A MATHEMATICAL MODEL APPROACH FOR OPTIMAL COST IN COVID-19 VACCINE DISTRIBUTION: Evidence from Lagos State, Nigeria

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ABSTRACT

Budgeted cost for COVID-19 vaccine distribution in Nigeria during the COVID-19 period was a crucial issue. This research analysed the budgeting techniques used by the Federal Government of Nigeria in budgeting for the distribution of the COVAX 3.94 million doses of the AstraZeneca/Oxford vaccine across states in Nigeria that resulted in high budgeted transportation cost. Using data from Lagos State population, Google map, Uber standard cost per kilometre, quantities of vaccines available, and employing the game theory and transportation model, this study revealed that transportation model is the optimal technique to solve transportation cost problem and to plan budgeted cost for vaccine distribution during a pandemic. However, population statistics and distance in kilometres were found to have impacts on transportation modelling for vaccine distribution. The study recommends that policy makers collaborate with researchers skilled in optimization to participate in budgeting of the cost for transporting vaccines during a pandemic.

Keywords: transportation model, vaccines, population, distance, Lagos State

JEL classification: R4, J1, J2, C6

1. Introduction

The global impact of the Coronavirus pandemic (COVID-19) on economic activities has been well documented in the literature, and the issue of distribution cost remains a notable challenge in many developing countries (Adebowale, 2021). Each state in Nigeria as well the federal capital territory had a budgeted cost for COVID-19 vaccines distribution. It was noted by scholars in the field of operations research (Punch, 2021) that the budget for transport cost for the COVID-19 vaccines was not mathematically evaluated, hence a huge amount was budgeted. However, many variables may have accounted for the high budgeted transportation cost by the Federal Government of Nigeria. Such variables may include the rate of insurgency, topology, population statistics of affected persons in Nigeria, corruption and political consideration.

Nigeria reportedly budgeted ₦10.6billion as transportation cost for the distribution of 3.94 million COVAX doses of Astra Zeneca /Oxford vaccine (Punch, 2021). This budgeted cost was considered too high compared to the population and the number of doses approved. In the case of Ghana, $200million was approved as additional finance for COVID-19 Emergency Preparedness and Response Project (World Bank, 2021a). In the year 2021, many countries declared compulsory vaccination against COVID-19. Taking South Africa's population statistics of about 59,392,255 (World Bank, 2021b) and the budgeting techniques used for COVID-19 transportation budgeted cost in Nigeria and Ghana, the value would out-run the gross domestic products of some smaller countries within the West African region. Based on this premise, it is thought that the techniques used for budgeting transportation cost of COVID-19 vaccine by countries within the West African region have not followed a mathematical model of operational research to minimize cost in relation to the transportation problem. Due to the complexity of optimizing the transportation problem in most developing countries, there is the need for adequate preparedness. Professionals in the field of mathematical sciences, accounting and finance, healthcare, management, and operational research should be included in the budgeting team for COVID-19 vaccine distribution in order to avoid spurious modelling of transportation cost.

A transportation model is necessary to solve the transportation problem. A transportation model is a special type of linear programming model where the objective is to minimize the cost of distributing a product from a number of sources or origins to a number of destinations. As developing countries received the COVID-19 vaccines for distribution, the need for adequate distribution of the vaccines from source to destination in a cost-effective manner was necessary due to binding budgetary constraints. The decision-making process involved in preparing for, and responding to COVID-19 vaccine supply and allocation is a strategic challenge for developing countries, and Nigeria in particular.

Accordingly, decision-making for COVID-19 vaccine distribution must balance preparedness and risk. Generally, the structures of optimization models in COVID-19 vaccine supply and allocation management must include: the 'preparedness phase' and the 'response phase' which integrate 'before' and 'after' pandemic occurrences respectively. In order to control the effect of COVID-19, the Federal Government of Nigeria in 2020 declared a total lockdown of the economy on the back of WHO's characterization of the disease as a pandemic and a public health crisis (Federal Ministry of Health, 2020).

