------------|
|                            | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ |
| Entropy method ($S_E$)     | 0.1727 | 0.0105 | 0.3260 | 0.4361 | 0.0443 | 0.0105 |
| Equal weight ($S_{eq}$)    | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 |
| Priority to criterium 1 ($S_1$) | 0.2500 | 0.1500 | 0.1500 | 0.1500 | 0.1500 | 0.1500 |
| Priority to criterium 2 ($S_2$) | 0.1500 | 0.2500 | 0.1500 | 0.1500 | 0.1500 | 0.1500 |
| Priority to criterium 3 ($S_3$) | 0.1500 | 0.1500 | 0.2500 | 0.1500 | 0.1500 | 0.1500 |
| Priority to criterium 4 ($S_4$) | 0.1500 | 0.1500 | 0.1500 | 0.2500 | 0.1500 | 0.1500 |
| Priority to criterium 5 ($S_5$) | 0.1500 | 0.1500 | 0.1500 | 0.1500 | 0.2500 | 0.1500 |
| Priority to criterium 6 ($S_6$) | 0.1500 | 0.1500 | 0.1500 | 0.1500 | 0.1500 | 0.2500 |
| Priority to criteria 2 and 6 ($S_{2,6}$) | 0.1250 | 0.2000 | 0.1250 | 0.1250 | 0.1250 | 0.3000 |
### Table 14. Ranking of alternatives for different scenarios using TOPSIS

| Alternatives | Entropy method ($S_e$) | Equal weight method ($S_eq$) | Priority to criterion 1 ($S_1$) | Priority to criterion 2 ($S_2$) | Priority to criterion 3 ($S_3$) | Priority to criterion 4 ($S_4$) | Priority to criterion 5 ($S_5$) | Priority to criterion 6 ($S_6$) | Priority to criteria 2 and 6 ($S_{2,6}$) |
|--------------|------------------------|-----------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| $A_1$        | 1                      | 3                           | 6                               | 3                               | 7                               | 7                               | 7                               | 3                               | 3                               |
| $A_2$        | 2                      | 1                           | 5                               | 1                               | 1                               | 1                               | 1                               | 1                               | 1                               |
| $A_3$        | 3                      | 2                           | 3                               | 2                               | 3                               | 3                               | 3                               | 2                               | 2                               |
| $A_4$        | 4                      | 4                           | 1                               | 4                               | 4                               | 4                               | 4                               | 4                               | 4                               |
| $A_5$        | 4                      | 4                           | 1                               | 4                               | 4                               | 4                               | 4                               | 4                               | 4                               |
| $A_6$        | 6                      | 6                           | 4                               | 6                               | 6                               | 6                               | 6                               | 6                               | 6                               |
| $A_7$        | 7                      | 7                           | 7                               | 7                               | 7                               | 7                               | 7                               | 7                               | 7                               |
| $A_8$        | 8                      | 8                           | 8                               | 8                               | 8                               | 8                               | 8                               | 8                               | 8                               |
| $A_9$        | 9                      | 9                           | 9                               | 9                               | 9                               | 9                               | 9                               | 9                               | 9                               |
| $A_{10}$     | 9                      | 9                           | 9                               | 9                               | 9                               | 9                               | 9                               | 9                               | 9                               |
| $A_{11}$     | 11                     | 11                          | 11                              | 11                              | 11                              | 11                              | 11                              | 11                              | 11                              |
Table 15. Ranking of alternatives for different scenarios using VIKOR

