Optimization of Transportation Cost of Plaster of Paris Cement

K. M. Oba

***Abstract*—**The transportation modelling technique was adopted in the solution of the problem of transportation of Plaster of Paris (POP) cement from three supply locations (construction materials markets) to three demand locations (construction sites) in Port Harcourt. The study was carried out for 40 kg bags of POP cement fully loaded on 600 bags per truck from the three selected construction materials markets in Port Harcourt. The costs of transporting the POP cement were determined and subjected to the North-West Corner, Least Cost, and Vogel's approximation methods to determine the initial feasible solution. Of the three results, the Least Cost Method turned out to have the lowest cost. Using the Stepping Stone Method, the optimum shipping cost was finally attained after two successive iterations. The optimum shipping cost was calculated to be $1,690 or ₦1,774,500 as of October 2023. As a result of this study, the application of transportation modelling can boost the effective management of the transportation of POP cement in construction projects.

***Keywords*—**Cost of POP cement, management of transportation, optimization of shipping cost, Plaster of Paris, transportation model.

I. Introduction

POP is a very common construction material. It has been in use for construction for centuries by the Romans and Egyptians [1]. It is a lightweight material made from gypsum [2]. Many claims to the origin of POP have been made, but [1] laid hold on King Henry III to have given it the name POP, when he visited Paris in AD1254, after seeing some walls made of the said material, which he later replicated in England that year. POP is also used in medicine for the management of bone fractures. POP is also used in medicine for the management of bone fractures. In Nigeria, the white powdered substance, POP cement has come to stay as construction practitioners have found a way to apply it to beautify their various building construction projects. The construction practitioners use POP cement for ceilings, walls, and other interior and exterior finishes on buildings. In Nigeria, POP cement comes in bags of 40 kg by weight. When used as a ceiling finishing, POP cement is usually reinforced with a sponge-like material called kenaf filament fiber in order to make it stronger and more rigid [4]

The transportation of POP cement is the process of shipping the material from one location to another. This is a very key component in construction. According to [5], the cost of transportation of cement is usually very high. This is the case for other materials including POP cement. Several studies, including [6], have established that the transportation of construction materials has not received much research attention in terms of risk management, planning, and procurement.

Construction practitioners and property developers are often faced with the problem of effective and efficient management of the movement of POP cement from the points of sale to the construction sites. While this is the case for most other construction materials, POP cement transportation needs care and attention as it could cake as a result of rainfall upon it during transportation. The most common means of transportation of construction materials in Nigeria is the road transport. This means it is also the most efficient in the country. On the contrary, the transportation of cement by means of river transport is the most efficient in Bangladesh [7].

Some factors affecting the transportation cost of POP cement are: cost of vehicle (either purchased or leased), cost of fuel, local taxes, truck driver, distance, client, and traffic. This calls for the dire need for the adoption of standard operations research techniques to optimize the cost of transporting the material to various construction sites. Previous studies [8]-[15] have been carried out to manage the transportation of various construction materials. Reference [15] was for the planning, management, control, purchasing and handling of construction and building materials, while [10] developed a transportation model, with a modified generic algorithm for the vehicle fleet. Several other studies, most of which are mathematical models [8], [12]-[14], have been conducted, but did not address the problem of transportation of POP cement for the purpose of construction. However, a recent study by [16] utilized a transportation modelling technique that addressed a transportation problem for cement.

The scope of this research is limited to construction projects and construction materials markets in Port Harcourt, the capital city of Rivers State, Nigeria. The oil and gas rich city of Port Harcourt has a large population, a smaller number of road networks, and a high amount of traffic volume. These in addition to the high cost of transportation, have made the process of transportation of POP cement a bit difficult. study aims to address the problem of managing the transportation of POP cement from some selected supply locations to some selected demand sites in a manner that aligns with sustainability, by cost reduction, number of trips reduction, reduction in social issues, and reduction of emission of greenhouse gases from the trucks used for the transportation.

II. Materials and Methods

POP was the material with which the study was conducted.