Different mathematical and inferential modelling techniques such as social distancing were used to minimize the continuous spread of the virus (COVID-19). As WHO collaborated with various countries to develop vaccines to combat COVID-19, the need for vaccine equity was considered a key component of the distribution plan among developed countries in order to reach a reasonable number and critical segments of the world population (Biden, 2021). This is because managing COVID-19 vaccine shipment from source to destination in a developing country requires more intense planning and accurate coordination otherwise additional complexities might occur in the process. Decision making in this area plays a critical role, from the economic, mathematical, and the societal perspectives. As explained by Adebisi et al. (2020), the imperative for planning and optimal budgetary allocation for healthcare in Nigeria and other West Africa countries cannot be overemphasized. Cost minimization would go a long way in ensuring positive healthcare outcomes. Unfortunately, there is a dearth of studies on a model for minimization of COVID-19 distribution costs in most developing countries. Since these countries have little or no control over production of the vaccines, it is reckoned that one way they can exert some influence on COVID-19-related healthcare outcomes is through cost-effective logistics. Lack of research attention concerning a model to aid such intervention is a serious gap in the literature. The authors, in this paper, seek to fill this gap. According to Nigeria budgeted report for vaccine distribution during the COVID-19 period, it is assumed that transportation modelling was not used as a method of preparing the cost budget for vaccine distribution due to the exigencies of governments in the West African region to provide a quick solution to COVID-19, hence the high cost of budget for vaccine distribution.

This study therefore focuses on the optimal distribution of AstraZeneca/Oxford COVID-19 vaccines to minimize distribution cost in Nigeria. The study used Lagos State of Nigeria as a case study. Lagos is the most populated city, not only in Nigeria but in the entire sub-Saharan Africa. With the estimated population figure of 20 million in a geographical space of 3,577 km^2 (Beshi & Kaur, 2020), it is considered ideal to use for the transportation model to use in seeking to minimize distribution cost.

2. Literature

Several optimization theories and concepts in the presence of incomplete information exist in the body of knowledge, though with relatively few applications in the delivery of desirable healthcare outcomes, especially among states in Nigeria. In this paper, we review the game theory and transportation model vis-à-vis previous works concerning the minimization of transportation cost of COVID-19 vaccines.

The Game theory refers to a situation in which one party has incomplete information regarding the willingness of a second party to pay a specific price to maximize personal benefits rather than follow historical reasoning (Fudenberg & Tirole, 1993). It is the duty of the government to maximize economic benefits by protecting its population from the virus by implementing specific strategies and incentives to obtain the desired outcome **(**Adebowale, 2021**).** Batkovskiy et al. (2016) used incomplete information and computer applications to solve problems relating to economic cost. They further assumed that it is not only the application of specialized software solutions that is of interest, but also an analyst's ability to build a mathematical and computational model of a controlled logistical system using standard software tools.

However, Lagos State, the highest populated state in Nigeria, as well as other states and regions in West Africa, applied lock down, social distancing, and other strategies and COVID-19 protocols in line with international standards to limit the spread of the virus. Adeyemo, Akindele, Aluko and Agesin (2012) stated the need for population strata as a cost-effectiveness measure to prioritize healthcare services using quality-adjusted life years and available resources in government. Williams, Abiola and Ojikutu (2021) transformed the transportation model to a linear programming model to solve the problem relating to the minimization of healthcare cost in tertiary institutions in Nigeria and concluded that healthcare cost can be optimized. Muhammed (2020) looked at the impact of appropriate modelling of logistic problems using discrete data for South African companies listed on the capital market and found that transportation modelling is essential for finding optimal cost in logistic problems. James and John (2021) stated that the use of transportation models in management sciences to solve logistics problems has not been fully utilized, hence an urgent request for the use of transportation model in logistic problems. Semad and Irfan (2017) stated that the transportation model is associated with a transfer of cargo from suppliers to consumers, and so, it can be used to solve other tasks that are not directly related to transit of goods. Batkovskiy et al. (2017) developed an optimization routine which involves the use of linear programming, transportation model and other probabilistic models of economic systems in the MS Excel environment. Beshi and Kaur (2020) stated that government is the principal agent in matters arising from the protection of life in whatever form, and government allocates funds to local governments, otherwise called segmented areas of the population, for effective running and implementation of government policies, including healthcare. Biden (2021) stated that it is the responsibility of governments in every city to create strategies to fight the

