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(RESEARCH ARTICLE)

Towards a sustainable road transportation system in urban areas: A case study of Owerri, Nigeria

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Abstract

Urban Areas in almost all cases develop outwards from the centre. Public facilities (schools, offices, markets) are usually located at about the centre while residential abodes radiate outwards. Such development pattern necessitates road transportation movement to the centre. This paper examines strategies that can be adopted to achieve the necessary movement in a sustainable manner for these urban areas, with Owerri Nigeria as a case study. A field study was conducted to ascertain the total passenger requirement, number and mix of passenger vehicles as well as measure three main road transport-induced air pollutants. The result of the field work showed existing commuter vehicles mix of 56.2:63.7: 19.6:1.6:1 for salons, wagons, mini-buses, coaster buses and big buses respectively, of a total of 85,950 vehicles. The survey also revealed ambient air pollutants level higher than the recommended standards. A new model was developed to achieve a vehicles remix of 10:33:53: 14:1 of same vehicle types and reduction in traffic volume and target air pollutants. The analyses showed that mini-buses and coaster buses have advantage over salon cars, wagon vehicles and big buses in terms of traffic congestions and pollutants release into the environment. The two bus types have least pollutants release per passenger carried. An optimal vehicle remix, which gives higher priority to these buses has been shown to reduce congestion by 40%, Carbon monoxide by 40%, Nitrogen Dioxide by 50% and Methane by 50%. Based on the findings, it is recommended that vehicular remix of 10:33:53:14:1, for salon: wagon: mini-buses: coaster buses: big buses be adopted for Owerri commuters' transportation need. Some policy measures were put forward to help achieve this. The measures include an outright ban on use of low-passenger-carrying vehicles for commercial purposes.

Keywords: Vehicles; Mix; Sustainability; Road; Transportation

1. Introduction

Roads are specially prepared land ways for vehicular and pedestrian movements. In its simplest form the road can be the natural surface. It can also be in modified surface using local materials. As traffic increases the road can be expanded, and in surfaces stabilized with imported materials, which can further be surfaced to improve speed and comfort.

Transportation is the movement of humans, animals and goods from one location to another. Modes of transportation include air, land, water, cable, pipeline and space. Transportation field can be divided into infrastructure, vehicles and operations (Wikipedia, 2018). Its activities affect humans and the natural environment to a very great extent. Nevertheless, it is vital for both the development of society as a whole as well as for the mobility of individuals. The ability to transport oneself and one's products wherever and whenever necessary is seen today as a matter of expectation by the society. The design and development of the infrastructure for the transportation sector and methods

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of transportation are closely related to to general social developments and have a decisive influence on the location of housing and industry (Murtaza, H, & Eric M., 2000). This is why coordinated efforts are necessary from actors who are active internationally, nationally, regionally and locally to ensure maximum environmental compatibility as the transport system is being transformed.

Generally and very often, the mobile units (automobiles) of the road transport system are powered by either petrol (gasoline) or diesel internal combustion engines. Such internal combustion engines are known to be major sources of outdoor air pollution, and traffic is the most notable source of air pollution in urban areas. The relentless motorization of society has entailed an increasing growth of vehicle emissions which impact negatively on urban air quality. Critical components of an integrated transportation system includes technical measures involving vehicles and fuels, transport demand management and market incentives and infrastructure & public transport improvements. These essential components are however lacking in the transport systems of many third world countries.

Road transportation system therefore, is the aggregate of all facilities put in place, maintained and or operated for the movement of people and goods by road. These include fixed structures (roads), mobile units (motor vehicles) and the operators of these facilities.

Sustainable development is an economic development that is conducted without depletion of natural resources, OALD (2004). Generally, sustainable development implies meeting the needs of the present generation without compromising the ability of future generations to meet their own needs (Brundtland 1987). A sustainable transportation system is one in which fuel consumption, vehicle emissions, safety, congestion and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generations of people throughout the world (Richardson, 1999). This entails three dimensions namely; economic sustainability (economic efficiency); environmental sustainability (ecological stability); and social sustainability (distributional/social equity). Sustainable road transportation system is expected to meet environmental needs/standards, be economically viable and be socio-politically acceptable.