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POP cement dealers at three major depots in Port Harcourt, Nigeria, were interviewed. Some truck drivers, project engineers, and property developers were also interviewed to gather primary data with which the costs of transportation of the POP cement in bags, were calculated using three demand locations and three supply locations in Port Harcourt. The maximum number of bags carried by each truck was 600. The POP cement weighs 40 kg per bag. The costs of transportation of each 600-bag truck of POP cement were calculated and are shown in Table I. These costs include cost of hiring the truck per day, cost of loading and offloading the material, and payment for local taxes and homage. The Nigerian Police is also factored into the cost as a miscellaneous expenditure. The values were in Naira, but converted to U.S Dollars, at ₦1,050 per US$ as of October 2023.

TABLE I
TRANSPORTATION DISTRIBUTION FROM SUPPLY TO DEMAND SITES

minimize	Project Locations with transportation costs ($)			Availability or supply (trips of 600 bag trucks)
P.O.P Cement depots	Eneka (X)	Rumumasi (Y)	Abuloma (Z)	
Mile 3, Diobu (A)	209	185	150	4
Creek Road, PHC township (B)	220	250	160	3
SARS road, Rukpokwu (C)	103	133	280	5
Requirement or demand (trips of 600 bag trucks)	3	3	6	

A. The Simplex Method of Solving Transportation Problems

The simplex method was described by [17] in four steps. The governing equation for transportation modelling is:

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad (1)$$

Subject to the constraints:
Supply constraint

$$\sum_{j=1}^{n} x_{ij} = a_i;\ i = 1,2,\dots,m \quad (2)$$

Demand constraint

$$\sum_{i=1}^{m} x_{ij} = b_j;\ j = 1,2,\dots,n \quad (3)$$

$x_{ij} \geq 0$; for all *i* and *j* when

$$no. of\ allocations = m + n - 1 \quad (4)$$

The solution is non-degenerate if (4) holds. However, when (4) does not hold, the solution is degenerate
The solution is degenerate. For a feasible solution to exist,

$$\sum Supply = \sum Demand \quad (5)$$

Equation (5) is referred to as the rim condition. However, if $\sum Supply < \sum Demand$, a dummy row would be introduced, whose supply is $\sum Demand - \sum Supply$. Similarly, if $\sum Supply > \sum Demand$, a dummy column would be introduced, whose demand is $\sum Supply - \sum Demand$. For the data in this study, m+n is 3+3-1 = 5; $\sum Supply = 12\ and \sum Demand = 12$. This means that the rim condition has been met.

III. RESULTS AND DISCUSSIONS

A. North-West Corner Method

This method was used to obtain an initial feasible solution as explained by [17]. Table II shows the allocation using this method.

TABLE II
INITIAL FEASIBLE SOLUTION USING THE NORTH-WEST CORNER METHOD

	X	Y	Z	s
A	209 3	185 1	150	4
B	220	250 2	160 1	3
C	103	133	280 5	5
d	3	3	6	

The shipping cost = (3*209) + (1*185) + (2*250) + (1*160) + (5*280) = **$2,872**

B. The Least Cost method

This was another method used to obtain an initial feasible solution following the procedures explained by [17]. The results of the allocation are shown in Table III.

TABLE III
INITIAL FEASIBLE SOLUTION USING THE LEAST COST METHOD

	X	Y	Z	s
A	209	185	150 4	4
B	220	250 1	160 2	3
C	103 3	133 2	280	5
d	3	3	6	

The shipping cost = (4*150) + (1*250) + (2*160) + (3*103) + (2*133) = **$1,745**

C. Vogel's Approximation Method

Table IV shows allocated results, using this method as explained by [17] to obtain the initial feasible solution.

D. The Optimal Solution

According to [17], the optimal shipping cost will be obtained either by the Modified Distribution (MoDi) method or the stepping stone method. For this study, the stepping stone method was used. This is as obtained in Tables V-VII. The results from the Least Cost Method gave a more feasible value than the other two methods used in obtaining the initial feasible solution. Results from Table III were used for the first iteration, using the stepping stone approach.

