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A Linear Programming Approach to Carpooling: Enhancing Commute Efficiency at Federal University of Technology Minna

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***Abstract*—This study explores the development of a carpooling system specifically designed for the Federal University of Technology Minna staff, utilizing the Civil Engineering Department as a case study. Amidst the escalating concerns of environmental sustainability, traffic congestion, and the economic burdens of individual commuting, carpooling presents itself as a sustainable alternative. Employing a mixed-methods approach, this research integrates a comprehensive survey to assess staff attitudes towards carpooling with the development of a linear programming model aimed at optimizing vehicle routes and allocations. The findings from the survey indicate a significant willingness among the staff to engage in carpooling, motivated by the anticipated benefits such as cost savings and reduced commuting times. The linear programming model further validates the practicality of substantially lowering total travel distances and emissions when compared to solo commuting practices. This targeted investigation showcases the carpooling system's capability not only to enhance commute efficiency among university staff but also positions it as a replicable and sustainable model for other academic institutions. The study contributes valuable insights into the design and operationalization of effective carpooling strategies within the university landscape, proposing a scalable framework applicable to similar urban contexts.**

Keywords—carpooling, linear programming, route optimization, sustainable transportation, commute optimization

I. INTRODUCTION

In an era characterized by heightened socio-economic pressures and environmental concerns, sustainable and cost-effective solutions to urban mobility are increasingly crucial. As an indispensable aspect of human life, mobility has been affected considerably by the rising cost of living and energy sources, creating substantial challenges for individuals and communities worldwide. The situation in Nigeria is no different and has recently been exacerbated due to the government's removal of fuel subsidies.

Nigeria is Africa's most populous country. It has subsidized petrol for decades to support living standards and minimize potential civil unrest. This policy, however, has weighed heavily on the nation's finances. In response to these economic pressures, the Nigerian government decided in 2023 to cease the subsidy, causing an immediate surge in fuel prices. Almost two months after the Nigerian President scrapped a popular but costly fuel subsidy, petrol prices have risen to 617 naira ($0.78) per litre, the highest in the history of Africa's largest oil producer [1]. This move has had significant consequences, chief among them being a steep increase in transportation costs, which has, in turn, heightened the cost of living for ordinary Nigerians.

In such a context, the quest for efficient, economical, and environmentally friendly means of transportation has never been more pressing. Carpooling has emerged as one of the potential solutions to these challenges. As an approach to shared mobility, carpooling involves several people using one vehicle for a trip instead of everyone using their own separate vehicles [2]. This shared mobility practice has been recognized globally for its potential to reduce fuel consumption, ease traffic congestion, lower transportation costs, and curtail greenhouse gas emissions [3]. The concept of carpooling is not entirely new; it dates back to the mid-20th century during World War II, when the United States introduced car sharing to save fuel for the war effort [4]. The concept has evolved over time, gaining momentum with advancements in technology and increasing awareness of environmental sustainability. Today, aided by digital platforms and mobile applications, carpooling services are provided on a large scale by companies like UberPool, BlaBlaCar, and Waze Carpool, transforming the way people commute [5].

Despite its global growth, carpooling is still a relatively novel concept in Nigeria. According to a report by Statista [6], only about 2% of Nigerians used carpooling services in 2017. This Fig. reflects both cultural and structural challenges in adopting shared mobility practices in Nigeria. However, the potential benefits of carpooling, especially in light of the recent fuel subsidy removal and consequent surge in transportation costs, warrant further exploration.

In this regard, the Federal University of Technology, Minna, provides an interesting case study. As a microcosm of Nigerian society, the university community comprises staff

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members who commute daily to the university. The recent economic changes may have significantly impacted their commuting behaviors and attitudes toward carpooling. Additionally, universities typically represent progressive environments open to innovation and change, making them suitable for exploring and potentially adopting new practices like carpooling.

Given the limited studies on carpooling in Nigeria, particularly within university contexts, this research seeks to fill this gap by developing a linear programming model for carpooling services that addresses the specific needs and context of the Federal University of Technology, Minna staff. Leveraging tools such as linear programming, the study will incorporate cost optimization as an objective function in response to the rising transportation costs induced by the removal of fuel subsidies.

Ultimately, the study's findings could provide insights not only into the viability of carpooling as a cost-effective solution to the transportation challenges faced by the university staff, but also into broader transportation and economic issues in Nigeria post fuel subsidy removal. Such insights could be valuable to policymakers, urban planners, transportation service providers, and researchers interested in sustainable urban mobility in developing countries.