The transportation of goods and passengers is increasing world-wide. A large share of this transport can be attributed to motor vehicles which often have serious impacts on human health, environmental quality, urban development patterns, road conditions, and road safety. Increasingly, developed and developing countries are seeking strategies to guarantee individual mobility, and at the same time trying to improve ecological and social conditions. Sustainability is increasingly adopted as a framework for designing and implementing such strategies. Due to their predominant role, road transport issues are of particular concern.

The World Health Organization (WHO), while discussing Sustainability of Transport Systems, noted that clustering many passengers together in one vehicle or other public transport mode reduces total traffic emissions of climate and air pollutants. Public transport use is also associated with more physical activity and less obesity, since public transport services are often accessed by walking and cycling. The WHO further stated that investment in mass public transport can also yield equity benefits by improving the mobility of women, the elderly and the poor, who often lack access to private vehicles. This, in turn, provides employment, education, health services and recreational opportunities (WHO, 2020).

Writing on Sustainable Transportation Options for Protecting the Climate, Drum-heller *et al,* (2001), noted that the sequence of actions leading to the creation of a transport system can be as follows;

- Analysis of the existing transport system;
- Determination of requirements for the new transport system;
- Selection of transport combination

The analysis of the existing system is the starting point for actions aiming at an improvement of the current situation. The analysis must include the current flows in the transport system, future demand for carriage of passengers and goods and the consequences of the functioning of the current system such as road congestion; noise emission; toxic emissions; accident statistics. In the next step is the need to identify the objective that to be achieved e.g. by determining the level of admissible exhaust emissions at a given flow density of vehicles.

The selection of the transport combination covers the identification of admissible solutions for example such related to the modification of the traffic organization (new traffic nodes, modification of the traffic signaling, limits in vehicle flow of a given type roads) and the evaluation of the consequences of their implementation. At the final stage of the process a decision is made as to which solution is the best in terms of the decision maker expectations, i.e. maximizes the function of benefit at assumed limitations (for example financial).

Merkisz-Guranoroska *et al*, (2013), in their work on Development of a Sustainable Road Transport System added that particularly difficult is the development of transport systems where the fundamental requirements for the new systems are environment related. Taking the environmental aspects into account limits the development of road transport systems that somewhat generate negative environmental impacts. The priority of the investors and decision makers is most often the maximization of the throughput of the new system at given limitations (related to the investment expenditure) or, possibly, building infrastructure at a minimum cost for a given network efficiency. Reducing negative impact of transportation on the environment either increases the capital expenditure for the construction of the system or limits the traffic, thus the system throughput. The complexity of such a decision problem requires a development of a decision-support tool for the best decision in terms of the configuration of a transport system meeting the assumed traffic throughput requirements but taking the environmental aspects into account at an acceptable level of capital expenditure. The decision-support tool in the said area may constitute a model of development of a pro-ecological transport system.

Modeling plays an important role in the cognitive process enabling the exploration of the relations and processes in complex systems. Besides, modeling enables a simulation of the functioning of a system depending on the implemented modifications and system organization. The effect of the model implementation will be to create the possibility of determination of the influence of transport node solutions and traffic organization of the actual level of exhaust emission in road transport. The application of the model will lead to conclusions as to how the structure of the road transport flow in connection with the road transport infrastructure influence the environment pollution level.

One sure way of arriving at the best sustainable road transportation system is by the optimization of such models.

Optimization is the act of obtaining the best solution under given circumstances. This technique provides a powerful tool in improving the engineering design in a rational manner and has been proved to be much more efficient than the traditional trial-and-error design process (Aravelli, 2014). Today, the optimization tool has become a part of every engineering study for design improvement.

