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Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

This Version is available at:
http://hdl.handle.net/11159/8253

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Modelling of Cost Estimates for the Geometrical Calibration of Upright Oil Storage Tanks

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ABSTRACT

Cost estimation is a fundamental activity in engineering management and business decision making. It normally involves estimating the quantity of labor, materials, utilities, floor space, sales, overhead, time and other parameters over a given period of time. These estimates are used typically as inputs to deterministic analysis methods or to stochastic analysis methods. Cost of tank calibration which depends on the factors such as the capacity of tank, number of labour, method adopted, equipment etc. has not been standardized. In an attempt to standardize the cost of tank calibration, two separate models, one each for the two common methods of tank calibration; manual strapping method and electro optical distance ranging. These models were validated with actual cost of tank calibration obtained from four renowned calibration companies in the country and were found to be within the acceptable limit of ±10% deviation.

Keywords: Calibration, Modeling, Cost Estimation, Oil Storage Tank, Standardization
**JEL Classifications:** C2, C3, C5, D7

1. INTRODUCTION

Calibration of tanks involves determining the corresponding volume of a tank at an incremental level. Tank capacity table (calibration chart) generated from an accurate tank calibration is essential in oil industries because it gives information about the quantity of product in the tank at a particular level/height (Sun, 2000). It also prevents unnecessary arguments/disputes about the receipt of refined product or crude oil into the oil storage tanks at the terminal. Though wet method of tank calibration is adjudged to be the most accurate method of tank calibration but Geometrical method is often used because geometrical method could be used to calibrate any size of tank while wet method is limited to small size tanks such as horizontal storage tanks (Agboola et al., 2017; API 2555, 1998).

Geometrical method of tank calibration can be broadly divided into manual strapping method (MSM) and electro-optical distance ranging (EODR) method. MSM which involves the winding of

steel tape round the circumference of each shell of a tank, is the oldest traditional method of tank calibration which could further be modified/divided into optical reference line method and optical triangulation method (Savaraman, 2012). A typical upright oil storage tank consists of two or more shells (courses) as shown in Figure 1.

As part of statutory requirements for continuous operation of oil terminal/depot in Nigeria, Department of Petroleum Resources (DPR)-an agency of Federal Government of Nigeria mandated all Tank Farm owners to calibrate their oil storage tanks atleast once in 5 years (DPR guide, 2005; Agbola, 2009). New oil storage tanks are expected to be calibrated before being put to use. Tank may also be re-calibrated before the required 5 years interval if a major work was done on the bottom of tank or inclusion/exclusion of deadwoods (API MPMS 2.2A, 2000).

Among the reasons why some Tank farm owners are not fulfilling this requirement of calibration and re-calibration of oil storage

Figure 1: Typical upright oil storage tank
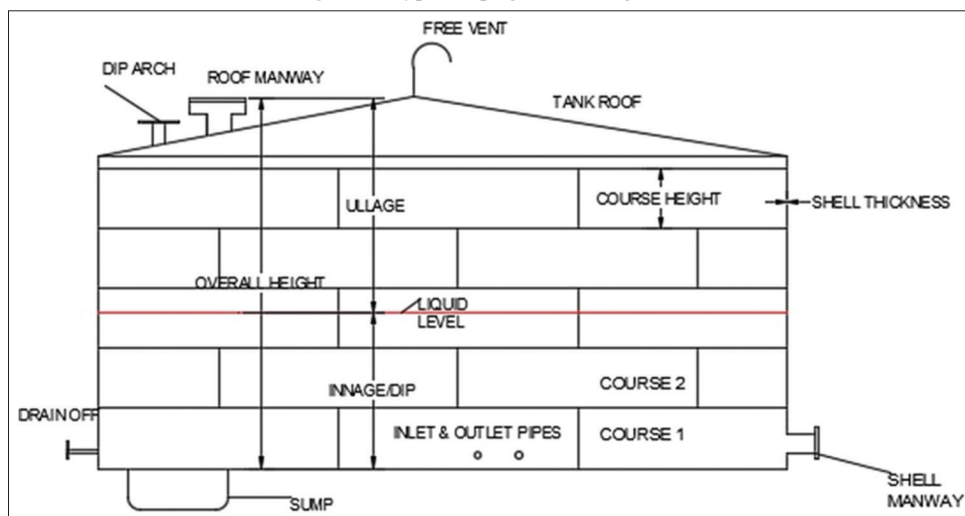
tank is because of the fear of excessive cost charged by the Tank calibrators (Tank calibration companies). It was reported that majority of the Tank calibrators bill their clients based on their perceived financial power (Agbola, 2009). A uniform billing rate has not being established by most of these calibrators. To forestall or minimize the problem of non-uniform billing, there is need to have a standardized/harmonized costing models for various geometrical method of tank calibration.