II. Literature Review

Carpooling, commonly referred to as ridesharing, is a transportation arrangement where individuals with a common destination or route share a vehicle to reduce costs and environmental impacts [7]. Typically involving more than two people, carpooling aims to decrease fuel consumption, traffic congestion, and carbon footprint [8]. Carpooling has a long history, becoming particularly organized in the United States during World War II due to fuel rationing [4]. It gained prominence again during the 1970s oil crisis, continuing as a popular commuting strategy in many developed nations into the 1980s and 1990s [9]. Over time, technological advancements have significantly shaped the evolution of carpooling. The rise of the internet and smartphones in the late 20th and early 21st centuries introduced new forms of carpooling, offering greater flexibility and convenience through platforms like UberPool and BlaBlaCar [7, 10]. Despite these advancements, carpooling's adoption varies by region and is influenced by cultural, socioeconomic, and policy factors. For instance, carpooling is more prevalent in North America and Western Europe than in other parts of the world [11]. A survey by Henderson et al. [12] indicates that carpooling accounts for about 10% of commute trips in the United States, 16% in Canada, and only about 2% in the United Kingdom. These disparities suggest that the success of carpooling programs is highly context-dependent.

Globally, carpooling has become a widespread practice driven by urbanization, environmental concerns, and digital technology advancements. In 2020, the global carpooling market was valued at USD 5.3 billion and is projected to reach USD 11.94 billion by 2027 [13]. In North America, carpooling has its roots in wartime conservation efforts, while in Europe, it is widely adopted, with platforms like BlaBlaCar leading the way [7, 14]. Asia has also seen rapid growth in carpooling, particularly in countries like China and India, driven by companies such as Didi Chuxing and Ola [15]. The global impact of carpooling is significant, with studies showing that it can reduce traffic congestion, fuel consumption, and greenhouse gas emissions. For instance, a UC Berkeley Transportation Sustainability Research Center study found that a single carpool trip could eliminate between 10 to 30 single-occupancy vehicle trips [16].

Carpooling offers numerous benefits at both individual and societal levels. It can reduce travel costs, decrease commuting stress, and provide opportunities for social interaction [17]. Societal benefits include reduced road congestion, lower fuel consumption, and decreased greenhouse gas emissions [18]. However, carpooling faces challenges, including coordination, privacy, and safety issues [7]. Achieving critical mass for efficient ride-matching can be challenging, and cultural attitudes toward sharing rides with strangers can also limit adoption [18]. Nevertheless, the growing sharing economy and technological advancements suggest that carpooling is becoming an increasingly viable transportation option.

Today, carpooling is gaining global attention due to a growing interest in sustainable transport and the rise of digital platforms that simplify ridesharing [10]. In Europe and North America, carpooling is becoming integral to urban mobility strategies to reduce private car use and its environmental impacts [19]. In Asia, ride-sharing companies like Grab and Gojek are transforming the carpooling landscape by offering affordable and reliable transportation options [20]. The sharing economy has also boosted carpooling, with services like Uber and Lyft expanding rapidly and creating new mobility options for urban residents. The rise of intercity carpooling services like BlaBlaCar, particularly in Europe, offers a cost-effective and environmentally friendly alternative to traditional transportation modes (Chan & Shaheen, 2012) [7]. Technology has played a crucial role in this transformation, enabling real-time ride-matching, dynamic pricing, and seamless integration with other digital services, thereby enhancing the user experience [10, 21].

Carpooling's economic impact is substantial, with the potential to reduce transportation costs significantly for individuals and society. For example, the American Automobile Association [22] reports that the average annual cost of owning and operating a vehicle in the United States can exceed $9,000, which can be significantly reduced through carpooling. At the societal level, carpooling could result in considerable cost savings. A simulation study by Furuhata et al. [18] found that if half of the commuters in Los Angeles participated in a two-passenger carpool, the total cost savings in time and fuel could exceed $1.1 billion annually. Carpooling services also stimulate local economies by creating job opportunities, with ride-sharing platforms providing employment for millions of drivers worldwide (Berger et al., 2018) [23]. Socially, carpooling can foster community, enhance social interactions, and improve access to transportation for low-income individuals, the elderly, and those with disabilities [24]. Environmentally, carpooling can significantly reduce greenhouse gas emissions and air pollutants, contributing to global efforts to combat climate change [25].

In Nigeria, carpooling exists primarily in the informal transport sector, particularly in metropolitan areas like Lagos, where private car owners often pick up passengers along their commute for a fee [26]. While platforms like GoMyWay and Jekalo have introduced more structured carpooling services, their impact remains limited [27]. The prevalence of carpooling in Nigeria is low, with a 2002 study by Oyesiku

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and Odufuwa [28] finding that only about 8% of commuters in Lagos engaged in formal carpooling. Attitudes towards carpooling in Nigeria are mixed, with safety concerns, particularly for female passengers, limiting its adoption [28]. Cultural and socio-economic factors also play a significant role, with high-status individuals often resistant to sharing rides due to societal norms [29]. Challenges to widespread carpooling adoption in Nigeria include security concerns, poor infrastructure, and regulatory barriers [27, 28]. Theoretical models for carpooling often aim to optimize efficiency while minimizing costs. Game theory has been employed to understand the interplay between participants and optimize carpooling strategies [30, 31]. The shareability network model is another common approach, aiming to maximize shareable rides within a system by considering factors such as delay tolerance and maximum ride time [32, 33]. Linear programming has also been used extensively to solve optimization problems in carpooling, such as the optimal allocation of passengers to drivers [34]. However, there are gaps in existing theoretical models, particularly in their application to contexts like Nigeria, where infrastructure and socio-economic realities differ significantly from more studied regions [35]. Additionally, many models do not fully account for the complexities of real-life carpooling, such as dynamic departure times and varying passenger preferences [15].

