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Preliminary Design of Monorail Network for Anambra State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author ENO designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors NSC and OPC managed the analyses of the study, literature searches and improved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Over the years rail track have existed in Nigeria without its proper utilization. Having an effective monorail network in the state will improve the transportation sector of the state since it is the trending technology in railway design. Introduction of monorail into the transportation system addresses the problems and defects associated with the old rail lines and also serve as an alternative means of transportation. This project develops a workable monorail network within the state using the flow model, the transportation algorithm and analysis was done using the North West Corner rule and Stepping-Stone method. The longest route is the Onitsha-Igbokwu route (53 km) while the shortest route is the Onitsha-Nnewi route (21 km). The total distance covered by the track is 525.8 km and will take 7.5 hrs to travel round the entire track at the cost of ₦2, 630.

Keywords: Monorail; transportation algorithm; network design scheduling, Rostering.

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1. INTRODUCTION

The quest for a different means of transportation other than road transportation has brought to the development of rail tracks as such to ease traffic and reduce the rate of road usage. The only means of transportation within the state is by road, this possess lots of stress on the road and also for the road users and in turn leads to several road hazards, high traffic jam and high cost of maintenance of the road. These transport terms: accessibility; economic efficiency and safety are appropriate elements of sustainable transport [1]. In recent years, the railway network has progressively fallen into a state of disrepair and if these problems are not resolved, road network will continue to be the only means of transportation in the country, as such, the challenges faced on road transportation will always exist. Nigeria's fairly maintained rail tracks of 3 ft. 6 in (1,067 mm) gauge has suffered lots of setbacks due to lack of maintenance culture by **NCR**[1]. Years of neglect of both rolling stock and **the right -of-way** have seriously reduced the capacity and utilization of the system. Couplings of the chopper kind, vacuum brakes and non-roller bearing plain axles are obsolete [2].

The cost of rehabilitating these rail systems and its reconstruction to standard gauge are high when compared to the construction cost of monorail lines. Monorail have numerous advantages over light rail system; the separate grade of monorail makes it safe as such cannot collide with cars or other vehicles or run over people, less destructive and disruptive due to it elevated nature and low maintenance cost, finally the cost of operation of monorail is far less to that of a light railway.

Network design requires the determination of movement pattern of the people living in the environment and then designing a transportation network to facilitate these movements. This network is built to enable mobility of the population and depends on population density and the geographical properties of the regions. Within **conurbations**, both the topology of the monorail network and the layout of shuttle train lines are typically complicated. This often requires many switches or the construction of level-free crossings around main stations to enable connections among all directions. In contrast, railway networks in rural regions usually consist only of singular lines that connect cities with a limited number of parallel track sections and only few switches [3].

To remedy the poor condition, efficiency and profitability of railway in the country, as well as that of the road, a new trend in rail design (monorail) is needed. This report is therefore geared towards designing monorail network, developing an algorithm (network analysis) as well as the scheduling process. The cost analysis of the entire transportation process and the transportation algorithm will be highlighted. The North West Corner rule was used to obtain the initial feasible solution and the Stepping-Stone method to find the optimal solution with lots of assumptions, restricting focus on balanced transportation problems where it is assumed that the total supply is equal to total demand.

Monorail has been in use in countries like Japan, Tokyo Monorail (17.8 km) is one of the world's busiest with the averages of 127,000 passengers per day and has served over 1.5 billion passengers since 1964 [4]. In the 1950s, a 40% scale prototype of a system designed for speed of 200 mph (320 km/h) on straight stretches and 90 mph (140 km/h) on curves was built in Germany [5]. The Shanghai Maglev Train (30.5 km) in China is the fastest commercial train currently in operation and has a top speed of 430 km/h (270 mph) having the longest maglev line. Chongqing Rail Transit also in China is the longest straddle-beam line covering about 86.8 km (53.9 miles) been the longest monorail route and the largest system [6]. Currently in Lagos State Nigeria a monorail is under construction and there is a proposal for such in Enugu State and Rivers State both in Nigeria [7].

2. METHODOLOGY

2.1 Flow Model

Even the simplest version of the rolling stock **rostering** problem is usually broken into two separate phases [8]: first, one solves the train length problem, in which the lengths of the trains on each route (including empty and piggy-back rides) are determined. The main goal here is to ensure that there are always enough train units available at each station for all scheduled rides departing from that station. In this phase rides are only assigned to train unit types, but not to specific train units.

