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3- Layer Optimization of Supply Chain Network for Liquefied Petroleum Gas Distribution in Nigeria

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Abstract
The challenges of supply chain management are widespread, especially in the oil and gas industry. Notwithstanding the significance of supply chain network management and its developing intricacy, the oil and gas business is still in the advanced phase of proficiently dealing with the supply of liquefied petroleum gas (LPG) across Nigeria. Presently, the significant challenge confronting the oil and gas sector is to minimize the overall cost of LPG distribution to end-users. An efficient way to achieve product scarcity and maintain price stability is designing a robust supply chain network that can expand its distribution network across Nigeria. This study developed a multi-echelon supply chain distribution network for the distribution of LPG across the states in Nigeria. The first stage of the echelon proposed Lagos State and Rivers State as initial supply hubs of LPG distribution. The second phase of the echelon supply chain network proposed six states, namely Oyo, Imo, Delta, Kaduna, Adamawa, and Abuja, as intermediate distribution centres. The final phase was the distribution of the LPG to the other states using the most cost-effective route across the states. The optimum routes for delivering LPG to the various states with minimum cost and distance travelled were obtained.

Keywords: *LPG distribution, Supply chain network, Non-linear regression*

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1. Introduction

The demand for natural gas as an alternative source of energy compared to other fossil fuels is growing at a fast rate globally. In 2018, natural gas demand grew by 4.6% (IEA, 2019). This growth is driven mainly by strong economic growth and the energy transition agenda occasioned by climate change, among many other factors. It is projected to become the second most sought-after energy source after oil in the next decade, and ultimately, the most sought after primary energy source in the coming decades (McKinsey and Co, 2022) Nigeria, the biggest sub-Saharan country with a populace surpassing 200 million individuals, accounted for 29 and 21 % of global proven oil and gas reserves, respectively, in 2018, making it the 9th largest country with proven natural gas reserves of about 206 TCF (DPR, 2021). When adequately harnessed in Nigeria, natural gas utilization can stimulate an estimated Gross Value Added (GRV) of $ 18.3 billion annually to the domestic economy and create an estimated 6.5 million Full Time Equivalent (FTE) jobs for the local economy (PWC, 2020).

Using natural gas as a fuel source for heating, cooking, and powering automobiles and as feedstock in many industries will significantly reduce global emissions (C2ES, 2013). However, in Nigeria, most people still live in homes where biomass-based fuel is utilized for cooking and heating (increasing global greenhouse emission levels), as they do not have access to Liquefied Petroleum Gas (WLPGA, 2015). LPG is a conventional name associated with the blend of hydrocarbons. The chemical composition of the LPG product varies, but the predominant ones known are butane (Isobutane) and propane. According to WLPGA (2017), at room temperature, LPG has the property of changing to liquid when compressed; likewise, at reduced pressure, it changes to gas. This makes it simple for storage and transportation. LPG is seaborne transported in the liquid state for enormous bulk mass and refrigerated. However, on land, it is transported and stored in compressed tanks. When compared with other unsustainable biomass and fossil fuel, LPG burns neatly. It creates no particulate matter, low discharges of carbon (IV) oxide, unburned hydrocarbons, carbon (II) oxide, and nitrous oxide than most petroleum derivatives and biomass. According to Yadav and Paul (2020), the maximum thermal efficiency of an LPG cook stove could be up to 68% for a brass burner and 64% for a cast iron burner.

LPG can be produced from natural gas processing or crude oil refining. All three (3) refineries in Nigeria are currently in bad shape (Ogbuigwe, 2018). Consequently, most of the LPG consumed in-country is imported, while the balance is supplied by the Nigeria Liquefied Natural Gas (NLNG) at Finima in Bonny Island. This presents only two major points for distributing or supplying LPG to all parts of the country, mainly through haulage trucks (Bob tail Truck). These limited sources of supply create bottlenecks in the distribution and efficient supply chain network (SCN) of the commodity to different parts of the country. Supply chain network can be characterized as the coordination, configuration, and constant improvement of a defined sequential set of coordinated activities. SCN aims to give maximum consumer service delivery at the minimum cost (Gross, 2012).

In recent years, supply chain management (SCM) has received much focus from researchers and professionals. Along these lines, there is a ton of writing where thoughts about this issue have been addressed. Hussain (2006) observed that a more proficient and cost-effective supply chain in the oil and gas sector addresses significant elements for keeping up consistent supplies of crude oil, minimizing lead times reduction and cost of distribution regardless of the extraordinary difficulties in the oil and gas industry' SCN. In addition, there are still avenues for improvement and cost investment along the supply chain network.