In Nigerian universities, transportation challenges, including congestion, inadequate infrastructure, and high costs, significantly impact students and staff. A study by Oni [36] highlights these challenges, noting that they lead to missed classes, heightened stress, and reduced productivity. The perception and attitude towards carpooling in Nigerian universities have not been thoroughly researched, though anecdotal evidence suggests a positive attitude given the transportation challenges. A study by Ajayi et al. [37] found a positive correlation between awareness of carpooling benefits and willingness to participate in carpooling programs in a Nigerian context. The feasibility of carpooling in Nigerian universities, including the Federal University of Technology, Minna, appears promising, given the geographically concentrated nature of universities and the existing transportation challenges. However, a comprehensive feasibility study is needed to assess infrastructure, user acceptance, and local socio-economic conditions [38].

III. Research Methodology

A. Materials and Methods:

This research employed a quantitative research design, utilizing a questionnaire-based survey to gather data from staff members at the Federal University of Technology (FUT), Minna. The participants in this study were staff members from Civil engineering department of the university who voluntarily responded to the questionnaire.

B. Data Collection

A structured questionnaire was developed to collect quantitative data on staff perceptions and attitudes toward carpooling. The questionnaire focused on variables such as commuting distances, preferences, and potential challenges. The survey was distributed electronically to staff members, ensuring widespread coverage and voluntary participation. Participants were informed about the purpose of the study and provided consent before completing the questionnaire. The collected data from the questionnaires were subjected to statistical analysis. Descriptive statistics, such as percentages and averages, were used to summarize key findings.

C. Development of Linear Programming Model

Based on the quantitative survey data, variables relevant to carpooling, such as commuting patterns, vehicle capacity, and potential constraints, were identified. A linear programming model was developed based on the identified variables. Mathematical formulations were established to optimize carpooling schedules and routes.

Assumptions

The model assumes that all staff have fixed commuting patterns and that vehicle capacities and routes remain constant. However, in real-world scenarios, commuting patterns are often dynamic. Factors such as:

Varying departure times: The model assumes that all staff members leave for work and return home at the same time, which may not be realistic. In practice, different work schedules and personal commitments could affect participation in carpooling.

Passenger preferences: The model assumes that all staff members are equally willing to share a ride. However, personal preferences, such as privacy concerns, safety, and compatibility with other passengers, could influence their willingness to participate in carpooling.

Traffic conditions: The model does not account for variable traffic conditions that could affect travel time and route efficiency. For example, congestion during peak hours might make some routes less optimal than others.

Constraints

The model effectively uses constraints such as vehicle capacity and the need for staff to be assigned to only one vehicle. However, additional real-world constraints could be considered, such as:

Flexible scheduling: Staff might have different arrival and departure times, which could make it challenging to assign everyone to a carpooling group without sacrificing convenience.

Geographical constraints: The model assumes that staff living in proximity are always the best candidates for carpooling together, but it doesn't consider alternative arrangements like shared pick-up points.

Limitations and Real-World Applicability

While the model is theoretically sound, potential limitations arise when applying it in real-world scenarios:

Data accuracy: The model relies heavily on accurate data for distances, fuel costs, and vehicle capacities. Any discrepancies in this data could lead to suboptimal results.

Behavioral factors: Human behavior plays a significant role in the success of carpooling. Preferences for flexibility, privacy, and comfort may not be fully addressed by the model, limiting its practical application.

Technological integration: The model assumes that coordination between passengers and vehicles happens seamlessly, but this may require the implementation of a digital platform for real-time ride matching and scheduling.

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Objective Function

Minimize the total distance traveled by all vehicles, adjusting for vehicle utilization:

$$Min\ Z = \Sigma_{i\in I, j\in J} d_j \cdot x_{ij} + P \cdot \left(\Sigma_i \left(1 - \Sigma_j x_{ij}\right)\right) \quad (1)$$

where:

d_j is the distance for route j,

x_{ij} is a binary decision variable indicating whether the vehicle i is assigned to route j,

P is the penalty for unused vehicles: this encourages the use of all vehicles by penalizing unused ones thereby optimizing fleet utilization

I is the set of vehicles,

J is the set of routes.

Constraints:

- Staff Assignment Constraint Each staff member is assigned to exactly one vehicle. This ensures each passenger has exactly one route

$$\sum_{i\in I} y_{ik} = 1, \ \forall K \in K \quad (2)$$

- Vehicle Capacity Constraint: The number of staff assigned to a vehicle does not exceed. This ensures that the number passengers assigned to a route does not exceed vehicle capacity.

$$\sum_{k\in K} y_{ik} \leq C_i, \forall i \in I \quad (3)$$

- Route Assignment Constraint: Staff can only be assigned to vehicles that are allocated to a route covering the staff's location.

$$y_{ik} \leq \sum_{j\in J} x_{ij,} \forall_i \in I, \forall k \in \quad (4)$$

K where staff $k's$ location is included in a route j

Where:

- y_{ik} is a binary variable indicating if a staff member k is assigned to the vehicle i,
- C_i is the capacity of the vehicle i,
- K is the set of staff.