Coronavirus in the period of the pandemic. Dixit, Ogundeji and Onwujekwe (2020) concluded that the response of government is optimal in fighting the virus and other health-related problems. Eniola (2020) stated that better healthcare outcomes can be achieved by African countries with greater support from developed countries in the fight against the COVID-19 pandemic. Therefore, the implementation of transportation modelling is an optimal tool for cost minimization for vaccine distribution across cities. Given this observation, this research formulated a transportation model to solve the transportation problem of high cost on vaccine distribution in the period of the pandemic, using data from Nigeria.

3. Methodology

The focus of this paper is cost, therefore we adopted the cost theory to minimize the cost associated with distributing vaccines during a pandemic. We used the Transportation Model which is a special case model of linear programming to solve the problem associated with high cost of moving vaccines from the storage location to demand points across Lagos State. We used the budgeted cost of ₦10.6 billion required to distribute COVAX 3,940,000 million doses of the AstraZeneca/Oxford vaccine across Nigeria and estimated the apportioned cost for Lagos State using population statistics. We employed population data, storage and demand locations to build a transportation model that minimizes budgeted distribution cost across all cities in Lagos State in a period of pandemic using COVID-19 as a case study.

Table 1. Population Data

States	Total	Proportion	COAX 3,940,000. million doses of the AstraZeneca/Oxford vaccine
Lagos State	21515232	0.11119	438086.7= 438087
Others	171985311	0.88881	3501913
Total	193500543	1	3940000

Source: National Bureau of Statistics and National Population Commission (2016)

Table 2. Lagos State Projected Population Data across Local Government Areas

Rank	LGA	Population
1	Alimosho	1,456,783
2	Ajeromi-Ifelodun	2,000,346
3	Kosofe	665,421
4	Mushin	633,543
5	Oshodi-Isolo	1,621,789
6	Ojo	598,336
7	Ikorodu	535,811
8	Surulere	504,409
9	Agege	461,123
10	Ifako-Ijaiye	428,812
11	Somolu	402,992
12	Amuwo-Odofin	500,576
13	Lagos Mainland	317980
14	Ikeja	313,333
15	Eti-Osa	287,958
16	Badagry	241,437
17	Apapa	217,661
18	Lagos Island	209,665
19	Epe	181,715
20	Ibeju-Lekki	117,542

Source: https://en.wikipedia.org/wiki/List_of_Lagos_State_local_government_areas_by_population

Table 3. Variables, Description, Measurements and Sources

Variable	Description	Measurement	Source
Demand	Measures the total quantity of vaccine required to vaccinate a community in a state or country	Total numbers of persons demanding vaccine within a community	Authors' computation using projected population data
Supply	Measures the quantity of vaccine available and stored in a particular location within a state or country	The ratio of total quantity of vaccine available to unvaccinated persons within the state	Authors' computation using vaccine quantity available and population data