LPG supply chain distributors typically need to make drastic decisions on the transportation cost and route at each phase of the SCN to meet the requirement of consumers' demand at the barest minimum cost. As highlighted by Uzorh and Nnanna (2018), for more than a decade, organizations, analysts, and researchers have neglected the approach of a coordinated perspective of the whole supply network design. Hence, for the effective distribution of LPG, the following factors must be considered (Adabi and Omrani, 2015): (i) The distribution planning decision deals with transportation logistics concerning the quantity of LPG demanded across different states, and (ii) A robust SCN to achieve the feat of product scarcity and maintaining price stability with quick response and availability of LPG to the end user(customers).

With respect to the aforementioned, there is a need to develop an extremely sophisticated supply chain network that can make a smooth flow of information, materials, and services from inbound and outbound to accomplish high consumer service delivery leading to good performance outcomes. Existing studies on a robust and efficient SCN for LPG distribution in Nigeria are scarce. In one such study, Ihemtuge and Aimikhe (2020) proposed distribution routes from the Port Harcourt and Lagos supply hubs. However, their work did not provide optimum routes across the country's 36 states (and Abuja) for efficiently distributing LPG. Hence, this study seeks to minimize LPG transportation costs and determine the best transportation route with respect to quantity at the various collection cities to avoid disruption in the SCN respectively across all 36 states (and Abuja) of the country. This is accomplished by developing an optimization model.

The research outcome will introduce a model that various decision makers can utilize in the SCN organization, such as distributors, manufacturers, and suppliers, to optimize their performance through the openness of processes to minimize total cost, which will result in enhanced product delivery time with respect to elimination and minimization of waste through just in time techniques with optimum material and supplier selection criterion. Furthermore, this study will give insights into the strategies needed to be embraced by LPG producers and marketers on optimization techniques and supplier selection to minimize cost. The outcome of this study will shed more light on LPG allocation and facility location to be used by distribution and facility managers to ascertain the optimal location of storage facilities and distribution tank farms in the logistics network, respectively.

2. Materials and methods

This study employed the case study research design to optimize an existing supply chain network of the LPG in Nigeria. The distribution network involved a total of thirty-six states, including FCT. The data used for the analysis of this study is limited to the 2019 third-quarter report of the Nigeria Bureau of statistics bulletin of petroleum products importation and consumption. The investigation utilized time series information on the cost of production per unit, yearly consumer interest, and transportation cost for the period. Secondary data on total production costs and capacity, annual demand at depots, transportation costs, and distance were obtained from articles and the Petroleum Products Importation and Consumption annual reports (NBS Report, 2019).

A Mixed Integer Linear Programming procedure was used to design an integrated supply chain network considering some parameters significantly affecting the profitability, such as cost. The developed model was evaluated by applying Microsoft Excel Solver and LINGO programming software due to its significant effectiveness in incorporating and solving transportation problems. The model minimizes total cost by considering the LPG quantity and distance traveled. Figure 1 shows the distribution of depots in Nigeria.

To use the LINGO software open the optimization interface, copy and paste the objective function and constraints to be solved on the interface. Convert the optimization model to the LINGO model by correcting the objective function and constraints syntax using the appropriate signs, and then add END at the end of the statements. On the menu bar, select solver and click on options. Go to the general solver tab. Check all the relevant boxes for non-negative constraints, costs, LPG quantity, and their ranges. Select Ok or solve, to solve the model. The user guide on the LINGO software can be found elsewhere (Schrage, 1999).