Cost estimate of a project is the probable cost of that project as computed from specifications, plans and other elements of the project. A cost estimate is adjudged acceptable if the difference between actual final cost and estimated cost is not more than 10%. Project in this context could mean a service rendered (as in case of tank calibration) or physical jobs such as construction or fabrication works. Determining the cost of products or services remains an arduous task, especially in competitive environments where price is a major factor. Companies must ensure that their product and service costs should not exceed the prevailing market prices (Hoozée et al., 2009). Also in the non-profit public sector, accurate cost estimations are essential based on the need to constantly prioritize spending and to minimize costs because of the limited resources and budget pressures (Linn, 2007; Sudarsan, 2006). Cost estimation which determines the final outcome of pricing system is relevant in every facet of human endeavours, especially in determining the price of crude oil. Some of the recent researches peculiar to oil pricing are: Oil price fluctuations and dependency malaise-what will engender socio-economic adjustments? Olabode (2018) reveals a critique on issues impacting on the bottom-line of selected oil export centric economies amongst other contextual dynamics. He mainly highlights matters dealing with capacity deficits, oil industry transparency and governance imperatives, policy inconsistencies, economic diversification, corporate social responsibility and optimizing governmental regulation. Adedoyin et al. (2018) also examined the validity of efficiency market hypothesis for the oil market using a novel Fourier unit root test that responsible for sharp shifts and smooth breaks based on daily data. Their findings revealed the existence of structural shifts and nonlinearity in the oil market indices suggesting that oil market is inefficient when structural breaks is calibrated into the model used.

A lot of studies have been done in the area of cost estimation and prediction, which include: Design cost modelling – A way forward (Lawther and Edwards, 2000), The standard cost model-a framework for defining and quantifying administrative burdens for businesses (Daniel et al., 2004), Salama et al., 2006, Predicting construction cost using multiple regression techniques (David et al. 2006), Using intelligent techniques in construction project cost estimation: 10-year survey (Abdelrahman et al., 2014), Development of an energy cost prediction model for a VRF heating system (Bo et al., 2018). Though few studies have been done in the field of tank calibration such as: New approach to calibration of vertical fuel tank (Knyva et al., 2013), calculation of oil tank volume and report generation system with trim and list corrections (Ming-Shen and Chia, 2016), application of statistical quality control (SQC) in the calibration of oil storage tanks (Agboola and Ikubanni, 2017), A concept of fuel tank calibration process automation within IoT infrastructure (Knyva et al., 2017); but there has not been any documented study on the cost modeling of tank calibration and that is what was why this study was undertaken.

2. MATERIALS AND METHODS

2.1. Techniques of Cost Estimation
Techniques of cost estimation are one of the major important steps in project management. A cost estimate establishes the baseline of the project cost at different stages of development of the project. A cost estimate at a particular stage of project development indicates a prediction given by the cost engineer based on the available data. According to American Association of Cost Engineers, cost engineering is "defined as that area of engineering practice where engineering judgment and experience are utilized in the application of scientific principles and techniques to the problem of cost estimation, cost control and profitability." The technique adopted in this study was similar to that of Amol et al., 2018.

2.2. Cost Modelling
Two separate models were developed, one each for MSM of tank calibration and EODR method. Cost of tank calibration CTC

depends on the number of variables such as:
1. Nominal volume/capacity of the tank in m³ N_v
2. No of labour and its associated cost L_a
3. Duration and its associated cost D_r
4. Cost based on nominal volume C_v
5. Location L_o
6. Cost of hiring or using equipment C_e
7. Statutory fees and associated logistics S_f
8. Marked-up profit and overhead cost M_p
9. Contingency cost C_c
10. Value added tax (VAT) V_t.