By ensuring these constraints are obeyed, the model aims to streamline passenger routing while minimizing operational distances and optimizing vehicle usage. This will allow for planning amongst staff with the same destination.

Model Parameters and Variables:

- Binary variables x_{ij} and y_{ik} ensure that vehicles are only assigned to feasible routes and staff members are allocated to vehicles accordingly.
- The model's parameters including distances (d_j). Vehicle capacities (C_i) and the penalty for unused vehicles (P), are based on the operational data and strategic goals of the carpooling system.

Assumptions:

- For fare calculation, we assume a fare per kilometer per person (f_{km}) of 25.0, with a 10% deduction rate (r_d) applied to incentives to incentivize carpooling. These assumptions are critical for understanding the cost implications of different carpooling strategies.

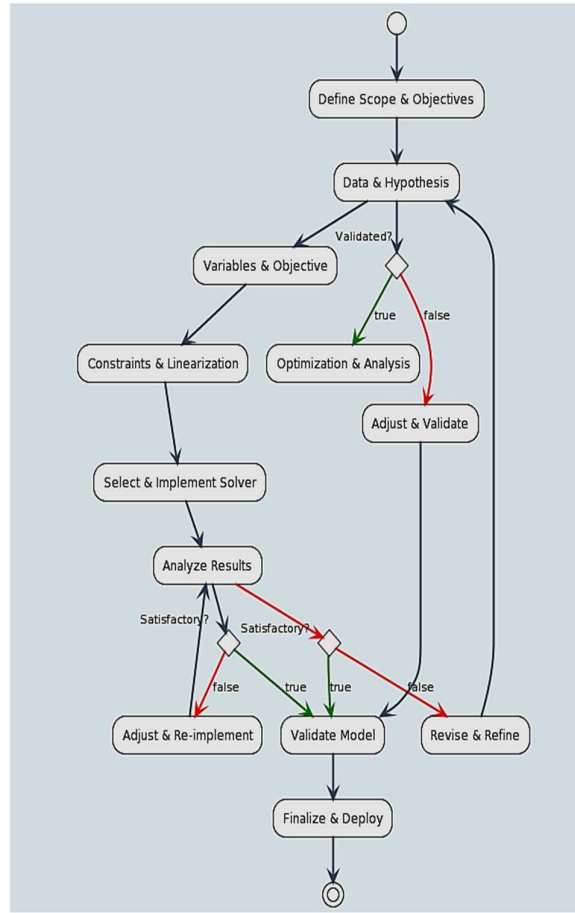

Fig. 1. Compact Iterative Development for Carpooling Service Model.

D. Process Flow for Carpool Optimization Model

The process depicted in Fig. 1 begins with defining the scope and objectives, which lay the foundation for the subsequent stages. Data collection and hypothesis formulation are critical early steps that guide the construction of variables and the objective function (step 2 in Fig. 1). The iterative nature of the model is captured by the validation loop, where the model's assumptions and results are continually refined based on feedback (steps 3 to 5 in Fig. 1).

The optimization and analysis phase (step 4 in Fig. 1) is pivotal, as it employs mathematical techniques to determine the most efficient allocation of resources within the carpooling service. Solver selection and implementation (step 6 in Fig. 1) involve computational considerations to ensure that the optimization is executed effectively.

Result analysis (step 7 in Fig. 1) assesses the outcomes against the objectives to determine the model's effectiveness. Adjustments and re-implementation (step 8 in Fig. 1) are made as necessary, and the model is rigorously validated (step 9 in

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Fig. 1) before being finalized and deployed (step 10 in Fig. 1) for practical use.

E. Derivations of Equations

1) Derivation of the Fare Calculation Equation: A fare calculation model was devised to accurately determine the cost implications of the carpooling system. This model considers the distance traveled and the number of passengers and incorporates a discount mechanism to encourage carpooling. The following equation formalizes the computation of the fare:

$$F_{initial} = d \times f_{km} \quad (5)$$

Where d = distance traveled

n = number of passengers (staff count)

f_{km} = fare per kilometre per person

r_d = deduction rate (10% or o.1%)

F_{inital} = initial fare before deduction

F_{final} = final fare after deduction

The $F_{initial}$ calculation is straightforward.

The deduction is a percentage of the initial fare:

$$Deduction = F_{initial} \times f_{km} \times r_d \quad (6)$$

The F_{final}, accounting for the deduction and multiplied by the number of passengers is:

$$F_{final} = (F_{final} - deduction) \times n \quad (7)$$

Substituting the values of $F_{initial}$ and $Deduction$ into the final fare equation gives:

$$F_{final} = (d \times f_{km} - (d \times f_{km} \times r_d))n \quad (8)$$

2) Mathematical Formulation of Emission and Fuel Consumption:

Fuel Usage Equation:

Given:

D = total distance traveled
R_f = fuel consumption rate
C_f = cost of fuel per liter
Fuel used F_u and total fuel cost F_c can be expressed as:

$$F_u = \frac{D}{R_f} \quad (9)$$

$$F_c = F_u \times C_f \quad (10)$$

CO_2 Emissions Equation:

Given:

E_f = emissions factor (2.31 kg CO_2/liter)
Total CO_2 emissions (E_t) can be expressed as:

$$E_t = F_u \times E_f \quad (11)$$

Assumptions:

The fuel consumption rate of 8 km/liter and CO_2 emissions factor of 2.31 kg CO_2 per liter are used based on industry standards for mid-sized gasoline vehicles, reflecting a balance between urban and highway driving conditions.