Variable	Description	Measurement	Source
Distance	Measures the length of the space between storage location and demand points	The distance in kilometres from supply point to demand point	Google Map link: https://www.google.com/maps/dir/Epe/Agege,+102212,+Lagos/@6.7291495,3.3749661,10z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1s0x103945de81c3d5c1:0x53ad7cfc19cae1be!2m2!1d3.9699874!2d6.5866632!1m5!1m1!1s0x103b9173e61df681:0x8a503f3a85dda06e!2m2!1d3.3208916!2d6.6179731!3e0
Population	Measures the total number of persons within the state or country prior to the period of the pandemic	Total persons assumed to be living in a community at the time of the pandemic	https://en.wikipedia.org/wiki/List_of_Lagos_State_local_government_areas_by_population
Cost per unit	Measures the cost of moving a vaccine from the storage location to demand points	(Distance between demand and supply points multiplied by Uber standard cost per kilometre)/expected supply	Computed by authors using Google Map, Uber cost per kilometre and expected supply computed in the study
Uber standard cost	Measures the cost per kilometre from point A to point B.	Computed cost per kilometre by Uber	Google link: https://technext.ng/2021/05/10/breaking-uber-increases-trip-fares-in-lagos-by-13/
Budgeted cost	Measures the amount budgeted for COVID-19 vaccine distribution.	₦3.9 billion Government budgeted cost for vaccine distribution	link: https://saharareporters.com/2021/03/06/covid-19-vaccine-government-budgets-n106billion-transportation-kano-lagos-katsina-get

Source: Authors' compilation.

Table 4. Distributing COVAX 438087 doses of the AstraZeneca/Oxford vaccine using the five Administrative Divisions and the State Capital as Supply Locations

Administrative Division	Supply Location	Population	Proportion	Storage (Hospital)
Ikeja	S_1- Ikeja	313333	0.211431	92625
Badagry	S_2- Badagry	241437	0.162917	71372
Ikorodu	S_3 –Ikorodu	535811	0.361555	158393
Lagos (EKO)	S_4 – Lagos	209665	0.141478	61980
Epe	S_5 – Epe	181715	0.122618	53717
	Total	1481961	**1**	438087 **vaccines Qty**

Source: Computed by Authors.

Table 5. Expected demand based on Population across Local Government Areas

Strata coding of demand points for vaccine	Population statistics for each community	Total population within a community	Vaccine collection centre based on community with highest population in each strata	Expected demand for the vaccine
D_i	Alimosho (11456783) & Ajeromi-Ifelodun (2000346)	$\sum_1^2 population$ 13457129	Alimosho	= 13457129 * **0.064861=** 872842.8
D_{ii}	Kosofe (665421) & Mushin (633543)	$\sum_1^2 population$ 1298964	Kosofe	= 1298964* **0.064861=** 84252.1
D_{igi}	Oshodi-Isolo (1621789) & Ojo (633543)	$\sum_1^2 population$ 2220125	Oshodi-Isolo	= 2220125* **0.064861=** 143999.5
D_{iv}	Ikorodu (535811) Surulere (504409)	$\sum_1^2 population$ 1040220	Ikorodu	= 1040220* **0.064861=** 67469.71
D_v	Agege (461123) & Ifako-Ijaiye (428812)	$\sum_1^2 population$ 889935	Agege	= 889935* **0.064861=** 57722.07
D_{vi}	Somolu (402992) & Amuwo-Odofin (318576)	$\sum_1^2 population$ 721568	Somolu	= 721568* **0.064861=** 46801.62
D_{ivi}	Lagos Mainland (317,980) & Ikeja (313333)	$\sum_1^2 population$ 631313	Lagos Mainland	= 631313* **0.064861=** 40947.59
D_{viii}	Eti-Osa (287958) &	$\sum_1^2 population$	Eti-Osa	= 631313* **0.064861=**

Strata coding of demand points for vaccine	Population statistics for each community	Total population within a community	Vaccine collection centre based on community with highest population in each strata	Expected demand for the vaccine
	Badagry (241437)	529395		34337.09
D_{ix}	Apapa (217661) & Lagos Island (209665)	$\sum_{1}^{2} population$ 427326	Apapa	= 427326* **0.064861=** 27716.79
D_x	Epe (181715) & Ibeju-Lekki (117542)	$\sum_{1}^{2} population$ 299257	Epe	= 427326* **0.064861=** 19410.11

Source: Computed by Authors.