TABLE IV
INITIAL FEASIBLE SOLUTION BY VOGEL'S APPROXIMATION METHOD

	X	Y	Z	s				
A	209	185 3	150 1	4	185-150 = 35	185-150 = 35	185-150 = 35	185-150 = **35**
B	220	250	160 3	3	220-160 = 60	250-160 = 90	250-160 = **90**	N/A
C	103 3	133	280 2	5	133-103 = 30	280-133 = **147**	N/A	N/A
d	3	3	6					
	209-103 = **106**	185-133 = 52	160-150 = 10					
	N/A	185-133 = 52	160-150 = 10					
	N/A	250-185 = 65	160-150 = 10					
	N/A	185-185 = 0	150-150 = 0					

The shipping cost = (3*185) + (1*150) + (3*160) + (3*103) + (2*280) = **$2,054**

The first unoccupied cell is A-X. A loop was formed between it and other nearby occupied cells with alternating plus and minus signs, starting A-X with a plus sign. The values from the loop formed were accumulated and the results were recorded in Table V. This was repeated for cells A-Y, B-X, and C-Z as they were the unoccupied cells, and the results were recorded in Table V. Since there was a negative value in the results from Table V, the solution has not yet attained optimality, hence the need for another iteration.

TABLE V
FIRST ITERATION

Cell	Occupied/unoccupied costs						Total
A-X	209	-150	160	-250	133	-103	-1
A-Y	185	-150	160	-250			-55
A-Z							
B-X	220	-250	133	-103			0
B-Y							
B-Z							
C-X							
C-Y							
C-Z	280	-160	250	-133			237

The greatest negative value (-55) corresponds to cell A-Y. This means the loop for the first iteration would commence there while linking the allocated values of the nearby occupied cells with alternating signs (loop A-Y, A-Z, B-Z, B-Y, A-Y). The loop has values (+0, -4, +2, -1, +0). The smallest negative value is -1. This was then added to the other values in the loop to give (1, 3, 0, 1). Table VI shows the new tableau resulting from the first iteration.

TABLE VI
OPTIMIZATION SOLUTION AFTER FIRST ITERATION

	X	Y	Z	s
A	209	185 1	150 3	4
B	220	250	160 3	3
C	103 3	133 2	280	5
d	3	3	6	

The total shipping cost = (1*185) + (3*150) + (3*160) + (3*103) + (2*133) = **$1,690**

TABLE VII
SECOND ITERATION

Cell	Occupied/unoccupied costs						Total
A-X	209	-185	133	-103			54
A-Y							
A-Z							
B-X	220	-160	150	-185	133	-103	55
B-Y	250	-160	150	-185			55
B-Z							
C-X							
C-Y							
C-Z	280	-150	185	-133			182

From Table VII, there are no more negative values. Hence the solution is optimal. The optimum shipping cost is **$1,690.** As an alternative, the optimal solution can also be obtained using Microsoft Excel solver. This is shown in Table VIII, as it gave the same result as the simplex approach.

The optimum shipping cost is **$1,690 (₦1,774,500)** from 5 allocations.

IV. CONCLUSION

POP cement in 40kg bags was loaded in 600-bag trucks and shipped from three construction materials markets (supply locations) to three construction sites (demand locations) in Port Harcourt, Nigeria. The allocation was successfully done by the use of the transportation model. The initial feasible solution was determined using the North-West Corner, Least Cost, and Vogel's Approximation methods. The results obtained were $2,872.00, $1,745.00, and $2,054.00 respectively. This showed that the Least Cost Corner method resulted in the best result, and was therefore used for the final test for optimality, using the stepping stone method. After two successive iterations, the optimum shipping cost was reached, to the tune of $1,690.00. The challenges and problems of effective and efficient management of transportation of POP cement during construction in the city of Port Harcourt have been successfully addressed in this study. It is hereby recommended that construction practitioners, stakeholders, researchers, and engineers now apply the transportation modelling technique to effectively manage construction projects that involve the use and transportation of POP cement.

TABLE VIII
OPTIMAL FEASIBLE SOLUTION USING MICROSOFT EXCEL SOLVER

minimize	Project Locations with transportation costs ($)			Supply	Availability or supply (trips of 600 bag trucks)
P.O.P Cement depots	Eneka (X)	Rumumasi (Y)	Abuloma (Z)		
Mile 3, Diobu (A)	0	1	3	4	4
Creek Road, PHC township (B)	0	0	3	3	3
SARS road, Rukpokwu (C)	3	2	0	5	5
Demand	3	3	6		
Requirement or demand (trips of 600 bag trucks)	3	3	6		
Optimum shipping cost ($)			1,690		

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