Urban area is a human settlement with a high population density and infrastructure of built environment, (Wikipedia, 2020). Urban Areas in almost all cases develop outwards from the centre. Public facilities (schools, offices, markets) are usually located at about the centre while residential abodes radiate outwards. Such development pattern necessitates road transportation movement to the centre

Owerri, the capital city of Imo State of Nigeria, is growing outwards from the city centre just as every other urban area. It sits at the intersection of roads from Port Harcourt, Onitsha, Aba, Umuahia, Okigwe and Orlu and at latitude 5^{o} 28' 35.6"(5.4766^{o}) North and longitudes 7^{o} 1′ 0.6″ (7.0168^{o}) East and elevation of 75m above sea level Encyclopaedia Britanica (2009).

2. Material and methods

The mobility need of commuters result in the use of vehicles and the powering of the vehicles produces air pollutants and could result in congestion on the roads, thereby hindering movement. The method of assessment therefore includes;

- Determination of the transport need and
- Measurement of pollution level (pollutants of interest)
- Determination of congestion level (Level of Service)

The assessment was carried out at five strategic representative locations in the Owerri Municipal viz; Amakohia Junction, Assumpta Junction, Emmanuel College Junction, Imo State University Junction and MCC/Wethedral Road Junction. The selected locations for the survey are points with high traffic and business activities. The result of the assessment was imputed into a model in terms of vehicle types and exhaust emissions, and optimized for vehicle and emission reductions.

2.1. Determination of Transport Need/Load

The vehicles, (in their various classes), traversing the five locations in the project area were counted over a 12-hour period – 7am to 6p.m. Based on an observed percentage occupancy of the passenger vehicles, the total passenger transportation needs at the five locations was determined. These locations record high traffic volumes within the hours of 7.30 – 9.30am (when offices and commercial activities commence) and 4.00 – 7.00pm in the evening at the close of work and market activities.

The time-segmented transportation needs/loads as well as the cumulative transportation needs/loads at the locations was evaluated.

2.2. Measurement of Target Air Pollutants

The target air pollutants – carbon monoxide (CO), Nitrogen dioxide (NO_2), Hydrocarbons-Methane (CH4) were measured using standard equipment called Aeroqual/crowcon Gasman Monitors. The measurements were at three intervals within 12 hours in a day for a total of two days at each location.

3. Results and Analysis

The field survey results obtained at the different locations were subsequently analyzed.

3.1. Survey Results

The vehicle counts, in types, from the four approaches, for each survey day are collated and the cumulative figures as well as the corresponding measured pollutants are presented in tables.

3.2. IMSU Junction

The figures for this junction are presented in Table 1 for day 1 and Table 2 for day 2.

Table 1 vehicle types for day 1

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	847	833	186	37	22	262	09	18	0.031
Afternoon (At 2pm)	10,112	8261	2628	125	54	684	05	0.169	ND
Evening (At 6pm)	14,579	12,487	4045	201	79	944	05	0.090	ND
	Standards						10	0.04-0.06	NS

ND: NON-DETECTED; NS: NOT STATED

Table 2 Vehicle types for day 2

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	687	769	112	09	04	34	09	0.084	ND
Afternoon (At 2pm)	15090	12661	2343	229	78	297	06	0.040	ND
Evening (At 6pm)	25022	20813	3443	357	106	555	14	0.086	ND
	Standards						**10**	**0.04-0.06**	**NS**

ND: NON-DETECTED; NS: NOT STATED

At this junction one of the measured values of CO is above the standard, two values are close to the standard while three are below the standard. Five of the Nitrogen dioxide values are above the standard while one is within the standard. Methane was only detected on one out of the six times. There is also a high volume of salon and wagon vehicles traversing this junction throughout the survey period, and occasionally resulting in traffic jam.

3.3. Amakohia Junction

The corresponding figures for Amakohia Junction are presented in Tables 3.3 and 3.4.

Table 3 Vehicle types day 1

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	754	597	160	08	05	57	3	0.134	ND
Afternoon (At 2pm)	7628	7110	1435	121	70	402	3	0.073	ND
Evening (At 6pm)	14057	13831	3285	297	127	783	7	0.111	ND
	Standards						10	0.04-0.06	NS

Table 4 Vehicle types 2

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	607	601	63	05	02	42	7	0.06	ND
Afternoon (At 2pm)	10581	8187	3405	544	62	435	6	0.043	ND
Evening (At 6pm)	16218	15311	5526	645	120	806	8	0.073	ND
	Standards						10	0.04-0.06	NS

ND = NONE DETECTED; NS = NOT STATED

Three of the Carbon monoxide values at this junction are well below the standard while three are very close to it. Four of the nitrogen dioxide values are well above the standard while two are within the standard. Methane was not detected.