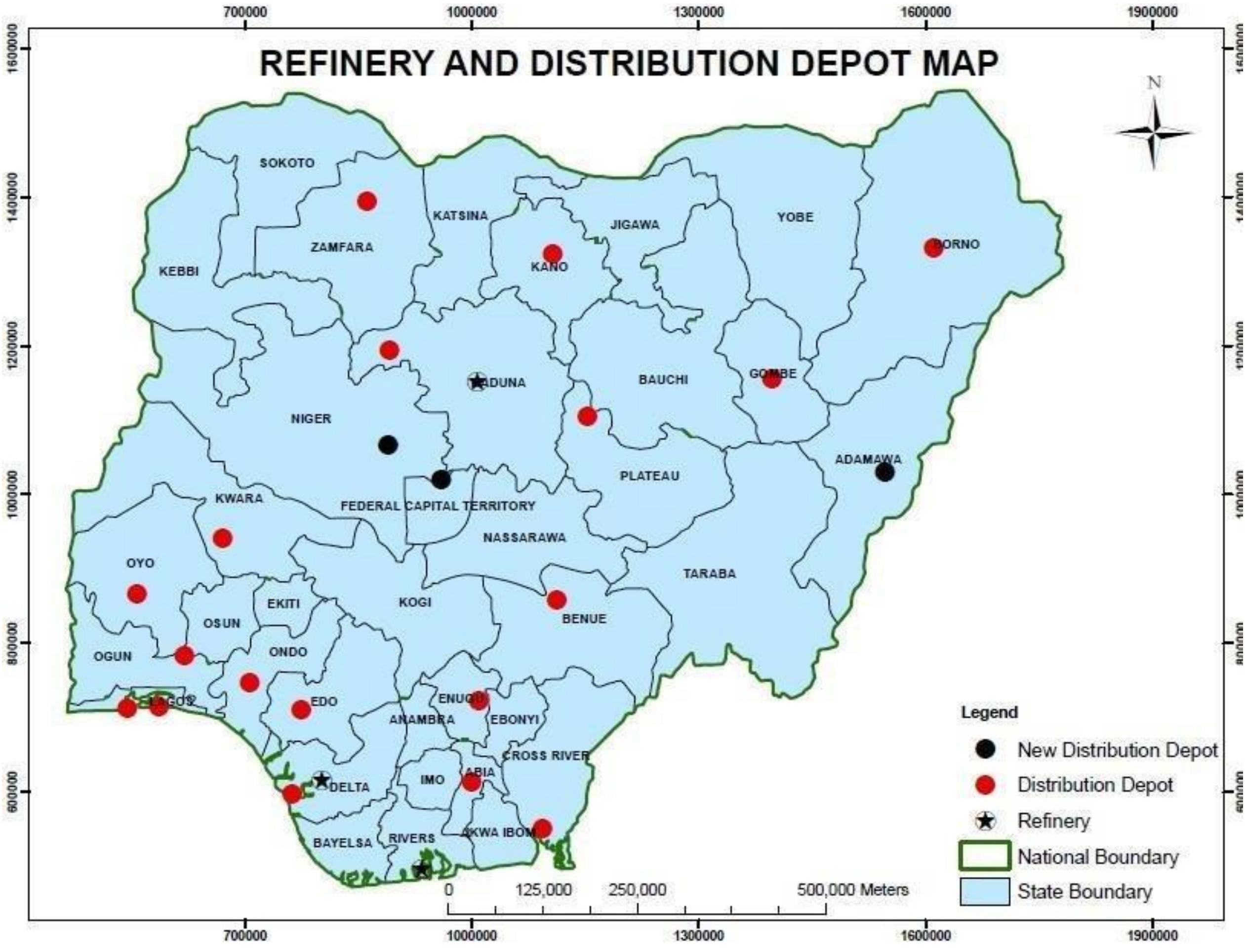

Fig. 1: Depot distribution in Nigeria (NBS Report, 2019)

First Echelon Distribution (Lagos State and Rivers States)

i. Cost per unit of LPG product
ii. Capacity limit for LPG
iii. Minimum quantity supplied
iv. Unit transportation cost of LPG product

Second Echelon Distribution (The Six Geographical States)

i. Capacity limit for storage plant for storing the LPG product.
ii. Transportation cost of the LPG product using the road.

Final Stage (Receiving States)

i. Demand for the finished LPG product

ii. LPG product at receiving State

Minimize the objective function in equation 1

$$\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}X_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{k} C'_{jh}Y_{jh} \qquad (1)$$

Subject to:

$$\sum_{j=1}^{n} X_{ij} \leq a_i \qquad \forall_i = \{1,2,3 \dots\dots\dots\dots m\} \qquad (2)$$

$$\sum_{j=1}^{n} X_{jh} \leq a_i \qquad \forall_i = \{1,2,3 \dots\dots\dots\dots m \qquad (3)$$

$$\sum_{i=1}^{m} X_{ij} \leq b_i \qquad \forall_j = \{1,2,3, \dots\dots\dots\dots, n\} \qquad (4)$$

$$\sum_{i=1}^{m} X_{jh} \leq b_i \qquad \forall_j = \{1,2,3, \dots\dots\dots\dots, n\} \qquad (5)$$

$$\sum_{e=1}^{m} a_i - \sum_{e=1}^{n} b_i \geq 0 \qquad \forall_e = \{1 \leq i \leq m\} \,\&\{1 \leq j \leq n \dots\dots\dots\dots, t\} \qquad (6)$$