[1] *Nigerian Railway Corporation.*

In the second phase, the train assignment problem is solved: specific train units are assigned to the scheduled rides. For each train unit a rotation is determined. A standard (and longtime) approach for modeling the train length problem phase is to use a flow model: a periodic directed graph is used to model the scheduled rides [9]. Each vertex in the graph represents one station at a specific time, that is, an (*s, t*) pair with station *s* at time *t*. A ride is represented by an edge, which leaves a vertex representing its departure (station and time), and enters a vertex representing its arrival (station and time). Each edge has a lower and upper bound for the required flow where the number of flow units corresponds to the number of train units. The lower bound corresponds to the passenger demand for the associated ride, while the upper bound corresponds to track/station limitations and thus a maximum number of allowed train units. Moreover, edges are added to the graph to represent trains waiting in a station after their arrival and potential empty rides [10].

Compliance with maintenance requirements is crucial to making routing solutions feasible: while ignoring certain real-world costs may lead to suboptimal solutions, solutions which ignore maintenance are invalid altogether. The empty rides between schedules will be used for maintenance purpose, this way the timetable will not be distorted.

Gantt chart is used to illustrate the starting and finishing time of each train units and also the **summary** element of the scheduling, this also shows the dependency (i.e. precedence network) relationships between activities in all routes and at the same time gives a clear picture of the scheduling process.

The cost was calculated using the following mathematical formula: -

$$5(X) = C \quad (1)$$

where X is the actual distance (Km) and
C is the approximated Cost per distance
5 is a Constant

In mathematical form, the **transportation algorithm** is expressed as

$$\sum_{i-1}^{m} Si = \sum_{j-1}^{n} dj \quad (2)$$

This is referred as a balanced transportation problem.

where *i* is Source to
j is Destination
s*i* is Supply from source i;
d*j* is Demand at destination j;
c*ij* is Cost per unit distributed from source *i* to destination *j*.

3. RESULTS AND ANALYSIS

3.1 Network Design

There is no map indicating the settlements in the state, designs were done considering only the road network, the topography of the state and the population movement. Three designs were done before selecting the one that is; more efficient, more stimulated and optimized, less complicated in terms of scheduling, and cost effective.

The first, Design 1 covers the entire local government area of the state with at least 2 terminals at each local government (40 terminals) and 4 service stations one each at the four geographical zones, making the design complicated and scheduling difficult. This leads to Design 2 which was developed with 12 terminals and 3 service stations, but these terminals did not conform to the rules in site and station selection and makes scheduling difficult. The subsequent design, been design 3 corrects the errors noticed and scheduling problems encountered in the preceding designs, giving room for modification and has 10 terminals with 3 service stations. In design 3 (Fig. 1), if considerations are made on the routes, the total distance covered by the route is 474km taking 6.77 hrs. at the cost of ₦2, 370. Fig. 2 is the skeletal view of the design indicating the longest route and the shortest route. Table 1 is a comparison table of the three design processes, considering time, distance covered by the tracks and the cost of transportation throughout the tracks.

Table 1. Comparison of design process

Design	Distance (km)	Time (hrs.)	Cost(₦)
Design 1	552.8	7.9	2764
Design 2	703.6	10.1	3518
Design 3	525.8	7.5	2630

From the skeletal view of the design, the longest route is the Onitsha-Igbakwu route having 53 km a kilometer higher than Onitsha-Umunze route with 52 km while the shortest route is the Onitsha-Nnewi route 21 km. The total distance covered by the track is 525.8 km and will take 7.5 hrs to travel round the entire track at the cost of ₦2630. The distance and cost calculation include the entire track but in reality some of the tracks will be used only on emergency purpose.