There is also a high volume of salons and wagons at the junction, in excess of five times the total of other passenger vehicles.

3.4. Assumpta Junction

The corresponding figures for Assumpta Junction are presented in tables 3.5 and 3.6.

Two of the Carbon monoxide values recorded at this junction are above the standard while four values are below the standard. Four values of nitrogen-dioxide are above standards while two are within the standards. Only on one occasion was a value recorded for methane.

The salons and wagons traversing this junction are close to ten times that of other passenger vehicles, very often resulting in traffic gridlock.

Table 5 Vehicle types for day 1

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	743	874	215	13	15	69	ND	0.090	1.00
Afternoon (At 2pm)	11332	10304	2152	135	74	714	6.00	0.060	ND
Evening (At 6pm)	20429	16775	3637	215	119	1727	17.00	0.005	ND
	Standards						10	0.04-0.06	NS

Table 6 Vehicle types for day 2

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	715	586	229	15	22	75	3.00	0.086	ND
Afternoon (At 2pm)	9733	11291	2908	275	234	507	11.00	087	ND
Evening (At 6pm)	14534	18853	3819	382	357	835	3.00	0.137	ND
	Standards						10	0.04-0.06	NS

ND: NON-DETECTED NS: NOT STATED

3.5. Emmanuel College

The corresponding figures for Emmanuel College junction are presented in Tables 3.7 and 3.8.

Table 7 Vehicle types for day 1

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	1498	2816	527	89	60	158	31.00	0.070	ND
Afternoon (At 2pm)	11154	11635	5014	473	316	584	17.00	0.048	ND
Evening (At 6pm)	21184	20391	11921	953	607	1276	7.00	0.068	1.00
	Standards						10	0.04-0.06	NS

ND = NONE DETECTED NS = NOT STATED

Table 8 Vehicle types for day 2

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	876	2135	434	38	33	180	80.00	0.073	1.00
Afternoon (At 2pm)	27734	32567	6706	114	128	1318	22.00	0.092	ND
Evening (At 6pm)	34101	38368	9496	228	227	1697	13.00	0.182	ND
	Standards						10	0.04-0.06	NS

ND = NONE DETECTED NS = NOT STATED

All the values of the Carbon-monoxide measured here are above the standard and in most cases about double the standard. All but one nitrogen dioxide values are above the standard while methane was detected on two out of the six times. There is a very high volume of salons and wagons at this junction, over eight times the total of other passenger vehicles. Expectedly traffic jam is very often experienced at the junction.

3.6. Wethedral/MCC Junction

The corresponding figures for the Wethedral/MCC junction are presented in Tables 3.9 and 3.10.

Table 9 Vehicle types for day 1

Period	Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	1108	2353	112	18	24	86	20.00	0.072	ND
Afternoon (At 2pm)	16151	15702	389	62	85	316	13.00	0.084	ND
Evening (At 6pm)	30647	23098	808	164	195	633	21.00	0.126	ND
	Standards						10	0.04-0.06	NS

Table 10 Cumulative vehicle types for day 2

Period	Cumulative Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	383	734	45	04	06	35	22.00	0.075	ND
Afternoon (At 2pm)	6639	13537	579	61	76	254	17.00	ND	ND
Evening (At 6pm)	10509	19579	883	106	107	405	3.00	0.091	ND
	Standards						10	0.04-0.06	NS

At this junction all but one value of Carbon monoxide is well above the standard. On five of the six times the nitrogen dioxide values are above the standard while methane was not detected. There is a very high volume of salons and wagons at the junction, in excess of over forty times that of other passenger vehicles, on the average, with traffic gridlock very often.