$$X_{ij} \geq 0 \qquad \forall_i, \forall_j \qquad (7)$$

The objective function of the model is to minimize the total cost of transportation for the supply chain network subject to the following constraints. Equation (2) expresses the supply constraints, which require that the total quantity of LPG transported from Lagos and Rivers States not exceed the capacity of the six (6) states in the geographical region. Equation (3) expresses the supply constraints, which require that the total quantity of LPG transported from the six geopolitical hubs of Oyo, Imo, Delta, Kaduna, Adamawa, and Abuja should not exceed the capacity of the receiving State across the cities. Equation (4) expresses the demand constraints, which require that the total quantity transported from Lagos and Rivers States should not exceed the capacity of the six (6) states in the geographical region. Equation (5) expresses the demand constraints, which require that the total quantity of LPG transported from Oyo, Imo, Delta, Kaduna, Adamawa, and Abuja should not exceed the capacity of the receiving State across the cities. Equation (6) requires that the total quantity of LPG supplied from Lagos and Rivers States should not exceed the demand capacity of the receiving State across the cities. Equation (7) requires that all decision variables defined are non-negative. Where C_{ij} is the unit Cost of transporting LPG from source i to destination j, X_{ij} is the quantity of LPG transported from source i to destination j, C'_{jh} is the unit Cost of transporting LPG from source j to destination h, and Y_{jh} is the quantity of LPG transported from source j to destination h. All possible transportation (ROUTE) each Bob tail Truck can take will be represented by the sum product of $C_{ij X_{ij}} + C'_{jh}Y_{jh}$. Hence the Cost Function of the first term for Lagos State can be expressed as:

C_{11} = The unit Cost of transporting LPG from Lagos to Oyo

C_{12} = The unit Cost of transporting LPG from Lagos to Imo

C_{13} = The unit Cost of transporting LPG from Lagos to Delta

C_{14} = The unit Cost of transporting LPG from Lagos to Kaduna

C_{15} = The unit Cost of transporting LPG from Lagos to Adamawa

C_{16} = The unit Cost of transporting LPG from Lagos to Abuja

The decision variable (All variables defined are non-negative)

X_{11} = The quantity of LPG transported from Lagos to Oyo

X_{12} = The quantity of LPG transported from Lagos to Imo

X_{13} = The quantity of LPG transported from Lagos to Delta

X_{14} = The quantity of LPG transported from Lagos to Kaduna

X_{15} = The quantity of LPG transported from Lagos to Adamawa

X_{16} = The quantity of LPG transported from Lagos to Abuja

Similarly, the Cost Function of the first term for Rivers State can be expressed as:

C'_{jh}= The unit Cost of transporting LPG from Rivers State to Oyo

C'_{jh}= The unit Cost of transporting LPG from Rivers State to Imo

C'_{jh}= The unit Cost of transporting LPG from Rivers State to Delta

C'_{jh}= The unit Cost of transporting LPG from Rivers State to Kaduna

C'_{jh}= The unit Cost of transporting LPG from Rivers State to Adamawa

C'_{jh}= The unit Cost of transporting LPG from Rivers State to Abuja

The decision variable

Y_{jh}= The quantity of LPG transported from Rivers State to Oyo

Y_{jh}= The quantity of LPG transported from Rivers State to Imo

Y_{jh}= The quantity of LPG transported from Rivers State to Delta

Y_{jh}= The quantity of LPG transported from Rivers State to Kaduna

Y_{jh}= The quantity of LPG transported from Rivers State to Adamawa

Y_{jh}= The quantity of LPG transported from Rivers State to Abuja

Hence, the first term can be expressed mathematically as shown in Equation (8). Fig. 2 shows the network distribution of LPG products across the stress.

$$\text{Minimize Cost} = (C_{11}X_{11} + C_{12}X_{12} + C_{13}X_{13} + C_{14}X_{14} + C_{15}X_{15} + C_{16}X_{16} + C_{21}X_{21} + C_{22}X_{22} + C_{23}X_{23} + C_{24}X_{24} + C_{25}X_{25} + C_{26}X_{26} + \cdots \ldots \ldots + (\,second\ term)\ C'_{1h}Y_{1h} \quad (8)$$

