The application of Mathematical Modelling to Optimize Steel Reinforcement Shipping Cost for Construction Projects by Julius Berger

ABSTRACT

The problem of transporting steel reinforcement for construction purposes has always been eminent in construction projects. In this study, the transportation modelwas applied while shipping steel reinforcement from three supply locations to three construction sites owned by Julius Berger construction limited, in the city of Port Harcourt. The study was done for 100-ton truck load of steel reinforcement bars with standard 12m lengths and diameters 8mm to 40mm. This was from the three selected steel depots in Port Harcourt. The costs of transporting the steel reinforcement bars were analyzed using the basic steps of simplex algorithm for solving transportation problems. The initial and optimum feasible solutions were obtained. The Stepping Stone method was used for the optimum solution after three consecutive iterations, which amounted to $3,813 or (₦2,897,880 as of March 2023). The result was compared with that obtained from Microsoft Excel solver. There was no difference between the two results.

Keywords: Julius Berger, Optimization of Shipping Cost, Reinforcement Cost, Transportation model.

1. INTRODUCTION

Steel is widely used globally in several industries for different purposes. The construction, and oil and gas industries have so far been the most beneficiaries of steel. Steel is mostly used as reinforcement and structural steel in columns, foundations, beams, slabs, stairs, girders, and other structural members in construction. The case is very much the same in Nigeria as most buildings are made of reinforced concrete. In [1] Nigeria's estimated annual steel consumption as at 2020 was 150kg/capital. This huge amount of steel and even more, are transported across the country for various construction works. Transportation of steel reinforcement has to do with the shipping of steel reinforcement from place to place.This is critical in the Nigerian construction industry. Some studies[2] however, posit that transportation of construction materials has been given less academic and scholarly intervention while considering the procurement planning and risk assessment for construction purposes. This is why Engineers, construction managers, and construction practitioners are regularly faced with difficulty in the management of shipping construction materials, especially reinforcing steel to their various construction sites. The reinforcement steel bars of varying diameters are of standard 12m lengths that are shipped from depots herein referred to as the supply locations to construction sites otherwise called the demand locations. The process of transportation involves time management, cost management, diesel cost, personnel, traffic, taxations, client, transportation truck, distance to site, demurrage, local authorities, and vendors. These amongst others, are factors affect the cost of transporting steel reinforcement for construction. This calls for a need to adopt operations research techniques to optimise the cost of shipping steel reinforcement.

In the past, studies by [3], [4], [5], [6], [7], [8], [9], [10] were done to manage and transport construction materials and other items. [10]published an article on the control, management, planning, purchasing and handling of construction materials. [5]developed a transportation model to improve transportation of goods from place to place, using a modified generic algorithm for the vehicle fleet. Similar studies [3], [7], [8], [9] have also been carried out, but were unable to address the problem of shipping steel reinforcement for to be used for construction. A recent study by [11]has however utilised a transportation model technique to solve a transportation problem with regards toshipping of sand. This means that, there is currently no such scholarly article published for steel reinforcement.
This study is a continuation of[11], with Julius Berger Construction Limited as the case study. Between the years 2015 and 2023, Julius Berger Construction Companyexecuted most of the construction projects in which the Rivers state government was the client. The projects of interest for this study are only those located in Port Harcourt, a big oil and gas city in Nigeria.Port Harcourt's high traffic volume, large population, andfewer road networks have all created difficulties in

the transportation of steel reinforcement and other construction materials. This study aims to address the problem of shipping steel reinforcement from three supply locations to three demand sites in a sustainable manner that reduces the number of trips, costs, social issues, and emission of greenhouse gases.

2. METHODOLOGY

The material under consideration was steel. Interviews were conducted on selected truck drivers, site supervisors, project managers, project engineers, and vendors of Julius Berger Construction Nigeria Limited. Some sellers of steel reinforcement at the three supply locations also partook in the interviews. The maximum capacity of each truck was 100 tons load of steel reinforcements of standard 12m length, and diameters ranging from 8mm to 40mm. The number of trips required per day and their costs were calculated with the information gathered from the interviews. Table 1 shows the cost of shipping steel reinforcement from three locations to three construction sites all within Port Harcourt. These, as of March 2023, were converted at the rate of ₦760 per US$. The costs include the cost of the truck lease (where applicable), the steel reinforcement purchase, the truck's fuel, the driver's wages, and taxes and homages for every 100 tons of steel transported. These are shown in Table 1 below.