F. Test on a Case Study

Step 1: Initially begin by extracting the origins and destinations relevant to the study area.

Step 2: A network graph was constructed to illustrate the connections among various locations within the region.

Step 3: Distances were assigned between network nodes (as weights on graph edges) based on calculated kilometers.

Sstep4: Dijkstra's algorithm was used to determine the most efficient routes between points within the network.

Step 5: Python script was developed capable of computing ride fares for passenger requests, factoring in distance-based fare reductions.

Step 6: A matching procedure was implemented to enable drivers to accommodate additional passengers, thereby increasing their earnings.

Step 7: Gather and analyze data pertaining to trips, including completed and canceled journeys, as well as user feedback, to assess the service quality for both drivers and passengers.

G. Illustrative Example

A schematic of the example shown in Fig. 2 shows the connectivity of the nodes and distances between the nodes.

A connectivity and cost matrix were created and used in Dijkstra's algorithm, as clarified in Table 1 and Table 2. These tables detail the parameters and results contributing to the trip cost calculations across different scenarios. The nodes B, C, D, E, F, G, H, I, J, K, L, M, and N represent different areas where the origins of the respondents, while U represents the university and destination. The links between the nodes represent the distances between them.

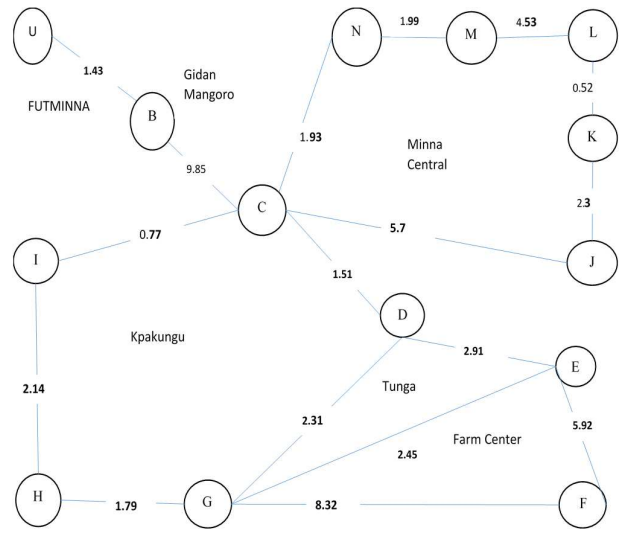

Fig. 2. Schematic showing distances between nodes.

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TABLE I. CONNECTIVITY MATRIX

	B	C	D	E	F	G	H	I	J	K	L	M	N	University
B	0	1	0	0	0	0	0	0	0	0	0	0	0	1
C	1	0	1	0	0	0	0	1	0	0	0	0	1	0
D	0	0	0	1	0	1	0	0	0	0	0	0	0	0
E	0	0	1	0	1	1	0	0	0	0	0	0	0	0
F	0	0	0	1	0	1	0	0	0	0	0	0	0	0
G	0	0	1	0	1	0	1	0	0	0	0	0	0	0
H	0	0	0	0	0	1	0	1	0	0	0	0	0	0
I	0	1	0	0	0	0	0	1	0	0	0	0	0	0
J	0	1	0	0	0	0	0	0	0	1	0	0	0	0
K	0	0	0	0	0	0	0	0	1	0	1	0	0	0
L	0	0	0	0	0	0	0	0	0	1	0	1	0	0
M	0	0	0	0	0	0	0	0	0	0	1	0	1	0
N	0	1	0	0	0	0	0	0	0	0	0	1	0	0
University	1	0	0	0	0	0	0	0	0	0	0	0	0	0

IV. RESULTS AND DISCUSSION

A. Survey Results

1) The main results of the survey, which are according to the structure of the questionnaire. The survey population comprised 75% men and 25% women. Moreover, 100% of the respondents belong to the School of Infrastructure and Processing Technology, Civil Engineering department,Federal University of Technology Minna. The dpartment ghas a Total of 35 staff but only 20 ofthem responded to the questionaire represent about 57.1%. Additionally, just over 20% of the respondents came from areas outside of Farm Center Minna, 20% from Gidan Magoro, 20% from Kpakungu areas, 20% from Minna Central, whereas just under 20% are living in Tunga.