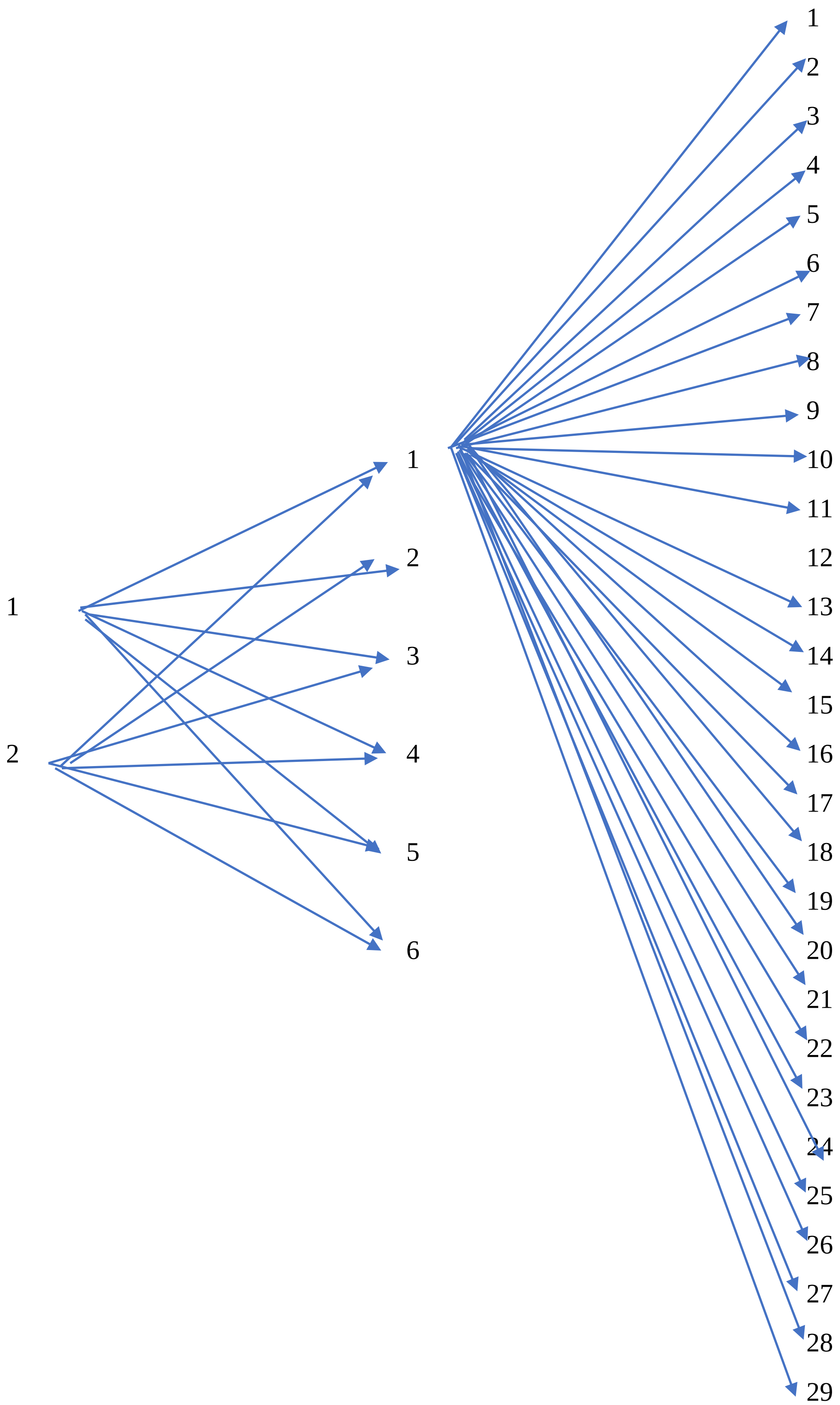

Fig. 2: 3- Layer Network distribution of LPG products across the states

3. Results and discussion

Table 1 shows the optimized cost of distributing LPG from the Lagos and Port-Harcourt depots to the hubs in the six geopolitical regions: Oyo State, Imo State, Delta State, Kaduna State, Adamawa State, and Abuja. Tables 2 to 7 show the LPG distribution from the hubs to the remaining 29 states in the country. These optimized results were obtained using the NBS 2019 unit cost of LPG and amount of LPG distributed across the 36 states.

Table 1: Transportation cost of LPG from Lagos State and Rivers State to Oyo State, Imo State, Delta State, Kaduna State, Adamawa State, and Abuja

	SW(Oyo)	**SE(Imo**	**SS(Delta)**	**NW(Kaduna)**	**NE(Adamawa)**	**NC(Abuja)**
SW (Lagos)	₦105,000	₦165,000	₦120,000	₦350,000	₦480,000	₦350,000
SS(PH)	₦140,000	₦130,000	₦80,000	₦450,000	₦350,000	₦550,000

Table 2: Transportation cost of LPG from the six geopolitical hubs to Ekiti, Osun, Ondo, Ogun, and Akwa-Ibom.

