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Simulation and analysis of vehicular speed at defined locations

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The aim of this study is to simulate and analyze vehicular speed at defined locations. A system that automatically monitors and reports vehicular speed at every coordinate in conformity to identified locations and informs vehicle owners or relevant authorities on dangerous speeding that could lead to accidents. Its input includes signals from the vehicle speedometer and GPS module that interprets the coordinates of locations. Several works had been done in this area which include tracking of vehicle speed by the owners or authority and speed reporting without information on the vehicle's actual location. This study is an enhancement to others as locations GPS were converted to names of towns, villages, or settlements along the Warri-Benin road before transmission to receivers. Data involving GPS coordinates and signal strength of selected three service providers were collated at designated and recognized locations along the road. Relevant models were developed for simulation on MATLAB 2019 environment for various levels of vehicular speed at the locations. The simulated results show a computed average speed of 200km/h, far above the maximum set speed limit of 100km/h by the Federal Road Safety Commission in 2014 for Nigeria roads that could lead to an accident. The detected speed was transmitted to receivers using the strongest available cellular network signal strength among chosen three service providers of AIRTEL, GLO, and MTN.

1. Introduction

One of the fundamental risk factors in traffic control is speed (Wegman et al., 2008). Driving at very high speeds results in the possibility of higher collisions that could result in severe accidents. Very high speeds also provide less time to process information and act on it for effective safety braking distance, therefore the possibility of avoiding an accident is minimal (Su et al., 2022; Aarts and Schagen, 2006). Over-speeding is most likely related to the illegal behavior of drivers hence, adequate training, long experience, and proper education are essential in developing a safe driving habit (Davey et al, 2006).

Employees' drivers of automobiles are usually involved in irresponsible driving habits such as over-speeding as driving dangerously is the major additional attribute among work-related drivers in relation to road accidents (Stradling, 2000).

2. Literature review

The global positioning system (GPS) application is described as useful in commerce, scientific, tracking, and surveillance (Kishore et al, 2010). It facilitates everyday activities such as banking, mobile phone operations, and even control of power grids by allowing well-synchronized hand-off switching (Abulude et al., 2015). Fig. 1 presents how a GPS satellite functions by transmitting signals to an object (vehicle) on the ground.

The global system for mobile communication (GSM) is a digital mobile telephony system that is widely used in Europe and other parts of the world. The network has four major sub-systems namely the switching system (SS), the base station system (BSS), the operation and support system (OSS), and the mobile station (MS) (Popović et al., 2019). GSM signal strength is defined as a measure of data transmission through electromagnetic waves (Barros et al., 2015). The factors that affect the Received Signal Strength as the quality of Radio Frequency planning, the number of base stations,

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and propagation effects such as reflection, diffraction, and scattering (Srbinovska et al., 2011). The four units of signal strength measurement are milliwatts (mW), mill decibels (dBm), Received Signal Strength Indicator (RSSI), and percentage signal strength (Nkordeh et al., 2016). The Base Station System (BSS) is described as a system that consists of the base station controllers (BSCs) and the base transceiver stations (BTSs). The BSC provides all the control functions and physical links between the MSC and BTS (de Aguiar et al., 2009). Shown in Fig. 2 is a typical GSM network architecture.