3.7. Exhaust Emission of vehicles.

The representative vehicles exhaust emissions for the three pollutants of interest are presented on Table 11.

Table 11 Exhaust Emission of Different Vehicles

Vehicle	Pollutants		
	CO, ppm	NO_2, ppm	CH_4, ppm
Car 1	234.30	0.56	284.00
Car 2	234.30	0.30	5613.00
Car 3	234.30	0.60	4227.00
Average	234.30	0.49	4229.00
Wagon 1	173.80	0.93	79.00
Wagon 2	68.80	0.49	87.00
Wagon 3	234.30	0.04	79.00
Average	158.97	0.49	81.67
Mini Bus 1	234.30	0.28	3797.00
Mini Bus 2	234.30	0.22	4461.00
Mini Bus 3	209.20	0.15	512.00
Average	225.93	0.22	2923.33
Coaster Bus 1	234.30	0.63	479.00
Coaster Bus 2	234.30	0.63	444.00
Coaster Bus 3	234.30	0.63	396.00
Average	234.30	0.63	439.67
Big Bus 1	ND	5.37	14.00
Big Bus 2	ND	5.37	14.00
Big Bus 3	ND	5.37	10.00
Average	ND	5.37	12.67
Truck 1	254.60	1.03	18.00
Truck 2	246.80	1.26	16.00
Truck 3	254.60	1.27	20.00
Average	252.00	1.19	18.00

3.8. Analysis of Results

Applying the principle of worst case scenario on the collated results and measured pollutants for the survey locations yields the following Tables.

3.9. Worst Case Results

The worst case results for the five junctions are presented in Tables 3.12, 3.13, 3.14, 3.15 and 3.16.

Table 12 For IMSU junction

Period	Cumulative Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 ppm	CH_4 Ppm
Morning (At 7am)	847	833	186	37	22	262	09	18	0.031
Afternoon (At 2pm)	15090	12661	3403	229	78	684	06	0.169	ND
Evening (At 6pm)	25022	20813	4820	357	106	944	14	0.090	ND

Table 13 For amakohia junction

Period	Cumulative Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 ppm	CH_4 Ppm
Morning (At 7am)	754	601	160	08	05	57	7	0.134	ND
Afternoon (At 2pm)	10581	8187	3405	544	70	435	6	0.073	ND
Evening (At 6pm)	16218	15311	5526	645	127	806	8	0.111	ND

Table 14 For amakohia junction

Period	Cumulative Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 ppm	CH_4 Ppm
Morning (At 7am)	743	874	226	15	22	75	3.00	0.090	1.00
Afternoon (At 2pm)	11332	11291	2908	275	234	714	11.00	0.087	ND
Evening (At 6pm)	20429	18853	3819	382	357	1727	17.00	0.137	ND

Table 15 For emmanuel college junction

Period	Cumulative Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	1498	2816	527	89	60	180	80.00	0.073	1.00
Afternoon (At 2pm)	11154	11635	6706	473	316	584	22.00	0.092	ND
Evening (At 6pm)	34101	38368	11921	953	607	1697	13.00	0.182	1.00

Table 16 for Wethedral/MCC junction

Period	Cumulative Vehicle Types						Pollutants		
	Sal. Veh. V_1	Wagon Veh. V_2	Mini Buses V_3	Coaster Buses V_4	Big Buses V_5	Trucks V_6	CO Ppm	NO_2 Ppm	CH_4 Ppm
Morning (At 7am)	1108	2353	112	18	24	86	22.00	0.075	ND
Afternoon (At 2pm)	16151	15702	379	62	85	316	17.00	0.084	ND
Evening (At 6pm)	30647	23098	883	164	195	633	21.00	0.126	ND

ND: NON-DETECTED ; NS: NOT STATED

3.10. Commuters Traversing The Junctions

The total commuters traversing the survey locations is the product of the number of vehicles and their weighted carrying capacities. From field observations the vehicles were averagely 60% loaded such that the following weighted capacities are derived.