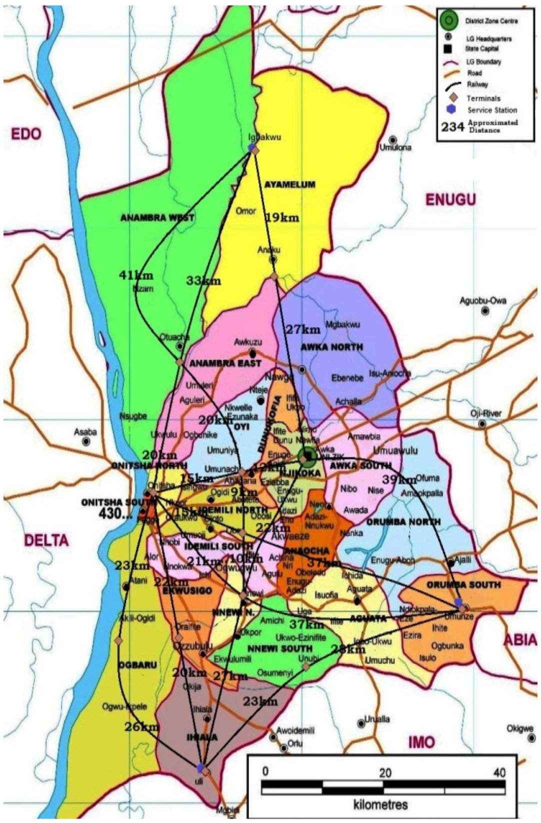

Fig. 1. Design 3 (Third design analysis)

3.2 Transportation Algorithm

It is important to introduce the notation used to describe the transportation algorithm and show that it can be formulated as a linear programming problem.

We use following notation;

X*ij* = the number of units to be distributed from source *i* to destination *j*.

A basic assumption is that the distribution costs of units from source *i* to destination *j* is directly proportional to the number of units distributed. Thus, Total supply = total demand

If $S_i > 0$ ($i = 1; 2; : : : ; m$) and
$d_j > 0$ ($j = 1; 2; : : : ; n$)

then $\sum_{i-1}^{m} Si = \sum_{j-1}^{n} dj$

s.t. $\sum_{i-1}^{n} xi,j = Si$ for i = 1, . . . , m
$\sum_{i-1}^{m} xi,j = di$ for j = 1, . . . , n
$xi,j \geq 0$ for i = 1, . . . ,m, j = 1, . . . , n.

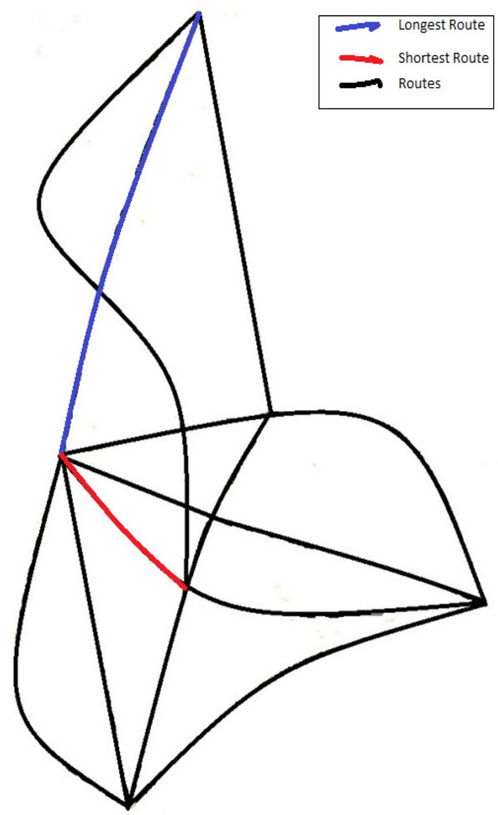

Fig. 2. Skeletal view of design

Table 2 shows the calculated distance from one source (*n*) to a destination (*m*), this distance is calculated from network design in Fig. 1.

Table 2. Distance table

Source (m)	Destination (n) (km)		
	Onitsha	**Awka**	**Nnewi**
Onitsha		27	21
Igbakwu	53	46	81
Uli	42	49	27
Umunze	52	39	37

Fig. 3 shows a simple network representation indicating the actual distance from one source to another destination. Since transportation analysis is all about meeting the demands by supplying the adequate number of train unit.

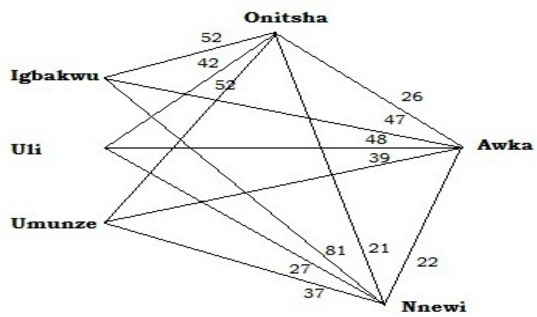

Fig. 3. Simple route network representation with respect to distance

3.3 Cost Analysis

Let ***Z***[2] be total costs from all the *m* sources to the *n* destinations.