	1	**2**	**3**	**4**	**5**
	Ekiti	**Osun**	**Ondo**	**Ogun**	**Akwa-Ibom**
Oyo	₦120,000	₦98,000	₦125,000	₦105,000	₦255,000
Imo	₦135,000	₦245,000	₦145,000	₦230,000	₦145,000
Delta	₦145,000	₦150,000	₦135,000	₦250,000	₦140,000
Kaduna	₦690,000	₦700,000	₦710,000	₦750,000	₦750,000
Adamawa	₦650,000	₦650,000	₦650,000	₦750,000	₦750,000
Abuja	₦500,000	₦600,000	₦550,000	₦700,000	₦650,000

Table 3: Transportation cost of LPG from the six geopolitical hubs to Bayelsa, Cross Rivers, Edo, Abia, and Anambra

	6	**7**	**8**	**9**	**10**
	Bayelsa	**Cross-River**	**Edo**	**Abia**	**Anambra**
Oyo	₦235,000	₦250,000	₦225,000	₦320,000	₦300,000
Imo	₦125,000	₦130,000	₦175,000	₦125,000	₦105,000
Delta	₦102,000	₦145,000	₦95,000	₦235,000	₦185,000
Kaduna	₦750,000	₦750,000	₦680,000	₦755,000	₦745,000
Adamawa	₦750,000	₦750,000	₦750,000	₦750,000	₦750,000
Abuja	₦675,000	₦680,000	₦450,000	₦680,000	₦650,000

Table 4: Transportation cost of LPG from the six geopolitical hubs to Ebonyi, Enugu, Katsina, Kano, and Kebbi

	11	**12**	**13**	**14**	**15**
	Ebonyi	**Enugu**	**Katsina**	**Kano**	**Kebbi**
Oyo	₦350,000	₦350,000	₦550,000	₦550,000	₦550,000
Imo	₦135,000	₦155,000	₦645,000	₦632,000	₦655,000
Delta	₦175,000	₦155,000	₦750,000	₦735,000	₦725,000
Kaduna	₦735,000	₦675,000	₦105,000	₦93,000	₦145,000
Adamawa	₦750,000	₦750,000	₦150,000	₦150,000	₦150,000
Abuja	₦635,000	₦610,000	₦350,000	₦350,000	₦350,000

Table 5: Transportation cost of LPG from the six geopolitical hubs to Sokoto, Jigawa, Zamfara, Bauchi, and Borno

	16	17	18	19	20
	Sokoto	**Jigawa**	**Zamfara**	**Bauchi**	**Borno**
Oyo	₦550,000	₦550,000	₦550,000	₦680,000	₦755,000
Imo	₦650,000	₦650,000	₦650,000	₦690,000	₦755,000
Delta	₦750,000	₦750,000	₦650,000	₦550,000	₦750,000
Kaduna	₦150,000	₦150,000	₦98,000	₦102,000	₦155,000
Adamawa	₦150,000	₦150,000	₦150,000	₦95,000	₦95,000
Abuja	₦350,000	₦350,000	₦350,000	₦350,000	₦350,000

Table 6: Transportation cost of LPG from the six geopolitical hubs to Gombe, Taraba, Yobe, Benue, and Kogi

	21	22	23	24	25
	Gombe	**Taraba**	**Yobe**	**Benue**	**Kogi**
Oyo	₦700,000	₦690,000	₦745,000	₦485,000	₦350,000
Imo	₦680,000	₦680,000	₦735,000	₦385,000	₦450,000
Delta	₦650,000	₦500,000	₦730,000	₦320,000	₦250,000
Kaduna	₦105,000	₦165,000	₦145,000	₦165,000	₦115,000
Adamawa	₦95,000	₦95,000	₦98,000	₦145,000	₦155,000
Abuja	₦350,000	₦350,000	₦350,000	₦350,000	₦95,000

Table 7: Transportation cost of LPG from the six geopolitical hubs to Kwara, Nasarawa, Niger, and Plateau

	26	27	28	29
	Kwara	**Nasarawa**	**Niger**	**Plateau**
Oyo	₦350,000	₦650,000	₦600,000	₦580,000
Imo	₦450,000	₦410,000	₦455,000	₦480,000
Delta	₦350,000	₦375,000	₦390,000	₦400,000
Kaduna	₦175,000	₦105,000	₦98,000	₦95,000
Adamawa	₦185,000	₦145,000	₦185,000	₦155,000
Abuja	₦135,000	₦102,000	₦103,000	₦150,000

Table 8 shows the computation result of Lagos and Rivers States distributing LPG products to the six different hubs in the geopolitical region. A total of twelve (12) possible routes were generated during computational evaluation. The optimized result reveals six (6) best routes at a minimum transportation cost of the LPG products within the six (6) geopolitical regions. Hence, the maximum supply limit for Lagos was estimated as 101,045,432 liters of LPG, while River State was put as 101,020,432 liters of LPG. In addition, it is preferable from a cost perspective to deliver LPG from Lagos State to Oyo (17,919,045 Liters), Kaduna (41,612.906 Liters), and Abuja (1,862,977 Liters). On the other hand, it is preferable to deliver LPG from Rivers State to Imo (29,519.242 Litres), Delta (29,054,245 Liters), and Adamawa States (2,821.441 Liters). A total of 17,919,045 Liters of LPG was distributed to Oyo State, 29,519.242 Litre to Imo State, 29,054245 Litres to Delta State, 41,612,906 Litres to Kaduna State, 2,821,441 Litres to Adamawa State and 1,862,977 Litres to Abuja.