Table 17 Passenger carrying capacity of vehicles

Vehicle Type	Design Capacity	Weighted Capacity
Saloon Vehicles	5	3
Wagon Vehicles	8	5
Mini Buses	15	9
Coaster Buses	33	20
Big Buses	53	32

Using the weighted carrying capacities and the cumulative vehicles accessing the locations, the total commuters traversing the locations are calculated as shown in Tables 3.18, 3.19, 3.20, 3.21 and 3.22 respectively.

Table 18 Total Commuters Traversing IMSU Junction in a 12-Hour Day

Veh. Types	Cumulative No	Weighted Capacity	Total Commuters
Saloon Veh. V_1	25022	3	75,066
Wagon Veh. V_2	20813	5	104,065
Mini Buses V_3	4820	9	43,380
Coaster Buses V_4	357	20	7,140
Big Buses V_5	106	32	3,392
Total 51,118			233043

Table 19 Total Commuters Traversing Amakohia Junction in a 12-Hour Day

Veh. Types	Cumulative No	Weighted Capacity	Total Commuters
Saloon Veh. V_1	1621	3	4863
Wagon Veh. V_2	1531	5	7655
Mini Buses V_3	5526	9	49734
Coaster Buses V_4	645	20	12900
Big Buses V_5	127	32	4064
Total 9450			79,216

Table 20 Total Commuters Traversing Assumpta Junction in a 12-Hour Day

Veh. Types	Cumulative No	Weighted Capacity	Total Commuters
Saloon Veh. V_1	20429	3	61,287
Wagon Veh. V_2	18853	5	94,245
Mini Buses V_3	3819	9	34,371
Coaster Buses V_4	382	20	7,640
Big Buses V_5	357	32	11,424
Total 43,840			208,987

Table 21 Total Commuters Traversing Emmanuel College Junction in a 12-Hour Day

Veh. Types	Cumulative No	Weighted Capacity	Total Commuters
Saloon Veh. V_1	34101	3	102303
Wagon Veh. V_2	38368	5	191,040
Mini Buses V_3	11921	9	107,289
Coaster Buses V_4	953	20	19,060
Big Buses V_5	607	32	19,424
Total 85,950			439,916

Table 22 Total Commuters Traversing Wethedral/MCC Junction in a 12-Hour Day

Veh. Types	Cumulative No	Weighted Capacity	Total Commuters
Saloon Veh. V_1	30647	3	91,941
Wagon Veh. V_2	23098	5	115,490
Mini Buses V_3	883	9	7,947
Coaster Buses V_4	164	20	3,280
Big Buses V_5	195	32	6,240
Total 54,987			224,898

Of the five junctions investigated Emmanuel College Junction recorded the highest number of vehicles and commuters traversing and highest values of pollutants. Further studies are based on the results from here, as a worst case scenario.

Table 23 shows the amount of the three pollutants of interest emitted into the environment by the vehicles traversing the Emmanuel college junction within 12 hours of the day.

Table 23 Total Pollutants Contribution by Vehicles that Accessed Emmanuel College Junction

Veh. Types	Total Veh.	Carbon Monoxide		Nitrogen Dioxide		Methane	
		Rate	Total x 10^3 ppm	Rate	Total x 10^3 ppm	Rate	Total x 10^6 ppm
Saloon Cars V_1	34101	234.3	7989.86	0.49	16.71	422.9	144.21
Wagon Veh.V_2	38368	158.97	6099.36	0.49	18.80	81.67	3.13
Mini Buses V_3	11921	225.93	2693.31	0.22	2.622	2923.33	34.85
Coaster Buses V_4	953	234.30	223.29	0.63	0.6	439.67	0.42
Big Buses V_5	607	42	5.49	5.37	3.26	12.67	0.0077
Total	85,950		17,031.29 x 10^3 ppm		41.992 x 10^3 ppm		182.62 x 10^6 ppm

3.11. Model Development

The aim of the model is to achieve a remix of the vehicles such that the total commuters of 439,916 are served with a reduction in number of vehicles and pollutants released into the environment. This can be obtained by optimizing the model equations obtained.