2.2.1. Cost estimation for tank calibration using MSM

Documented information about the previous calibration exercises as regards the number of personnel used, duration and the capacity of the tank were used to generate the capacity-personnel-duration (CPD) decision matrix for MSM as displayed in Table 1.

$$\text{Nominal volume / Capacity } N_v = \frac{\pi d^2 h}{4} \quad (1)$$

where d and h are nominal diameter and height respectively, Number of labour L_a is obtained from CPD in Table 1 for MSM, Cost of hiring an engineer, senior technician and even technician is related to the prevailing minimum wage (M_{in}) in the country by:

Cost of hiring an engineer C_{hE} per day for tank calibration $= \left(\dfrac{M_{in}}{176}\right) \times 97.7778$

Cost of hiring a senior technician C_{hST} per day for tank calibration $= \left(\dfrac{M_{in}}{176}\right) \times 68.4444$

Cost of hiring a technician C_{hT} per day for tank calibration $= \left(\dfrac{M_{in}}{176}\right) \times 48.8889$

So the number of labour and the associated cost

$$L_a = \left[N_E \times \left(\frac{M_{in}}{176}\right) \times 97.7778\right] + \left[N_{ST} \times \left(\frac{M_{in}}{176}\right) \times 68.4444\right] + \left[N_T \times \left(\frac{M_{in}}{176}\right) \times 48.8889\right] \quad (2)$$

Table 1: Capacity-personnel-duration (CPD) decision matrix for MSM

Capacity (m³)	Personnel	Duration (days)
≤1000	1 engineer, 1 technician	1
1001-10,000	1 engineer, 2 technician	3
10,001-20,000	1 engineer, 1 senior technicians, 2 technicians	4
20,001-50,000	1 engineers, 1 senior technicians, 3 technicians	4
≥50,000	1 engineers, 2 senior technicians, 3 technicians	5 or more

MSM: Manual strapping method

where N_E, N_{ST} and N_T are the number of engineer, senior technician and technician required as obtained from CPD

Duration is also obtained from CPD in Table 1

Duration and its associated cost

$$D_r = \left\{ \begin{bmatrix} N_E \times \left(\frac{M_{in}}{176}\right) \times \\ 97.7778 \end{bmatrix} + \begin{bmatrix} N_{ST} \times \left(\frac{M_{in}}{176}\right) \times \\ 68.4444 \end{bmatrix} + \begin{bmatrix} N_T \times \left(\frac{M_{in}}{176}\right) \times 48.8889 \end{bmatrix} \right\} \times N_D \quad (3)$$

where N_D is the number of days taken,

$$\text{Cost based on nominal volume } C_v = N_v \times 10 \quad (4)$$

Location L_o refers to the distance apart between the operational base of the calibrating company (calibrator) and the geographical point/position of the tank(s) to be calibrated. It is the product of "distance apart" and "the prevailing rate per km."

$$\text{Location } L_o = (D_a \text{(km)} \times 2 \times P_r \,(N_E + N_{ST} + N_T)) + (N_D \times H_A) \quad (5)$$

where D_a is the distance apart, P_r is the prevailing rate per km, H_A is hotel allowance (accommodation) for personnel. Note that H_A has the same value as the cost of hiring each category of staff,

Cost of hiring or using equipment C_e = (Current cost of hiring strapping tape C_{stp} + current cost of hiring pocket measuring tape C_{pt} + current cost of hiring leveling instrument C_{li} + cost of hiring ultrasonic thickness measurement (UTM) machine C_{utm}) × number of days N_{Ds},

$$\text{Cost of hiring or using equipment } C_e = (C_{stp} + C_{pt} + C_{li} + C_{utm}) \times N_D \quad (6)$$

Statutory fees and associated logistics S_f = Current statutory fee S_{cf} + 20% of S_{cf}

$$\text{Statutory fees and associated logistics } S_f = S_{cf} + 20\% \text{ of } S_{cf} \quad (7)$$

Sub total 1 S_{T1} = Summation of equation 3 – 7

$$\text{Sub total 1 } S_{T1} = \left\{ \begin{bmatrix} N_E \times \left(\frac{M_{in}}{176}\right) \\ \times 97.7778 \end{bmatrix} + \begin{bmatrix} N_{SV} \times \left(\frac{M_{in}}{176}\right) \\ \times 68.4444 \end{bmatrix} + \begin{bmatrix} N_T \times \left(\frac{M_{in}}{176}\right) \times 48.8889 \end{bmatrix} \right\} \times N_D$$