| Alternatives | Equal weight method ($S_{eq}$) | Entropy method ($S_E$) | Priority to criterion 1 ($S_1$) | Priority to criterion 2 ($S_2$) | Priority to criterion 3 ($S_3$) | Priority to criterion 4 ($S_4$) | Priority to criterion 5 ($S_5$) | Priority to criterion 6 ($S_{6}$) | Priority to criterion 2 and 6 ($S_{2,6}$) |
|--------------|-------------------------------|------------------------|-----------------------------|-------------------------------|-----------------------------|-----------------------------|-----------------------------|-------------------------------|---------------------------------|
| $A_1$        | 11                            | 10                     | 7                           | 9                             | 11                          | 11                          | 11                          | 11                            | 11                              |
| $A_2$        | 10                            | 9                      | 7                           | 4                             | 9                           | 10                          | 10                          | 10                            | 10                              |
| $A_3$        | 11                            | 11                     | 4                           | 9                             | 9                           | 9                           | 9                           | 9                             | 9                               |
| $A_4$        | 11                            | 11                     | 9                           | 7                             | 2                           | 2                           | 2                           | 2                             | 2                               |
| $A_5$        | 11                            | 11                     | 7                           | 7                             | 7                           | 7                           | 7                           | 7                             | 7                               |
| $A_6$        | 11                            | 11                     | 9                           | 7                             | 7                           | 7                           | 7                           | 7                             | 7                               |
| $A_7$        | 11                            | 11                     | 8                           | 9                             | 6                           | 6                           | 6                           | 6                             | 6                               |
| $A_8$        | 11                            | 11                     | 11                          | 9                             | 5                           | 5                           | 5                           | 5                             | 5                               |
| $A_9$        | 11                            | 11                     | 7                           | 6                             | 5                           | 4                           | 4                           | 4                             | 4                               |
| $A_{10}$     | 11                            | 11                     | 2                           | 2                             | 2                           | 2                           | 2                           | 2                             | 2                               |
| $A_{11}$     | 11                            | 11                     | 2                           | 2                             | 2                           | 2                           | 2                           | 2                             | 2                               |

Agboola et al., Cogent Engineering (2020), 7: 1770913
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9. Sensitivity analysis

The reason for conducting sensitivity analysis is to evaluate the effect of changing the objective weights of criteria on the ranking of alternatives (Ali et al., 2011; Saeed et al., 2017). These changes create different scenarios that may alter the ranking of alternatives. According to Nazari-Shirkouhi et al. (2017), the results are said to be sensitive when original ranking is changed by changing the objective weights of the criteria, otherwise results are termed robust.

Sensitivity analysis was carried out by using nine (9) scenarios. Objective weights were first re-assigned using Entropy method instead of initial CRITIC method used. The second scenario was to assign equal weights to all the criteria. All the nine scenarios are presented in Table 13. Then, ranking based on sensitivity analysis for TOPSIS and VIKOR ispresented in Tables 14 and 15, respectively.

Tables 14 and 15 show a considerable difference in the ranking of alternatives when compared with the initial ranking by TOPSIS (Table 8) and VIKOR (Table 11). This shows that ranking results based on the two methods are sensitive to a change in the objective weights of the criteria. In all the nine scenarios considered for sensitivity analysis for the TOPSIS method, alternative 2 is adjudged to be the best option because it was ranked 1st seven times while alternative 11 was the worst alternative because it was ranked least in all the nine scenarios. In sharp contrast to sensitivity analysis for TOPSIS, sensitivity for VIKOR rated alternative 11 as the best due to the fact that it was ranked first in all the scenarios. As could be seen in Table 15, alternatives 7–11 maintain a higher degree of consistency because they retain their positions virtually in all the scenarios. Also, in Table 14, there is consistency in the alternatives 1–5.

10. Conclusion

CRITIC and TOPSIS as MCDA tools have been successfully adopted for the selection of the Height-Diameter ratio for the optimal design of a 13,000 m³ oil storage tank. Objective weight of each criterion [Area occupied by the tank (m²), Weight (kg), Wind Moment (Nm), Seismic Ringwall Moment RWM (Nm), Base shear (N) and Estimated Cost (₦)] was determined by CRITIC method while the ranking and final selection of Alternatives (Height-Diameter ratios) were done by using TOPSIS. The ranking results obtained through TOPSIS were compared with the VIKOR method as a confirmatory test. VIKOR method also ranked alternatives A₄ and A₅ as the best alternatives. This study reveals that the best alternatives to achieve the optimal design of 13,000 m³ oil storage tanker are to select Height-Diameter ratios of 0.8 or 0.9. To further justify the effectiveness of the MCDA used, Spearman’s rank correlation coefficient r was determined for TOPSIS and VIKOR and the result showed that there is a high correlation of 0.8727 between them. Sensitivity analysis conducted reveals that both TOPSIS and VIKOR used in the ranking of the alternatives are sensitive to the changes in objective weight of the criteria.