Tables 9 to 14 show the computation result of the minimization routine on the LPG distribution route from the six hubs in the geopolitical zones to the remaining 29 states. From Table 9, it is best to supply LPG from Oyo State to Ekiti State (6,896,409 Liters), Osun State (2,891,018 liters), Ondo State (2,445,860 liters) and Ogun State (2,891,018 liters). In comparison, Delta State will distribute LPG products to Akwa-Ibom (5,418,490 liters), Bayelsa (1,582,909 liters), Cross-River (3,012,073 liters), and Edo State (11,642,549 liters).

Table 10 shows that it is preferable to distribute LPG from Imo State to Abia (4,264,839 liters), Anambra (11,553,400 Liters), Ebonyi (7,419,791 liters), and Enugu States (6,281,212 Litres). Similarly, Kaduna is best suited to supply LPG to Katsina (4,913,119 liters), Kano (12,893,861 liters), Kebbi (108,954 liters), and Sokoto (174,652 liters). Table 11 shows that it is preferable to distribute LPG from Delta State to Benue State (1,807,190 liters). Kaduna is best suited to supply LPG to Jigawa (43,124 liters), Zamfara (84,723 liters), Bauchi (9,252,490 liters), and Gombe States (3,175,365 liters). Adamawa State is the preferred hub to deliver LPG to Borno (2,761,441 liters), Taraba 35,000 liters) and Yobe States (25,000 liters). Table 12 shows that it is preferable to distribute LPG from Oyo State to Kwara (2, 794740 liters). Delta State is best suited to supply LPG to Kogi (4,441,084 liters) and Kwara State (1,149,950 liters), while Kaduna state will distribute LPG to Niger (2,481,025 liters) and Plateau (8,485,593 Litres). The best route to supply Nasarawa State (1,862,977 Litres) is through Abuja.

The results of this study is in good agreement with the study of Ihemtuge and Aimikhe (2020), which showed that it is preferable to distribute LPG from the Rivers State (Port Harcourt) hub to the South and North eastern States of the country, compared to using the Lagos State route. However, due to the scarce literature on this subject, further validation of the results of this study, is required.

Table 9: Computational result of the distribution of LPG from the six geopolitical hubs to other states

	Ekiti	**Osun**	**Ondo**	**Ogun**	**Akwa-Ibom**	**Bayelsa**	**Cross-River**	**Edo**
Oyo	6,896,409	2,891,018	2,445,860	2,891,018	0	0	0	0
Imo	0	0	0	0	0	0	0	0
Delta	0	0	0	0	5,418,490	1,582,909	3,012,073	11,642,549
Kaduna	0	0	0	0	0	0	0	0
Adamawa	0	0	0	0	0	0	0	0
Abuja	0	0	0	0	0	0	0	0
	6,896,409	**2,891,018**	**2,445,860**	**2,891,018**	**5,418,490**	**1,582,909**	**3,012,073**	**11,642,549**

Table 10: Computational result of the distribution of LPG across the Six (6) geopolitical region

	Abia	**Anambra**	**Ebonyi**	**Enugu**	**Katsina**	**Kano**	**Kebbi**	**Sokoto**
Oyo	0	0	0	0	0	0	0	0
Imo	4,264,839	11,553,400	7,419,791	6,281,212	0	0	0	0
Delta	0	0	0	0	0	0	0	0
Kaduna	0	0	0	0	4,913,119	12,893,861	108,954	174,652
Adamawa	0	0	0	0	0	0	0	0
Abuja	0	0	0	0	0	0	0	0
	4,264,839	**11,553,400**	**7,419,791**	**6,281,212**	**4,913,119**	**12,893,861**	**108,954**	**174,652**

Table 11: Computational result of the distribution of LPG across the six (6) geopolitical region.