N_v x 10) + ((D_a (km) x 2 x P_r ($N_E + N_{ST} + N_T$)) + N_D x H_A) + (($C_{stp} + C_{pt} + C_{li} + C_{utm}$) x N_D) + (S_{cf} + 20% of S_{cf}) (8)

Marked-up profit and overhead cost M_p = 50% of S_{T1} (9)

Sub total 2 S_{T2} = Summation of S_{T1} and M_p

Contingency cost C_c = 10% of S_{T2} = 10% × ($S_{T1} + M_p$) (10)

Sub total 3 S_{T3} = Summation of S_{T2} and C_c

Value added tax VAT = 5% of S_{T3} = 5% × ($S_{T2} + C_c$) (11)

Grand total = $S_{T3} + VAT$ (12)

Cost of tank calibration $CTC_{MSM} = S_{T3} + VAT$ (13)

2.2.2. Cost estimation for tank calibration using EODR
Just like MSM, the CPD decision matrix is generated for EODR as displayed in Table 2.

Nominal volume/Capacity $N_v = \dfrac{\pi d^2 h}{4}$ (14)

Where d and h are nominal diameter and height respectively

Number of Labour L_a is obtained from CPD in Table 2 for EODR

Cost of hiring an engineer, a surveyor and even technician is related to the prevailing minimum wage (M_{in}) in the country by:

Cost of hiring an engineer, senior technician and even technician is related to the prevailing minimum wage (M_{in}) in the country by:

Table 2: Capacity-personnel-duration (CPD) decision matrix for EODR

Capacity (m³)	Personnel	Duration (days)
≤1000	1 engineer, 1 surveyor	1
1001-10,000	1 engineer, 1 surveyor	1
10,001-20,000	1 engineer, 1 surveyor, 1 technician	2
20,001-50,000	1 engineer, 1 surveyor, 1 technician	3
≥50,000	1 engineer, 1 surveyor, 1 technician	3 or more

EODR: Electro-optical distance ranging

Cost of hiring an engineer ChE per day for tank calibration

$= \left(\dfrac{M_{in}}{176}\right) \times 97.7778$

Cost of hiring a surveyor ChSV per day for tank calibration $= \left(\dfrac{M_{in}}{176}\right) \times 97.7778$

Cost of hiring a technician ChT per day for tank calibration $= \left(\dfrac{M_{in}}{176}\right) \times 48.8889$

So the number of labour and the associated cost

$$L_a = \left[\dfrac{N_E \times \left(\dfrac{M_{in}}{176}\right) \times}{97.7778}\right] + \left[\dfrac{N_{SV} \times \left(\dfrac{M_{in}}{176}\right) \times}{97.7778}\right] + \left[N_T \times \left(\dfrac{M_{in}}{176}\right) \times 48.8889\right]$$ (15)

Where N_E, N_{SV} and N_T are the number of engineer, surveyor and technician required as obtained from CPD

Duration is also obtained from CPD (Table 2)

Duration and its associated cost

$$D_r = \left\{ \left[\dfrac{N_E \times \left(\dfrac{M_{in}}{176}\right) \times}{97.7778}\right] + \left[\dfrac{N_{SV} \times \left(\dfrac{M_{in}}{176}\right) \times}{68.4444}\right] + \left[N_T \times \left(\dfrac{M_{in}}{176}\right) \times 48.8889\right] \right\} \times N_D$$ (16)

Where N_D is the number of days taken,

Cost based on nominal volume $C_v = N_v \times 10$ (17)

Location L_o refers to the distance apart between the operational base of the calibrating company (calibrator) and the geographical point/position of the tank(s) to be calibrated. It is the product of "Distance apart" and "the prevailing rate per km."

Location $L_o = ((D_a \text{(km)} \times 2 \times P_r (N_E + N_{ST} + N_T)) + N_D \times H_A)$ (18)

Table 3: Cost estimating model for tank calibration using manual strapping method (MSM)

Diameter "d" (mm)	22,493	Height "h" (mm)	15,100	Nominal capacity (m³)	6001
No. of engineer N_E	1	No. of Technician N_T	2	No. of S_{nr} technician N_{ST}	1
No. of days	4	Distance apart D_a (Km)	443	Prevailing rate per km	10
Cost of hiring strapping tape C_{stp}	5,000	Cost of hiring pocket tape C_{pt}	300	Cost of hiring levelling instrument C_{li}	10,000
Cost of hiring UTM machine C_{utm}	10,000	Statutory fees its logistics S_{cf}	200,000	Current minimum wage M_{in}	18,000