2) Trip characteristics: According to the means of transport they use, the the sample's respondents stated that they use public transportation for their trips (50%). Approximately 63% of the respondents stated that their average weekly commute distance to the university is more than 20 km, while about 20% of the respondents commute an average weekly distance of 10-20 km, and 30% of the respondents commute less than 5km. Regarding average time spent on the daily commute to the university, over 37.5% of the respondents spend less than 30 minutes on the daily commute to the university(one-way), while 62.5% stated that they spend about 30 minutes hours on the daily commute to the university (One-way). Additionally, just over 90% of the respondents usually go to work at 8:00 am, whereas just under 10% go to work at 8:30 am. These statistics depicts a regular daily commut to work with most repondents using public transportaion. This also implies that the respondents using shared vehicles will be perceived to be a better option than the public transportation.

3) Perceptions and Awareness: The overwhelming majority of the participants (81.8%), as shown in Fig. 3, are aware of the carpooling concept, 9.1% are somewhat familiar, and 9.1% are not familiar, which shows that the carpooling concept is not anonymous to the staff. This has always been practiced informaly even before this study. Colleagues will normally solicit to share a ride since the campus is not so close to major settlements.

TABLE II. DISTANCE MATRIX

	B	C	D	E	F	G	H	I	J	K	L	M	N	U
B	0	9.8	0	0	0		0	0	0	0	0	0	0	1.4
C	9.8	0	1.5	0	0	0	0	0.7	0	0	0	0	1.9	0
D	0	1.5	0	2.9	0	2.3	0	0	0	0	0	0	0	0
E	0	0	2.9	0	5.9	2.4	0	0	0	0	0	0	0	0
F	0	0	0	5.9	0	8.3	0	0	0	0	0	0	0	0
G	0	0	2.3	2.4	8.3	0	1	0	0	0	0	0	0	0
H	0	0	0	0	0	1.7	0	2.1	0	0	0	0	0	0
I	0	0.7	0	0	0	0	1.7	1	0	0	0	0	0	0
J	0	5.7	0	0	0	0	0	0	0	2.3	0	0	0	0
K	0	0	0	0	0	0	0	0	2.3	0	0.5	0	0	0
L	0	0	0	0	0	0	0	0	0	0.5	0	4.5	0	0
M	0	0	0	0	0	0	0	0	0	0	4.5	0	1.9	0
N	0	1.9	0	0	0	0	0	0	0	0	0	1.9	0	0
U	1.43	0	0	0	0	0	0	0	0	0	0	0	0	0

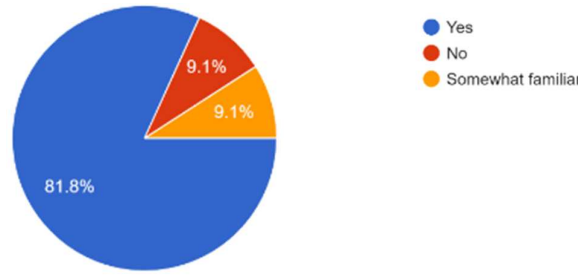

Fig. 3. Awareness of the carpooling concept.

However, despite the awareness of carpooling, the overwhelming majority (45.5%) do not travel as carpoolers (Fig. 3). These results may be connected to the fact some colleagues prefer privacy concerns, safety, different schedules, etc.

Also, Fig. 4 shows that 63.6% of the respondents believed carpooling could help reduce transportation costs for staff members, 27.3% agreed, while a meager 9.1% strongly disagreed. Additionally, 54.5% of the participants believe carpooling contributes to saving time during commutes to some extent, while 9.1% of the respondents disagree (Fig. 5).

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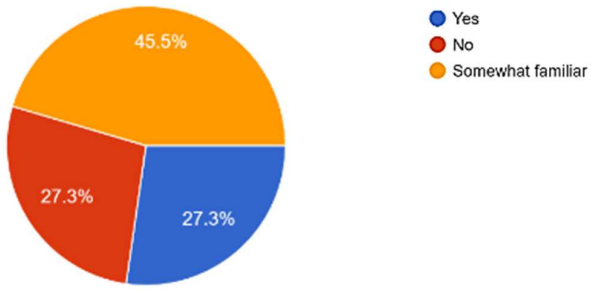

Fig. 4. Travel by carpooling.

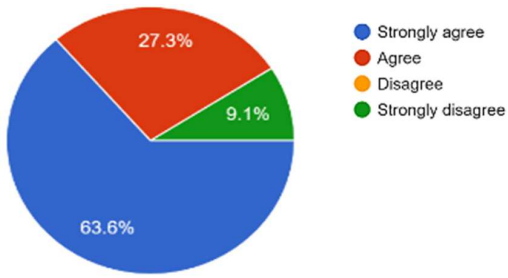

Fig. 5. Reduction in transportation cost by carpooling.

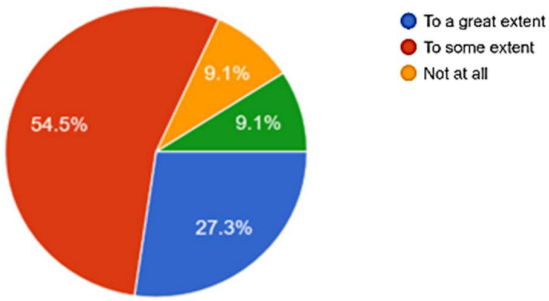

Fig. 6. Contribution to saving time by carpooling.