	Jigawa	**Zamfara**	**Bauchi**	**Borno**	**Gombe**	**Taraba**	**Yobe**	**Benue**
Oyo	0	0	0	0	0	0	0	0
Imo	0	0	0	0	0	0	0	0
Delta	0	0	0	0	0	0	0	1,807,190
Kaduna	43,124	84,723	9,252,490	0	3,175,365	0	0	0
Adamawa	0	0	0	2,761,441	0	35,000	25,000	0
Abuja	0	0	0	0	0	0	0	0
	43,124	**84,723**	**9,252,490**	**2,761,441**	**3,175,365**	**35,000**	**25,000**	**1,807,190**

Table 12: Computational result of the distribution of LPG across the six (6) geopolitical regions

	Kogi	Kwara	Nasarawa	Niger	Plateau	Total
Oyo	0	2,794,740	0	0	0	17,919,045
Imo	0	0	0	0	0	29,519,242
Delta	4,441,084	1,149,950	0	0	0	29,054,245
Kaduna	0	0	0	2,481,025	8,485,593	41,612,906
Adamawa	0	0	0	0	0	2,821,441
Abuja	0	0	1,862,977	0	0	1,862,977
	4,441,084	**3,944,690**	**1,862,977**	**2,481,025**	**8,485,593**	

4. Conclusion

This study has provided an optimized multi-echelon supply chain distribution network for the distribution of LPG across the cities in Nigeria from the two current LPG hubs at atlas cove, Lagos and Port Harcourt. The first stage of the echelon used Lagos State and Rivers State as the point of LPG distribution. The second phase of the supply chain network proposed six states in each geopolitical zone, namely Oyo, Imo, Delta, Kaduna, Adamawa, and Abuja, to stand as an intermediate distribution centres. The final phase was distributing the LPG to the other states using the most cost-effective route across the cities. The proposed distribution network of LPG can be an adequate substitute while waiting for the three refineries and other planned and uncompleted LPG production facilities in the country to come on-stream and become fully operational.

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Appendix

Table A1: State distribution of truck out volume of LPG for 3rd Quarter of 2019 (NBS Report, 2019)

State	July	August	September	Q3 2019 Total	Q2 2019 Total
Abia	1,272,041	1,544,224	1,448,174	4,264,839	1,261,762
Adamawa	80,080	145,250	120,350	345,680	274,590
Akwa-Ibom	1,811,185	1,677,363	1,929,942	5,418,490	3,962,378
Anambra	3,842,826	3,960,640	3,749,934	11,553,400	8,000,472
Bauchi	8,326,972	266,141	659,377	9,252,490	381,744
Bayelsa	36,224	740,010	806,675	1,582,909	1,967,459
Benue	979,196	320,394	507,600	1,807,190	651,236
Borno	321,775	1,137,084	1,302,582	2,761,441	3,795,039
Cross River	1,403,368	826,572	782,133	3,012,073	2,555,877
Delta	942,429	6,445,345	6,257,681	13,645,455	15,160,854
Ebonyi	6,346,580	602,483	470,728	7,419,791	835,091
Edo	427,262	5,127,889	6,087,398	11,642,549	11,840,412
Ekiti	6,024,476	412,933	459,000	6,896,409	773,282
Enugu	351,240	2,362,469	3,567,503	6,281,212	7,484,407
FCT	3,123,335	2,881,794	3,413,499	9,418,628	8,384,161
Gombe	3,009,847	84,994	80,524	3,175,365	549,812
Imo	125,625	3,231,480	3,653,055	7,010,160	6,111,485
Jigawa	43,124	-nil-	-nil-	43,124	0
Kaduna	2,887,879	1,584,721	2,318,008	6,790,608	4,050,119
Kano	1,575,367	5,237,383	6,081,111	12,893,861	10,316,399
Katsina	4,248,733	153,198	511,188	4,913,119	128,190
Kebbi	108,954	-nil-	-nil-	108,954	20,060
Kogi	1,351,480	1,504,837	1,584,768	4,441,084	3,237,161
Kwara	1,061,391	1,338,000	1,545,299	3,944,690	3,090,500
Lagos	7,772,970	7,611,110	9,084,853	24,468,933	27,242,780
Nasarawa	576,028	631,876	655,073	1,862,977	1,286,423
Niger	557,150	1,095,553	828,322	2,481,025	1,851,564
Ogun	794,328	1,024,300	1,072,390	2,891,018	2,052,420
Ondo	506,150	702,320	1,237,390	2,445,860	2,074,750
Osun	-nil-	134,857	538,464	673,321	26,250
Oyo	68,920	1,559,130	1,755,970	3,384,020	3,517,814
Plateau	1,339,500	3,812,660	3,333,433	8,485,593	7,498,725
Rivers	2,549,829	6,317,432	7,697,688	16,564,943	16,852,021
Sokoto	-nil-	71,536	103,116	174,652	35,000
Taraba	-nil-	-nil-	35,000	35,000	0
Yobe	-nil-	-nil-	-nil-	0	0
Zamfara	-nil-	42,738	41,985	84,723	17,600
Total	**63,866,258**	**64,545,977**	**73,678,628**	**202,090,863**	**157,270,237**