UTM: Ultrasonic thickness measurement

Table 4: Cost estimating model for tank calibration using electro optical distance ranging (EODR) method

Diameter "d" (mm)	24,220	Height "h" (mm)	15,540	Nominal capacity (m³)	7161
No. of engineer N_E	1	No. of technician N_T	1	No. of surveyor N_{hSV}	1
No. of days	5	Distance apart D_a (Km)	443	Prevailing rate per km	10
Cost of hiring total station C_{ts}	50,000	Cost of hiring pocket tape C_{pt}	300	Cost of calibrating certifying total station C_{cts}	10,000
Cost of hiring UTM machine C_{utm}	10,000	Statutory fees its logistics S_{cf}	200,000	Current minimum wage M_{in}	18,000

UTM: Ultrasonic thickness measurement

Where D_a is the distance apart and P_r is the prevailing rate per km

Cost of hiring or using equipment C_e = (Current cost of hiring total station C_{ts} + current cost of hiring pocket measuring tape C_{pt} + cost of calibration and certification of total station C_{cts}) × number of days N_D

Cost of hiring or using equipment $C_e = ((C_{ts} + C_{pt}) \times N_D) + C_{cts}$ (19)

Statutory fees and associated logistics S_f = Current statutory fee S_{cf} + 20% of S_{cf}

Statutory fees and associated logistics $S_f = S_{cf} + 20\%$ of S_{cf} (20)

Sub total 1 S_{T12} = Summation of equation 16 – 20

Sub total 1

$$S_{T12} = \left\{ \begin{bmatrix} N_E \times \left(\dfrac{M_{in}}{176} \right) \times \\ 97.7778 \end{bmatrix} + \begin{bmatrix} N_{SV} \times \left(\dfrac{M_{in}}{176} \right) \times \\ 68.4444 \end{bmatrix} + \begin{bmatrix} N_T \times \left(\dfrac{M_{in}}{176} \right) \times \\ 48.8889 \end{bmatrix} \right\}$$

$$+ (N_v \times 10) + \begin{pmatrix} (D_a (km) \times 2 \times P_r (N_E + N_{ST} + N_T)) \\ + N_D \times H_A \end{pmatrix}$$ (21)

$$+ ((C_{ts} + C_{pt}) \times N_D) + C_{cts}) + (S_{cf} + 20\% \text{ of } S_{cf})$$

Marked-up profit and overhead cost M_p = 50% of S_{T12} (22)

Sub total 2 S_{T22} = summation of S_{T12} and M_p

Contingency cost C_c = 10% of S_{T22} = 10% × ($S_{T12} + M_p$) (23)

Sub total 3 S_{T32} = Summation of S_{T22} and C_c

Table 5: Output interface for various cost elements

Personnel and duration cost	0.00
Cost based on nom. capacity	0.00
Cost based on location	0.00
Cost of hiring equipment	0.00
Statutory fee and associ. cost	0.00
Sub-total 1	0.00
Marked up profit and overhead	0.00
Sub-total 2	0.00
Contingency	0.00
Sub-total 3	0.00
Value added tax VAT	0.00
Grand Total	0.00

Value added tax $VAT = 5\%$ of $S_{T32} = 5\% \times (S_{T22} + C_c)$ (24)

Grand total $= S_{T32} + VAT$ (25)

Cost of tank calibration $CTC_{EODR} = S_{T32} + VAT$ (26).

Having identified the major costing elements and developed cost estimation models, a simple MS-Excel program each, was developed for both MSM and EODR to ease computation. Tables 3 and 4 represent the input interfaces of Excel program for MSM and EODR respectively. Table 5 is the output section for various costing elements that culminate into Grand total cost of calibration.

3. RESULTS AND DISCUSSION

3.1. Results
Four (4) different companies, two each from Lagos and Portharcourt Nigeria were contacted to give their best quotations for the calibration of five tanks using both MSM and EODR. The four companies are denoted by A, B, C and D because they preferred that their names were not mentioned in this article. Table 6 shows the Nominal dimensions of the five tanks and the best quotations of each company based on MSM. All the five tanks are located in Portharcourt, Nigeria. Companies A and B are based in Portharcourt while C and D have their operational base in Lagos. Table 7 shows the quotations obtained from each company based on EODR.