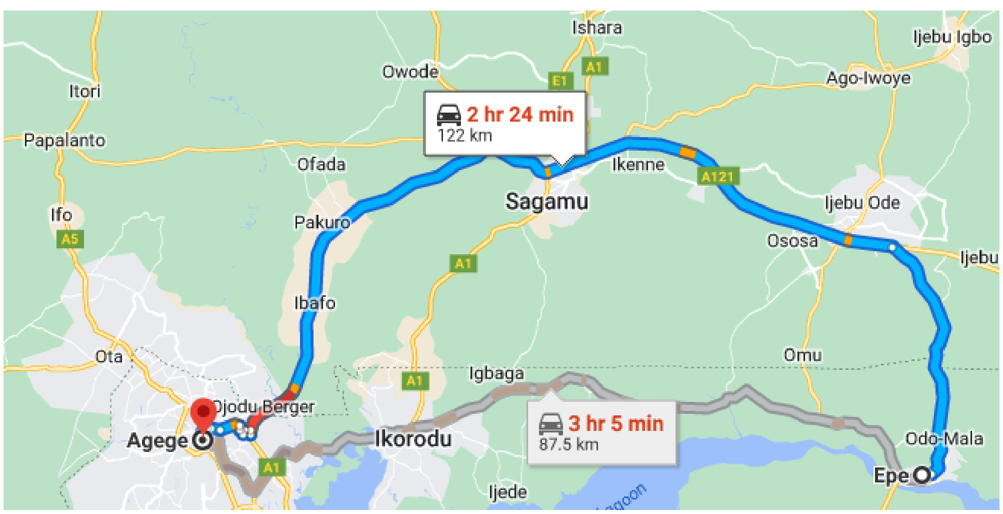

Figure 1. Distance between Agege Demand Point (DV) and Epe Storage Point (S_5) Location from a Point in Lagos State.

Source: Google Map.

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Table 6. Cost Per Unit of moving vaccine from Epe storage point (S_5) to Agege Demand Point (D_v) using distance between points (see figure 1), Uber standard cost per Kilometre and total quantities of vaccine to be shipped from source to destination point in Lagos State, Nigeria

To / From	D_i	D_{ii}	D_{igi}	D_{iv}	D_v	D_{vi}	D_{ivi}	D_{viii}	D_{ix}	D_x	S
S_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	54032
S_2	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	41634
S_3	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	92396
S_4	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}	C_{38}	C_{39}	C_{40}	36155
S_5	C_{41}	C_{42}	C_{43}	C_{44}	*122km*	C_{46}	C_{47}	C_{48}	C_{49}	C_{50}	31335
Dum.	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	1139947
D	872842	84252	144000	67470	57722	46802	40948	34337	27717	19410	1395499

Source: Authors' computation, 2022

3.1 Transforming Transportation Model to Linear Programming Model

MINIMIZE VACCINE COST (MVC) = $C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8 + C_9 + C_{10} + C_{11} + C_{12} + C_{13} + C_{14} + C_{15} + C_{16} + C_{17} + C_{18} + C_{19} + C_{20} + C_{21} + C_{22} + C_{23} + C_{24} + C_{25} + C_{26} + C_{27} + C_{28} + C_{29} + C_{30} + C_{31} + C_{32} + C_{33} + C_{34} + C_{35} + C_{36} + C_{37} + C_{38} + C_{39} + C_{40} + C_{41} + C_{42} + C_{43} + C_{44} + C_{45} + C_{46} + C_{47} + C_{48} + C_{49} + C_{50}$

Subject to the constraints:

$C_1 + C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8 + C_9 + C_{10} \geq 54032$ (Quantity of vaccine stored at Ikeja)

$C_{11} + C_{12} + C_{13} + C_{14} + C_{15} + C_{16} + C_{17} + C_{18} + C_{19} + C_{20} \geq 41634$ (Quantity of vaccine stored at Badagry)

$C_{21} + C_{22} + C_{23} + C_{24} + C_{25} + C_{26} + C_{27} + C_{28} + C_{29} + C_{30} \geq 92396$ (Quantity of vaccine stored at Ikorodu)