Table 1.Transportation Distribution

minimization	Project Locations with transportation costs ($)			Availability or supply (trips of 100 tons trucks)
Steel depots	N.T.A flyover (X)	Rumukwurusi flyover (Y)	Rumuokuta flyover (Z)	
Kala (A)	100	197	88	9
Mile 3 (B)	132	201	112	4
Iriebe steel village (C)	238	93	206	20
Requirement or demand (trips of 100 tons trucks)	11	15	7	

2.1. The Simplex Algorithm

The steps for the solution of a transportation problem were outlined in [12].

The governing equation of a transportation model is:

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

Subject to the constraints:
Supply constraint

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

Demand constraint

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

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

When $no.of\ allocations = m + n - 1$ (4)
The solution is said to be non-degenerate

However, when $no.of\ allocations < m + n - 1$ or $> m + n - 1$, (5) then the solution is degenerate.

For a feasible solution to exist,

$$\sum Supply = \sum Demand \quad (6)$$

This is called the rim condition.

For this study,
The no. of allocation = 3+3-1 = 5.

$\sum Supply = 33 \text{ and } \sum Demand = 33$

The rim condition has been satisfied since $\sum Supply = \sum Demand$.

3. RESULTS AND DISCUSSION

3.1. The Least Cost method

This least cost method was used to determine an initial feasible solution. The first allocation was made to the least or lowest value in Table 2. This was done such that the lesser of the supply or demand was satisfied. The process was repeated until all appropriate allocations were made.

Table 2.Initial feasible solution usingLeast Cost method

	X	Y	Z	s
A	100 / 2	197	88 / 7	9
B	132 / 4	201	112	4
C	238 / 5	93 / 15	206	20
d	11	15	7	

The initial shipping cost = (2*100) + (7*88) + (4*132) + (5*238) + (15*93) = **$3,929**

3.2. The North-West corner method

An initial feasible solution was obtained using this method. The first allocation was made to the cell at the North-West corner or top left corner, such that the lesser of the supply or demand was satisfied. The process was repeated in a step-wise manner until all appropriate allocations were made. This is shown in Table 3.

Table 3.Initial feasible solution using North-West Corner method

	X	Y	Z	s
A	100 / 9	197	88	9
B	132 / 2	201 / 2	112	4
C	238	93 / 13	206 / 7	20
d	11	15	7	

The initial shipping cost = (9*100) + (2*132) + (2*201) + (13*93) + (7*206) = **$4,217**

3.3. The Vogel's Approximation method

In Table 4, this method was demonstrated in obtaining an initial feasible solution. On the first row, the difference between the least value and the second to least value was determined. This was also done on the first column. The highest of all the results was chosen as the position for the first allocation to be made such that the smaller of the supply or demand was satisfied. This process was repeated until all appropriate allocations were made.

Table 4.Initial feasible solution usingVogel's Approximation method

	X	Y	Z	s				
A	100 / 7	197 / 2	88	9	100-88 = 12	100-97 = 97	100-97 = **97**	100-100 = 0
B	132 / 4	201	112	4	132-112 = 20	132-201 = 69	132-201 = 69	132-132 = 0
C	238	93 / 13	206 / 7	20	206-93 = **113**	238-93 = **145**	N/A	N/A
d	11	15	7					
	132-100 = 32	197-93 = 104	112-88 = 24					
	132-100 = 32	197-93 = 104	N/A					
	132-100 = 32	201-197 = 4	N/A					
	132-100 = **32**	N/A	N/A					

The initial shipping cost = (7*100) + (2*197) + (4*132) + (13*93) + (7*206) = **$4,273**

3.4. The Optimum solution

The stepping stone method was used in obtaining the optimum feasible solution as shown in Tables 5 to 10 below. From the three methods used to determine the initial feasible solution, the result from the Least cost method was the lowest. This means the results obtained from Table 2 will be used for the first iteration to obtain the optimal shipping cost.

Thefirst unoccupied cell was assigned a positive sign. A loop was created, linking the first unoccupied cell with the occupied ones within that loop, with alternating signs. This was repeated for all unoccupied cells as shown in Table 5. The summation of all the results from each loop was obtained. The negative sign convention found on the results show indicate that the solution is not optimal yet, and there will thereforebe further iteration.