3.1.1. Percentage deviation (PD) from the model
Accuracy and correctness of a cost model is measured by its PD from the actual cost (Mohamad, 2016). According to Mohamad (2016), a good cost model should not have a deviation from the actual cost exceeding ±10%.

$$\text{Percentage Deviation } (PD) = \left| \frac{\text{Modelled cost} - \text{Present cost}}{\text{Modelled cost}} \right| \times 100\%$$ (27)

Tables 8 and 9 show the PD for MSM and EODR respectively.

3.2. Discussion
PD of the modeled cost from the actual cost was computed in Tables 8 and 9. Positive PD indicates that actual cost of calibration is less than the modelled cost estimates, while negative PD shows that the actual cost is greater than the modelled cost estimates. It was observed that all the PDs fall within the acceptable limit

Table 6: Nominal dimensions of the tanks and the best quotation from the five companies based on MSM

Tank ID	Nominal dimension (m)	Quotation for tank calibration from various companies based on MSM				
		Company A	Company B	Company C	Company D	Cost modelled
Tank 4	24.22D×15.54H	800,000.00	830,000.00	850,000.00	750,000.00	822,392.50
Tank 5	22.49D×15.1H	750,000.00	820,000.00	830,000.00	750,000.00	802,302.18
Tank 6	24.47D×12H	750,000.00	800,000.00	830,000.00	750,000.00	796,120.41
Tank 8	29.96D×20.99H	1,000,000.00	1,100,000.00	1,200,000.00	1,000,000.00	1,097,474.80
Tank 9	16.13D×12.3	670,000.00	720,000.00	750,000.00	680,000	741,886.74

MSM: Manual strapping method

Table 7: Nominal dimensions of the tanks and the best quotation from the five companies based on EODR

Tank ID	Nominal dimension (m)	Quotation for tank calibration from various companies based on EODR				
		Company A	Company B	Company C	Company D	Cost modelled
Tank 4	24.22D×15.54H	900,000.00	900,000.00	950,000.00	880,000.00	895,399.95
Tank 5	22.49D×15.1H	830,000.00	900,000.00	950,000.00	860,000.00	875,309.25
Tank 6	24.47D×12H	830,000.00	870,000.00	950,000.00	850,000.00	869,127.87
Tank 8	29.96D×20.99H	1,260,000.00	1,270,000.00	1,400,000.00	1,280,000.00	1,367,987.27
Tank 9	16.13D×12.3	750,000.00	800,000.00	830,000.00	800,000.00	814,894.19

EODR: Electro-optical distance ranging

Table 8: Percentage deviation from the actual cost when using MSM method

Tank ID	Company A	Company B	Company C	Company D
4	2.72	−0.93	−3.36	8.80
5	6.52	−2.21	−3.45	6.52
6	5.79	−2.21	−3.45	6.52
8	8.88	−0.49	−4.26	5.79
9	9.69	−0.23	−9.34	8.88

MSM: Manual strapping method

Table 9: Percentage deviation from the actual cost when using EODR method

Tank ID	Company A	Company B	Company C	Company D
4	−0.51	−0.51	−6.10	1.72
5	5.18	−2.82	−8.53	1.75
6	4.50	−0.10	−9.30	2.20
8	7.89	7.16	−2.34	6.43
9	7.96	1.83	−1.85	1.83

EODR: Electro-optical distance ranging

of ±10% (Mohamad, 2016). Also the actual cost of calibrating tanks using EODR is slightly higher than the cost incurred when using MSM because EODR is seen as a new method of Tank calibration with higher accuracy. This further confirms the validity of the cost model developed.

4. CONCLUSION

Two separate models have been developed for estimating the cost of calibrating oil storage tanks using MSM and EODR methods. These models have been validated by applying them to a real world practice in Nigeria and found to be within the acceptable deviation. With the development of this model, it will serve a veritable tool for both the Tank owners as well as the Tank calibration companies to have a unified billing rate in the country to ensure fair transaction between them. The developed model has been introduced to some tank calibration companies such as NACE Engineering Limited, Saltlight Engineering and Inspection Company Limited, and Mascortech Services.

Further work can be done on the model to make it applicable globally by incorporating other prevailing factors in such countries.

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