$C_{31} + C_{32} + C_{33} + C_{34} + C_{35} + C_{36} + C_{37} + C_{38} + C_{39} + C_{40} \geq 36155$ (Quantity of vaccine stored at Lagos Island)

$C_{41} + C_{42} + C_{43} + C_{44} + C_{45} + C_{46} + C_{47} + C_{48} + C_{49} + C_{50} \geq 31335$ (Quantity of vaccine stored at Epe)

$C_1 + C_{11} + C_{21} + C_{31} + C_{41} \geq 872842$ (Alimosho Demand location D_i)

$C_2 + C_{12} + C_{22} + C_{32} + C_{42} \geq 84252$ (Kosofe Demand location D_{ii})

$C_3 + C_{13} + C_{23} + C_{33} + C_{43} \geq 144000$ (Oshodi-Isolo Demand location D_{iii})

$C_4 + C_{14} + C_{24} + C_{34} + C_{44} \geq 67470$ (Ikorodu Demand location D_{iv})

$C_5 + C_{15} + C_{25} + C_{35} + C_{45} \geq 57722$ (Agege Demand location D_v)

$C_6 + C_{16} + C_{26} + C_{36} + C_{46} \geq 46802$ (Somolu Demand location D_{vi})

$C_7 + C_{17} + C_{27} + C_{37} + C_{47} \geq 40948$ (Lagos Mainland Demand location D_{ivi})

$C_8 + C_{18} + C_{28} + C_{38} + C_{48} \geq 34337$ (Eti-Osa Demand location D_{viii})

$C_9 + C_{19} + C_{29} + C_{39} + C_{49} \geq 27717$ (Apapa Demand location D_{ix})

$C_{10} + C_{20} + C_{30} + C_{40} + C_{50} \geq 19410$ (Epe Demand location D_x)

$$C_{ij} \geq 0 \quad i=1,2,3,4\ldots, j=1,2,3\ldots..10.$$

Table 7. Transportation Model and the R-Programing

To / From	D_i	D_{ii}	D_{igi}	D_{iv}	D_v	D_{vi}	D_{ivi}	D_{viii}	D_{ix}	D_x	S
S_1	0.115	0.082	0.18	0.246	0.148	0.033	0.131	0.049	0.164	0.295	54032
S_2	0.248	0.215	0.017	0.165	0.116	0.414	0.248	0.066	0.199	0.248	41634
S_3	0.067	0.133	0.111	0.044	0.245	0.067	0.156	0.200	0.200	0.044	92396
S_4	2.679	0.383	1.658	0.892	1.786	0.255	1.020	3.827	0.255	3.444	36155
S_5	1.267	2.019	0.891	1.926	2.141	1.267	0.167	1.611	1.792	0.892	31335
Dum.	0	0	0	0	0	0	0	0	0	0	1139947
D	872842	84252	144000	67470	57722	46802	40948	34337	27717	19410	1395499

Source: Authors' computation, 2022

```
library(lpSolve)

# Set transportation costs matrix

costs <- matrix(c(10, 2, 20, 11,

                  12, 7, 9, 20,
```

```
            4, 14 , 16, 18), nrow = 3, byrow = TRUE)

costs <-
matrix(c(0.115,0.082,0.18,0.246,0.148,0.033,0.131,0.049,0.164,0.295,0.248
,0.215,0.017,0.165,0.116,0.414,0.248,0.066,0.199,0.248,0.067,0.133,0.111,
0.044,0.245,0.067,0.156,0.200,0.200,0.044,2.679,0.383,1.658,0.892,1.786,0
.255,1.02,3.827,0.255,3.444,1.267,2.019,0.891,1.926,2.141,1.267,0.167,1.6
11,1.792,0.892,0,0,0,0,0,0,0,0,0,0),

nrow=6, byrow = TRUE)


# Set customers and suppliers' names

colnames(costs)<-c(“D_I”,“D_II”, “D_III”, “D_IV”,“D_V”, “D_VI”,
“D_VII”, “D_VIII”, “D_IX”, “D_X”)

rownames(costs) <- c("S_1", "S_2", "S_3", “S_4”, “S_5”, “Dum”)

# Set unequality/equality signs for suppliers

row.signs <- rep("<=", 6)

# Set right hand side coefficients for suppliers

row.rhs <- c (54032, 41634, 92396, 36155, 31335, 1139947)

# Set unequality/equality signs for customers

col.signs <- rep(">=", 10)

# Set right hand side coefficients for customers

col.rhs <- c(872842, 84252, 144000, 67470, 57722, 46802, 40948, 34337,
27717, 19410)

# Final value (z)
```

```
lp.transport(costs, "min", row.signs, row.rhs, col.signs, col.rhs)

# Variables final values

lp.transport(costs, "min", row.signs, row.rhs, col.signs, col.rhs)$solution
```