The survey results also showed that half (50%) of the respondents agree to a great extent that carpooling can promote social cohesion among staff members, and 50%, to some extent, think carpooling could promote social cohesion, as shown in Fig. 6.

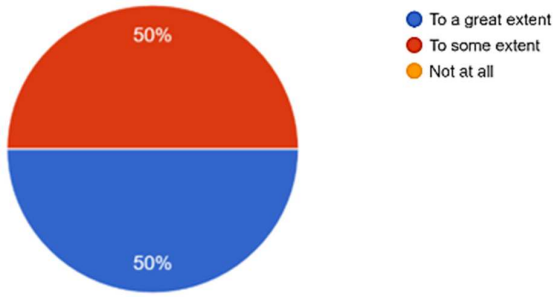

Fig. 7. Role of carpooling in social cohesion.

However, despite the awareness of carpooling, the overwhelming majority (45.5%) do not travel as carpoolers (Fig. 7).

4) General preferences for the carpooling system and indication of its specific characteristics: Regarding their willingness to use a carpooling program at the Federal University of Technology Minna, over 81.8% of the respondents can be considered potential users (Fig. 8). The Federal Government of Nigeria removed subsidies on fuel; thereby, the cost of transportation has skyrocketed. This explains why most respondents are open to carpooling.

In addition, there is an indication that the preferred (63.6%) carpooling arrangement was sharing a ride with colleagues residing in the same neighbourhood, while 36.4% of the respondents preferred carpooling arrangements with colleagues from the same department or faculty (Fig. 9). The respondents are positive about using a carpooling system organized in the university, as they believe it would save the cost of commuting daily to the university

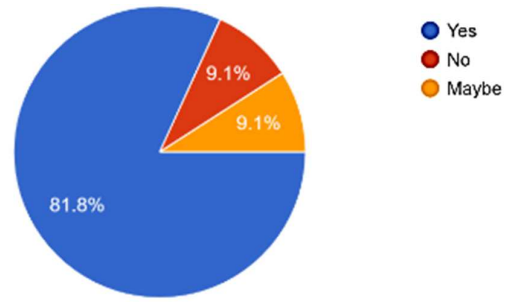

Fig. 8. Willingness to participate in a carpooling program at FUT Minna.

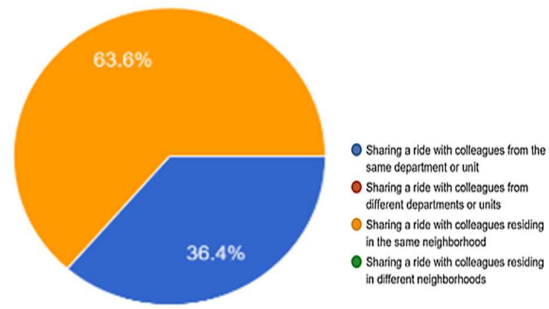

Fig. 9. Willingness to participate in a carpooling program at FUT Minna.

B. Linear Programming Model

1) Vehicle Assignment and Route Analysis: The linear programming model optimized vehicle assignments to different routes to minimize distance and maximize staff distribution. The allocation of vehicles to specific routes. Vehicle2 and Vehicle4 were assigned to Route1, Vehicle3 to Route4, Vehicle6 to Route3, and Vehicle7 to Route5 as presented in Table 3. It can be seen that no route has been assigned to Vehicle 1 and Vehicle 5. This distribution ensured

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all vehicles were utilized, adhering to the model's constraints. The model added a penalty of 2 for vehicles that are unused. This is to ensure that generated solutions encourage the assignment of vehicles, but two vehicles were still unused. Similarly, two routes were not assigned because their distances were not selected since the model minimizes distance.

TABLE III. VEHICLE/ROUTE ASSIGNMENT

Vehicle assignment/route assignment	Route 1	Route 3	Route 4	Route 5
Vehicle 1				
Vehicle 2	■			
Vehicle 3			■	
Vehicle 4	■			
Vehicle 5				
Vehicle 6		■		
Vehicle 7				■

2) Staff Distribution: The distribution of staff among the vehicles, as shown in Table 4, was evenly spread, ensuring that each vehicle was operating at optimal capacity. This uniform distribution plays a pivotal role in maximizing the efficiency of the carpooling system. Route Utilization, , showed an equitable distribution of vehicles across all routes except Route 2. This balanced utilization is crucial for a comprehensive carpooling service that caters to the varied needs of staff members across different locations.