In Table 3, each term in the objective function ***z***[3] represents the total cost (***Z***) of transportation on one route.

Minimal $\sum_{i-1}^{m} Si = \sum_{j-1}^{n} dj$ ***Z*** i,j xi,j

Table 3. Cost and requirement table

Source (m)	Destination (n) (₦)			Supply
	Onitsha	Awka	Nnewi	
Onitsha	_	150	100	3
Igbakwu	300	250	400	4
Uli	200	250	150	7
Umunze	300	200	200	8
Demand	10	7	5	

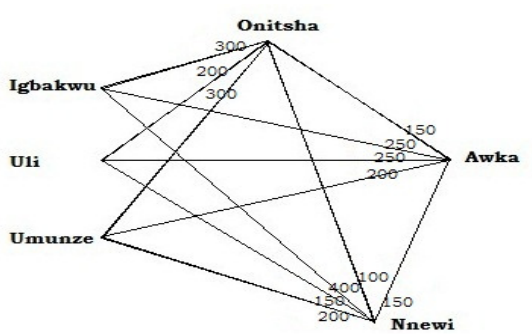

Fig. 4. Cost requirement diagram with the cost of transporting from one destination to another

[2]*Denotes Total Cost of Transportation.*
[3]*Estimated cost of transportation from each source (m) to destination (n).*

The requirement is that the destination needs to met within constrain of source and the suppy must be equal to the demand.

From Table 3, a transportation table is constructed and its various components labeled. The North West Corner rule is used in finding the initial feasible solution with respect to cost. This gives a rough picture of an attempt on how to utilize available resources to achieve a goal. The optimized solution of Stepping-Stone method is presented in Table 4.

Table 4. Representing the initial feasible solution with costs

To (*n*) **From (*m*)**	**Onitsha**	**Awka**	**Nnewi**	**Supply capacity**
Onitsha		150 2	100 1	3
Igbakwu	300 2	250 1	400 1	4
Uli	200 4	250 2	150 1	7
Umunze	300 4	200 2	200 2	8
Demand requirements	10	7	5	22

The total cost of transportation Z obtained is ₦5100

4. IMPLEMENTATION

4.1 Service Stations and Terminals

There are three (3) service stations in accordance with the final route design. The service stations are in charge of the general maintenance of both the rail track and the shuttle train buses. The service stations and terminals are clearly indicated in Fig. 3, and are;

- Igbakwu Service Station- located at Ayamelum L.G.A, North of the State;
- Uli Service Station- located at Ihiala L.G.A, South-West of the State;
- Umunze Service Station- located at Orumba South L.G.A, South-East of the State.

The terminals are distributed strategically, the three service stations which also serve as terminals is not included in the listing of the terminals. Starting in alphabetical order, the terminals are shown in Table 5.

Table 5. Terminals and its location

Terminals	Location
Abagana-Umunachi terminal	Dunukofia L.G.A
Akili-Ogidi terminal	Ogbaru L.G.A
Anaku terminal	Ayamelum L.G.A
Awka terminal	Awka South L.G.A within the state capital
Nnewi terminal	Nnewi North L.G.A
Oba terminal	Idemili South L.G.A
Onitsha terminal	Onitsha South L.G.A
Otuocha terminal	Anambra East L.G.A
Ozoubulu terminal	Ekwusigo L.G.A
Unubi terminal	Nnewi South L.G.A

Table 6. Representation of routes

Main Routes			
Onitsha	→		Awka
Onitsha	→		Igbakwu
Onitsha	→		Uli
Onitsha	→		Umunze
Onitsha	→	Nnewi	Umunze
Awka	→	Nnewi	Uli
Awka	→		Umunze
Awka	→		Igbakwu
Alternative Routes			
Onitsha	→	Nnewi	Uli
Onitsha	→	Otuocha, Nzam	Igbakwu
Otuocha	Umunachi	Oba, Nnewi	Uli
Uli	→	Umunze	Umunze

4.2 Routes

The major movement within the State is between the commercial city of Onitsha and the State district capital Awka; the routing is done in accordance to the algorithm. The routes are represented in Table 6.