Solving the Objective function obtained from table 4.21;

$$3v_1 + 5v_2 + 9v_3 + 20v_4 + 32v_5 = 439916 \qquad \text{Eqn (1)}$$

Subject to:

For a 40% reduction in CO,

$$234.3v_1 + 158.97v_2 + 225.93v_3 + 234.3v_4 + 42\,v_5 = 10{,}218.774 \times 10^3 \text{ Eqn (2)}$$

For a 50% reduction in NO_2,

$$0.49v_1 + 0.49v_2 + 0.22v_3 + 0.63v_4 + 5.51v_5 = 20.996 \times 10^3 \qquad \text{Eqn (3)}$$

For a 50% reduction in CH_4,

$$4229v_1 + 81.67v_2 + 2923.33v_3 + 439.67v_4 + 12.67v_5 = 91.31 \times 10^6 \quad \text{Eqn (4)}$$

That 80% of the commuters use buses

$$0 + 0 + 9v_3 + 20v_4 + 32v_5 = 351{,}933 \quad \text{Eqn (5)}$$

It should be noted that the ambient pollutants measured indicated that a reduction by about half of the emission will bring them within the acceptable standards; Tables 4.12 to 4.16

In Matrix form the five equations are thus;

V_1	**V_2**	**V_3**	**V_4**	**V_5**	
3	5	9	20	32	439,916
234.3	158.97	225.93	234.3	42	10,218,774
0.49	0.49	0.22	0.63	5.51	20,996
4229	81.67	2923.33	439.67	12.67	91,310,000
0	0	9	20	32	351,933

Solving the matrix using Tora Equation Solver yields;

V_1 = 4,278.05, V_2 = 15,029.77, V_3 = 23,688.8, V_4 = 6,220.14, V_5 = 447.85

Using these values (rounded off), multiplied by the weighted capacity of each vehicle type yields Table 24 while the values multiplied by the rate of emission of each vehicle type yields Table 25.

Table 24 Total Commuters Provided For By The New Scheme

Veh. Types	Number of Vehicle	Weighted Capacity	Total
Saloon Veh. V_1	4,278	3	12,834
Wagon Veh. V_2	15,050	5	75,150
Mini Buses V_3	23,689	9	213,201
Coaster Buses V_4	6,220	20	124,400
Big Buses V_5	448	32	14,336
Total	49,665		439,921

Table 24 shows a total of 49,665 vehicles for the cumulative commuters of 439,921 as against 85,950 vehicles for 439,916 commuters in Table 21. This amounts to a reduction of 36,285 vehicles or 42.22% in passenger traffic volume.

Table 25 shows exhaust emissions of 10,219,880 ppm of Carbon monoxide, 20,998ppm of Nitrogen dioxide and 91,312,000ppm of Methane as against 17,005,800ppm, 41,992ppm and 182,620,000ppm respectively in Table 4.23. These amount to 40% reduction in Carbon monoxide, 50% reduction in Nitrogen dioxide and 50% reduction in Methane, of exhaust emissions due to passenger vehicles.

The analyses of the field data revealed a typical existing passenger vehicle mix of 34,101:38,368: 11,921: 955: 607, totaling 85,950 for Salon Vehicles: Wagon vehicles: Mini Buses: Coaster Buses: Big Buses, for a total of 439,916 commuters, from Table 21

The ratio can therefore be written as 56.2: 63.7: 19.6 : 1.6 :1

It also shows a very high volume of 72,469 vehicles out of 85,950 or 84.3% of low-passenger carrying capacity vehicles (salons and wagons).

These low-passenger carrying vehicles emit into the environment,

14,089.22 x 10^3 ppm or 82.7% of the Carbon Monoxide

35.51 x 10^3 ppm or 84.6% of the Nitrogen dioxide and 147.34 x 10^6 ppm or 80.7% of the Methane.