TABLE IV. STAFF/VEHICLE ASSIGNMENT

Staff assignment/Vehicle assignment	1	2	3	4	5	6	7
Staff 1		■					
Staff 2		■					
Staff 3				■			
Staff 4		■					
Staff 5			■				
Staff 6						■	
Staff 7						■	
Staff 8							■
Staff 9			■				
Staff 10							■
Staff 11			■				
Staff 12						■	
Staff 13		■					
Staff 14			■				
Staff 15				■			
Staff 16							■
Staff 17		■					
Staff 18							■
Staff 19						■	
Staff 20							■

3) Environmental and Utilization Impact: Table 5 highlights the significant reduction in CO_2 emissions achieved through carpooling, underlining the system's environmental benefits. The total fuel cost and CO_2 emissions were estimated using equations 9 and 10. This reduction is expected since the number of vehicles has reduced and the total distance traveled by vehicles has also reduced. This approach has the potential to mitigate traffic congestion. Theoretically, this is the case; however, in the Nigerian context, where most people don't own personal vehicles, the impact of these emissions might be much less.

TABLE V. METRIC ANALYSIS

Metric	Without Carpooling	With Carpooling	Savings
Total distance (Km)	445.44	109.49	335.95
Total Fuel (l)	55.68	13.69	41.99
Total Fuel Cost (#)	36749	9035	27714
CO_2 Emissions (kg)	128.62	31.62	97
Vehicle Utilization Rate (%)	10	90	80

These savings are generalized since, in practice, some passengers normally travel less distances. Thus, this approach enhances collective benefit.

The impact of carpooling further reinforces this, showing a considerable decrease in emissions compared to non-carpooling scenarios. The implemented carpooling model successfully applies linear programming to optimize route assignments and vehicle utilization. The results underline the potential for substantial cost savings and environmental benefits through reduced emissions. Moreover, the data indicates a shift towards improved vehicle utilization rates, suggesting an increase in operational efficiency. This shift is economically beneficial and promotes environmental sustainability, as evidenced by the reduction in CO_2 emissions.

V. DISCUSSION

The findings from the carpooling linear programming model and accompanying survey data suggest that carpooling could bring economic and environmental benefits to staff at the Federal University of Technology Minna. However, to fully grasp the effectiveness of this model, it's crucial to cross-reference the results with actual data from real-world scenarios.

The model shows that carpooling could reduce total commuting distance by 75%, which leads to similar reductions in fuel consumption and CO_2 emissions. These Fig.s—fuel consumption dropping by 75% and CO_2 emissions by 80%—are impressive. However, they are based on ideal conditions where traffic flows smoothly. Traffic congestion, road maintenance, and other delays—especially in Nigeria's urban centers—often disrupt travel, making the model's results too optimistic. Evaluating how these factors impact commuting could paint a more accurate picture.

The survey data adds another layer to this analysis. Many staff already use public transport, but the model assumes all employees drive private cars. As a result, it likely needs to overestimate the potential cost and emissions savings that carpooling could offer. By contrasting the model's projections with data on those using public transport, researchers could estimate more realistic additional savings from carpooling.

Human behavior also affects the outcome. The model assumes all staff members will participate, but survey responses suggest otherwise. Preferences like concerns over privacy and different work schedules limit participation. These behavioral factors are difficult to model but essential for understanding how widely carpooling might be adopted. Incorporating these elements into future models will help policymakers see more clearly what can be achieved.

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Furthermore, carpooling is not static. Schedules change, and unexpected events can alter plans, but the model does not reflect this dynamic reality. It assumes fixed schedules and routes, simplifying the complexity of coordinating a real carpool system. Introducing flexibility into the model—perhaps using mobile applications that adjust in real-time—could help improve its accuracy and usefulness.

Finally, while carpooling has clear environmental advantages, the extent of these benefits may be smaller in Nigeria, where many staff already use public transport—a relatively low-emission alternative. A deeper comparison between carpooling and public transportation's environmental impacts would clarify which option is better for reducing emissions in this context.

Moving forward, to get the most out of the carpooling model, researchers should focus on incorporating traffic variability, comparing public transportation data, considering human behavioral factors, and allowing for flexible scheduling. These improvements would give a more accurate representation of the real-world impact carpooling could have at the university.

VI. Conclusion

The study presents the adoption and implementation of carpooling services within a university setting, with a focus on understanding staff perceptions, reducing CO_2 emissions, and improving vehicle utilization. The research employed a mixed-method approach, integrating a survey to capture staff attitudes toward carpooling and a linear programming model to optimize carpooling routes and schedules.

The survey findings indicate a significant awareness of carpooling concepts among staff, with over 65% of respondents showing a willingness t metrics o participate in a carpooling program. The preferred arrangement involves sharing rides with colleagues from the same neighborhood, highlighting the importance of convenience and social cohesion. Despite this, a substantial portion (45.5%) do not currently travel as carpoolers, suggesting room for increased adoption.

The linear programming results demonstrate tangible benefits from carpooling, such as a 75% reduction in total fuel consumption and an 80% improvement in vehicle utilization rates when carpooling is adopted versus not carpooling. This translates into considerable cost savings and a reduction in CO_2 emissions, affirming the environmental and economic advantages of carpooling.

The research underscores the potential of carpooling to foster social interaction, reduce transportation costs, and contribute to environmental sustainability. The findings provide a valuable contribution to understanding carpooling's benefits and can inform the development of policies and programs to promote its wider adoption. For future research, it is recommended to explore the integration of technological solutions to address barriers to carpooling, such as scheduling flexibility and privacy concerns.

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