4.3 Scheduling (Rostering)

The scheduling method adopted is the one highlighted on the flow model, the departure and estimated arrival time of the shuttle trains from one terminal to another is shown in Fig. 3 and was calculated using the approximate distance stated in Fig. 2 and a speed of 70 km/h of the shuttle train.

Using the displacement, time and rate formula,

$$d = tr \qquad (3)$$

Making time (*t*) the subject of the formula in the above equation,

$$t = \frac{d}{r} \qquad (4)$$

where *d* is distance (km)
r is speed (km/h) and
t is time (hr.) will be converted to minutes.

Table 7. Actual time to and fro the routes

Routes	Time (munities)	Allocations	Track description
Onitsha-Awka	30	4	Double track
Onitsha-Igbakwu	50	2	Single track
Onitsha-Uli	45 50	4	Ring route
Onitsha-Umunze	55	2	Single track
Onitsha-Nnewi-Umunze	53	2	Single track
Awka-Nnewi-Uli	53	2	Single track
Awka-Umunze	44	2	Single track
Awka-Igbakwu	49	2	Single track

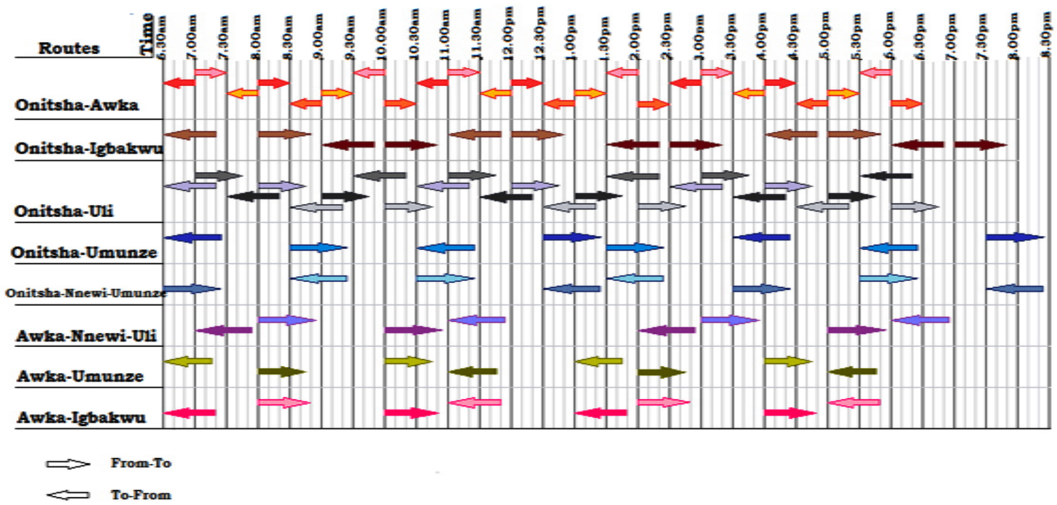

Fig. 5. Graphical representation of the scheduling

Considering the time for the passengers to board and discharge the shuttle train, which will affect the total time the shuttle train will take to reach its final destination before making a return trip which is five to ten minutes (5-10mins) will be added to the actual time it will take the shuttle train to move from one terminal to the next which forms the time (T).

Table 7 above contains the time (T) it will take a shuttle train while Fig. 5 contains the actual graphical scheduling.

The direction of the arrow in Fig. 5 shows where the shuttle movement initiated from. When the arrow faces left, it shows that the shuttle is moving from destination to source while if the arrow is facing right it means that the shuttle is moving from source to destination.

5. CONCLUSION

The framework being to introduce rail track in the transportation sector of the state will be achieved, if positive response is made, and the routing and scheduling being effective and efficient; there is always room for expansion by adding more tracks, shuttles and routes. The scheduling done in Fig. 5 is well explanatory and gives a clear picture on how the movement of shuttles will be, at the same time provides estimated arrival time. Graphically presented schedule (timetable) helps to prevent collision of shuttles if the time tables are followed strictly since provisions are made on delay in the **rostering**. Not forgetting safety during implementation, thus safety signs are to be put in place where necessary like where the track meets with the roads, bridge etc. to guide the road users, also an awareness campaign should be carried out to educate people on what to do and not to go around the rail track for the safety of all. The implementation on the work shows a clear picture of the practical application of the flow model.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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