Table 25 Total Pollutants Emission by the New Scheme

Veh. Type	Total No.	Carbon Monoxide		Nitrogen Dioxide		Methane	
		Rate	Total x 10^3	Rate	Total x 10^3	Rate	Total x 10^6
Saloon Cars V_1	4,278	234.3	1002.335	0.49	2.096	4229	18.092
Wagon Veh. V_2	15,030	158.97	2389.32	0.49	7.365	81.67	1.228
Mini Buses V_3	23,689	225.93	5,352.056	0.22	5.212	2923.33	69.251
Coaster Buses V_4	6,220	234.30	1,457.35	0.63	3.919	439.67	69.251
Big Buses V_5	448	42	18.816	5.37	2.406	12.67	2.735
Total	49,665		10,219.88 X 10^3		20.998 X 10^3		91.312 X 10^6

This scenario of many vehicles plying the roads, carrying a few passengers but releasing high pollutants resulting in the twin problems of traffic congestion on the roads and highly polluting the environment is very typical in Nigerian Cities. It therefore needs to be addressed.

The new scheme being put forward has the following corresponding ratio as can be seen from Table 24.

4,278 : 15, 050 : 23, 689 : 6, 220 : 448 for 439,921commuters.

This can be written as 9.5: 33.6: 52.9: 13.9: 1

It is now tilted to favour the high-passenger-carrying vehicles while taking into account pollutants release by them. In the new scheme, the low-passenger-carrying vehicles now total only 19,328 vehicles out of 49,665, amounting to 38.9%.

In the new scheme, the low-passenger-carrying vehicles now emit to the atmosphere:

3,391.66 x 10^3 ppm or 33.2% Carbon monoxide

9. 461 x 10^3 ppm or 45.1% of Carbon monoxide and

19.32 x 10^6 ppm or 21.2% of Methane.

Worthy of note in the new scheme is that vehicles of high-passenger-carrying capacities release greater percentage of the pollutants. In the typical case the buses with a combined capacity of 351,937, which is 80% of total demand of 439,921, will emit 66.8% of carbon monoxide, 54.9% of Nitrogen dioxide and 78.8% Methane.

Note also that the new scheme reduces total traffic volume by 36,285 vehicles from 85,950 to 49,665 representing 42.2%, for a little more commuters. The new scheme as in Tables 3.25 will result in exhaust emissions of 10,219,880 ppm of Carbon monoxide, 20,998ppm of Nitrogen dioxide and 91,312,000ppm of Methane as against 17,005,800ppm, 41,992ppm and 182,620,000ppm respectively in Table 23. These amount to 40% reduction in Carbon Monoxide, 50% reduction in Nitrogen dioxide and 50% reduction in Methane, of exhaust emissions due to passenger vehicles.

4. Conclusion

The existing commuter vehicle mix in Owerri, Imo State Nigeria is 56,2:63,7:19.6:1.6:1 for salons, wagons, mini buses, coaster buses and big buses respectively. This gives a total of 85,950 vehicles at a typical junction in a 12 hour period. The ambient air pollutants associated with this existing scenario is at a level well above the WHO acceptable standards.

By adopting the newly developed model, a remix of 10:33:53;14;1 of the same vehicle types is achieved. Thus, there is a reduction of about 40-50 percent in traffic volume and associated target air pollutants.

This is obviously more sustainable and more desirable in the 21st century urban centre of Owerri.

Recommendations

This study has shown that mini-buses and coaster buses have advantage over salon cars, wagon vehicles and big buses in terms of traffic congestions and pollutants release into the environment. Thus, the two bus types could be said to have least pollutants release per passenger carried.

To achieve the desired remix, it is recommended that government should adopt economic policies embedded in some kind of "push and pull" strategy, leveraging on ''disincentive and incentive'' measures. Specifically government should;

- deliberately increase licensing fees for salons and wagons
- introduce bus lanes on major roads (Orlu, Okigwe, Wethedral, Asuumpta, Egbu, Douglas), which gives access to buses only thus reducing their trip time
- introduce equal toll fees on city roads for salons, wagon, and buses
- introduce annual parking fees for cars and wagons.
- encourage private-private or public-private cooperations in the public bus transportation system with grants.
- consider a regulatory policy of outright ban of such low-carrying-capacity vehicles like salons and wagons for commercial purposes, particularly on some major roads where bus lanes have been recommended.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

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