Further study shall be the detailed design of oil storage tank using the height-diameter ratio of 0.8. This is expected to include material selection and other design considerations, simulation, etc.

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References
Agboola, O. O., Akinruli, B. O., Akintunde, M. A., Ikubanni, P. P., & Adeleke, A. A. (2019). Comparative analysis of Basic Strapping Method (BSM) and Two-Point Method (TPM) in the study of storage tank. Journal of Physics: Conference Series, 1378 (022062), 1 - 10. https://doi.org/10.1088/1742-6596/1378/2/022062

Agboola, O. O., Ikubanni, P. P., Ikubanni, R. A., Adeediran, A. A., & Ogunsimi, B. T. (2017). Generation of calibration charts for horizontal petroleum storage tanks using Microsoft Excel. MAPAN-Journal of Metrology Society of India, 32(4), 321 - 327. https://doi.org/10.1007/s12647-017-0224-6

Ali, A., Salman, N. S., Loghman, H. S., & Ayyub, A. (2013). A unique fuzzy multi-criteria decision making: Computer simulation approach for productive operators’ assignment in cellular manufacturing systems with uncertainty and vagueness. International Journal of Advanced Manufacturing Technology, 56(1-4), 329-343. https://doi.org/10.1007/s00170-011-3186-9

Ammar, A. A., Samah, Z. N., & Farhan, L. R. (2018). Efficient design of a large storage tank for liquefied natural gas. Journal of University of Babylon for Engineering Sciences, 26(6), 362-383. https://www.journalofbabylon.com/index.php/JUBES/article/download/1459/1174/

API Standard 650. (2012). Welded steel tanks for oil storage (11th ed.). American Petroleum Institute.

Bobatunde, M. O., & Igborhwen, D. E. (2019). A CRITIC–TOPSIS framework for hybrid renewable energy systems evaluation under techno-economic requirements. Journal of Project Management, 4(2), 1-18. https://doi.org/10.5267/jrpm.2018.12.001

Bagheri, M., Shojaei, P., & Kharami, M. (2018). A comparative survey of the condition of tourism infrastructure in Iranian provinces using VIKORD and TOPSIS. Decision Science Letters, 7(1), 87–102. https://doi.org/10.5267/j.dsl.2017.4.001

Boli, S., & Korukoglu, S. (2009). Operating system selection using fuzzy AHP and TOPSIS methods. Mathematical and Computational Applications, 14(2), 119–130. https://doi.org/10.3390/mca14020119

Bhushan, M., Otaoglu, S. K., Yazdani, M., & Ignatius, J. (2012). A state-of-the-art survey of TOPSIS applications. Expert Systems with Applications, 39 (17), 13051–13069. https://doi.org/10.1016/j.eswa.2012.05.056

Diakouliki, D., Mavrotas, G., & Papayannakis, L. (1995). Determining objective weights in multiple criteria problems: The CRITIC method. Computers & Operations Research, 22(7), 763–770. https://doi.org/10.1016/0305-0548(94)00059-H

EEMUA 159. (2003). Users’ guide to the inspection, maintenance and repair of aboveground vertical cylindrical steel storage tanks (3rd ed). The Engineering Equipment and Materials Users Association. London, United Kingdom.