Table 5.First iteration for constants

S/N		un c						total
1	1-1							
2	1-2	197	-93	238	-100			242
3	1-3							
4	2-1							
5	2-2	201	-93	238	-132			214
6	2-3	112	-132	100	-88			-8
7	3-1							
8	3-2							
9	3-3	206	-238	100	-88			-20

Table 6.Optimization for first iteration

	X	Y	Z	s
A	100	197	88	9

	X	Y	Z	s
	2		7	
B	132 4	201	112	4
C	238 5	93 15	206	20
d	11	15	7	

The total shipping cost = (2*100) + (7*88) + (4*132) + (5*238) + (15*93) = **$3,929**

The cell that had the maximum negative total value from Table 5 is 3-3. Hence the creation of a loop with the least negative value being -5. This led tothe second iteration as 5 is subtracted and added within the loop according to the assigned sign convention.

Table 7.Second iteration for constants

S/N		unc						total
1	1-1							
2	1-2	197	-93	206	-88			222
3	1-3							
4	2-1							
5	2-2	201	-132	100	-88	206	-93	194
6	2-3	112	-132	100	-88			-8
7	3-1	238	-206	88	-100			20
8	3-2							
9	3-3							

Table 8.Optimization for second iteration

	X	Y	Z	s
A	100 7	197	88 2	9
B	132 4	201	112	4
C	238	93 15	206 5	20
d	11	15	7	

The total shipping cost = (7*100) + (2*88) + (4*132) + (15*93) + (5*206) = **$3,829**

The cell that had the maximum negative total was 2-3. Hence the creation of a loop with the least negative value being -2. This led tothe third iteration.

Table 9.Third iteration for constants

		un						total

		un						total
S/N		c						
1	1-1							
2	1-2	197	-93	206	-112			198
3	1-3	88	-100	132	-112			8
4	2-1							
5	2-2	201	93	-206	112			200
6	2-3							
7	3-1	238	-206	112	-132			12
8	3-2							
9	3-3							

Since all there are no more negative total results in Table 9, the solution is therefore optimal, hence there will be no more iteration.

Table 10.Optimization for third iteration

	X	Y	Z	s
A	100 9	197	88	9
B	132 2	201	112 2	4
C	238	93 15	206 5	20
d	11	15	7	

The optimum shipping cost = (9*100) + (2*132) + (2*112) + (15*93) + (5*206) = **$3,813**

Table 11 shows Microsoft Excel solver solution for the optimum shipping cost.

Table 11.MS Excel approach to the optimal solution

min	Project Locations with transportation costs ($)			Supply	Availability or supply (trips of 100 tons trucks)
Steel depots	N.T.A flyover (X)	Rumukwurusi flyover (Y)	Rumuokuta flyover (Z)		
Kala (A)	9	0	0	9	9
Mile 3 market (B)	2	0	2	4	4
Iriebe steel village (C)	0	15	5	20	20
Demand	11	15	7		
Requirement or demand (trips of 100 tons trucks)	11	15	7		
Optimum shipping cost ($)	**3,813**				

The result of the optimal solution is **$3,813 (₦2,897,880)**. This was obtained from 5 allocations exactly the same way as the result from the computer, using MS excel solver.

4. CONCLUSION

The steel reinforcement bars stacked in 100tons-trucks to be transported from three steel depots to three construction sites in Port Harcourt have been successfully allocated using the transportation modelling technique. The initial feasible solution was determined. This was done by the use of the Least Cost, North-West Corner, and Vogel's Approximation methods. The results obtained were $4,217.00, $3,929.00, and $4,223.00 respectively. This indicates that the Least Cost Corner method had the smallest result, and was therefore selected andused for the optimality test, using of stepping stone method. The optimal solution was achieved after three consecutive iterations with an optimum shipping cost of $3,929.00. By the application of the Transportation modelling technique to ship steel reinforcement form place to place for the purpose of construction, this research has contributed to knowledge in the aspect of cost minimization. Construction practitioners, stakeholders, engineers, and researchers, can begin to adopt this technique to better organise, manage, control, operate, plan, and execute construction projects as recommended by this study.

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