4. Discussion

The findings of this study support the game theory that incomplete information could be maximized and streamlined to the objective of the research. The result of this study shows that, using linear programming, budgeted cost for vaccine distribution can be minimized if population data and distance in kilometres from source to destination is applied in a transportation model. The results have been successful in supporting the game theory, especially where information required to model an optimal result is limited. It confirms the statement that the transportation model is a minimization model and can be used by researchers to solve problems relating to the distribution of tangible items. It equally corroborates the results of the study by Semad and Irfan (2017), which shows that shipment of medical products from source to destination during disaster management, can be optimized with stochastic programming. The result of this study also supports the works of Cornuejols and Tutuncu (2006) and Batkovskiy et al. (2016), which show that the transportation model is useful for solving transportation problems. The result of this study also supports the works of Mohammed (2020) and Craven and Islam (2005). Mohammed (2020) showed that distance in kilometres has been used accurately to solve problems related to logistics and supply chain. The work of Adeyemo et al. (2012), which was similarly based on a segmented population, equally supported cost minimization by government in a transportation modelling framework. The results of this study also corroborate the work of Williams et al. (2021), indicating that the transportation model is a satisfactory model when used to minimize cost. This study’s findings also support the work of Batkovskiy et al. (2017) and Adebisi et al. (2020) in modelling optimal budgetary allocation for the healthcare system. The research by Craven and Islam (2005) found that non-linear transportation modelling may be complex for modelling in the field of finance and economics if information is limited. The outcome, however, differs from the work of James and George (2021), who only optimized a transportation model for shipment of medical equipment.

The data obtained and tested in this study shows that vaccine distribution is made for persons, hence population statistics are the key information needed for the distribution. This research does not support the manual computation of the North West Corner method, the Vogel method and the least cost method, due to the constraint variables used. This research corroborates the work of Arora (2015) in the use of algorithm and supports the use of R, python, LINDO and other programming tools for optimal results.

5. Conclusion

This research aimed to answer the research question of whether a transportation model as a method of linear programming would assist government in minimizing the cost for vaccine distribution during a period of pandemic in the future. The transportation model of linear programming has given researchers in the field of mathematical sciences, and operations research in particular, innovative ideas on issues relating to cost minimization and the required data and variables needed. The result of this research validates the dominant view in the body of knowledge that the transportation model is the optimal model to minimize cost of distribution of tangible items from source location to destination. Specifically, government would be able to minimize the cost of shipping COVID-19 vaccines across several locations indicated in the budget.

However, the research result indicates that for budgeted distribution cost to be minimized, two essential variables are required. The first is population statistics and the other is the distance between the vaccine storage location and the demand points. Also, remarkably, the results of this study successfully demonstrated the quantitative processes needed to effectively implement a transportation model with more than ten constraints.

There is a possibility that if this model is replicated across other states in Nigeria and in the West Africa region, it would yield results that minimize budgeted cost for vaccine distribution and help contain the spread of the virus at the national and regional levels. Accordingly, the model is highly recommended for experts in Mathematical Sciences, Finance, Accounting, Operations Research and Healthcare Providers in containing future pandemics.

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