Enarevo, D. R., Izelcu, C. O., Oreo, B. U., & Emogbetere, E. (2016). Design and development of a 10 million liters capacity petroleum product storage tank. The International Journal of Engineering and Science, 5(7), 45–56. http://www.theijes.com/papers/v5/17/Version-2/FO5050720405056.pdf

Equipment Design Lecture 11 Tanks, Vessels & drums – Sizing. Tikrit University. Retrieved December 4, 2019, from https://ceng.tu.edu.iq/ched/images/lectures/chemlec/sta/c1/EQUIPMENT_DESIGN_Lecture_11.pdf

John, M. L. (2004). Floating roof design considerations (Tank Issue). 37. American Petroleum Institute

Madic, M., Nedic, B., & Radovanovic, M. (2015). Business and engineering decision making by using multi-criteria decision making methods. University of Kragujevac.

Madic, M., & Radovanovic, M. (2015). Ranking of some most commonly used nontraditional machining process using ROV and CRITIC methods. UPB Scientific Bulletin, Series D, 77(2), 193–204, https://www.scientificbulletin.upb.ro/rev_docs_arhiva/full/e8_598887.pdf

Manoj, M., & Sagar, S. (2018). Comparison of new multi-criteria decision making methods for material handling equipment selection. Management Science Letters, 8(3), 139–150. https://doi.org/10.5267/j.msl.2018.1.004

Milic, M., & Zapac, G. (2012). An objective approach to determining the weight criteria. Vojnatehnički glasnik, 60(1), 39–56. https://doi.org/10.5937/vojtehgl2101039M

Napp, A., Phaneendra, A., Diwakar, R. V., & Srikrishn, S. (2016). TOPSIS based approach for selection of third party reverse logistics service provider: A case study of mobile phone industry. Imperial Journal of Interdisciplinary Research, 2(4), 177–181. https://www.onlinejournal.in/IJIRV214/033.pdf

Nazarl-Shirkouhi, S., Miri-Nargesi, S., & Ansarinejad, A. (2017). A fuzzy decision making methodology based on fuzzy AHP and fuzzy TOPSIS with a case study for information systems outsourcing decisions. Journal of Intelligent & Fuzzy Systems, 36(6), 3921–3943. https://doi.org/10.3233/jifs-12495

Okpala, A. N., & Jambo, P. P. (2012). Design of diesel storage tank in consonance with requirements of American Petroleum Institute (API) standard 650. Industrial Engineering Letters, 2(4), 7–20. http://cite-seerx.ist.psu.edu/viewdoc/download?doi=10.1.1.664.7488&rep=rep1&type=pdf

Opricovic, S. (1998). Multicriteria optimization in civil engineering (in Serbian). Faculty of Civil Engineering, Prasenjit, C., & Shankar, C. (2016). A comparative analysis of VIKORD method and its variants. Decision Science Letters, 5(5), 469–486. https://doi.org/10.5267/j.dsl.2016.5.004

Saeed, M., Salmani, N., & Ali, B. (2017). A novel interval type-2 fuzzy evaluation model based group decision analysis for green supplier selection problems: A case study of battery industry. Journal of Cleaner Production. Accepted manuscript. https://doi.org/10.1016/j.jclepro.2017.08.154.

Samuel, A. O. (2013). Viability of oil refining in Nigeria: A technical and economic consideration. International Journal of Science & Engineering Research, 4(2), 20–28.

San Cristóbal, J. R. (2011). Multi-criteria decision-making in the selection of a renewable energy project in Spain: The VIKORD method. Renewable Energy, 36(2), 498–502. https://doi.org/10.1016/j.renene.2010.07.031

Stanojkovic, J., & Radovanovic, M. (2017). Selection of solid carbide end mill for machining aluminum 6082-T6 using CRITIC and TOPSIS methods. Journal of Production Engineering, 201(1), 133–136. https://doi.org/10.24687/JPE-2017-01-133

Tilg, H., & Rebai, A. (2017). A TOPSIS method based on intuitionistic fuzzy values: A case study of North African airports. Management Science Letters, 7(7), 351–358. https://doi.org/10.5267/j.msl.2017.4.002