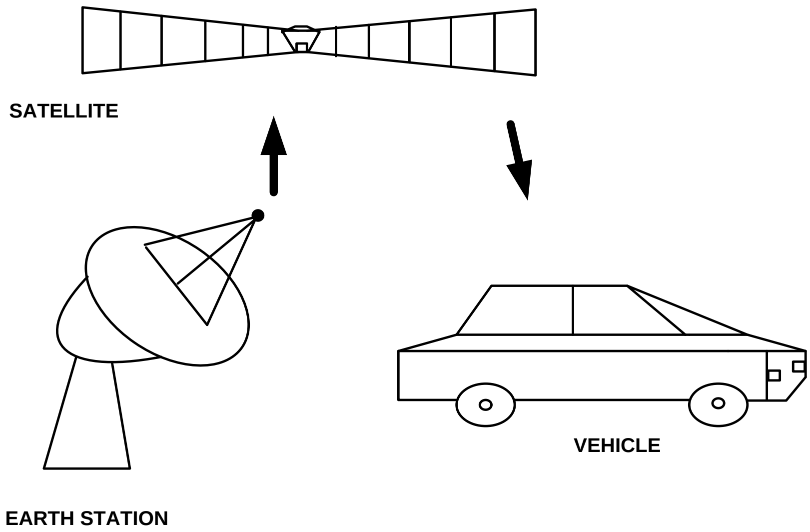

Fig. 1: Satellite functions tracking a vehicle

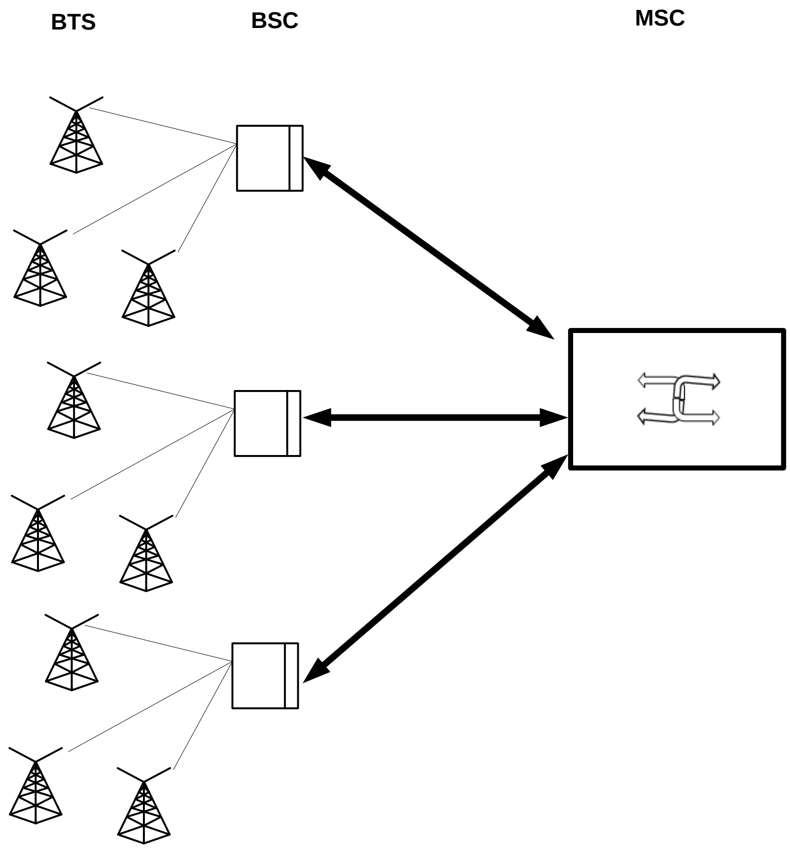

Fig. 2: GSM network architecture (Alexei et al., 2009)

The vehicle speed control system using GSM/GPRS is a system that tends to control the speed of the automobile with the aid of computer software to alert third parties or vehicle owners on overspending in real-time. The auto-sensing system transmits data to the distant receiver. However, the application of GSM/GPRS technologies permits the tracking of the objects and makes available current information. This information is permitted to allow users on the internet as the server gets the signals. Therefore, the application is applied in real-time traffic surveillance. It makes available compatibility and portability for the user to get the signals worldwide (Devikiruba, 2013). The system is very good for speed control but cannot report the exact location where overspending occurs. A framework that utilized a mainstream innovation that interface smartphone application with a microcontroller. The framework uses a vehicle gadget that works with the aid of a Global Positioning System (GPS) and Global framework for versatile correspondence/General Packet Radio Service (GSM/GPRS) innovation which is one of the most well-known ways for the vehicle. The gadget is implanted inside a vehicle whose position is to be resolved and followed continuously (Lee et al., 2014). The effects on the number of crashes of vehicles increase or decrease the average speeds on road section mostly due to changes in speed limit. Furthermore, the effect of the speed driven by individual vehicle drivers with respect to that of the other traffic was examined (Elvik et al., 2019). Overspeeding was acclaimed to have contributed to 32% of severe or fatal accidents (Heydari et al., 2019) while the vehicles speed limit on Nigerian roads were put at 50km/h for urban roads, 80km/h for rural roads, and 100km/h for highways (Gwaivangmin, 2016).

3. Materials and methods

3.1. Models for vehicle speed reporting system

Various mathematical models were developed for the vehicle speed reporting system, categorized into two main sections namely vehicle location and dangerous speed detection.

3.2. Model for vehicle location

The distance between two points Δd, having different Latitudes and Longitudes along the earth's surface as shown in Fig. 3 can be computed using the Haversine (hav) formula of Eq. 1 that calculates the distance between two points on the earth's surface while ignoring contours and hills (Grewal et al., 2007).

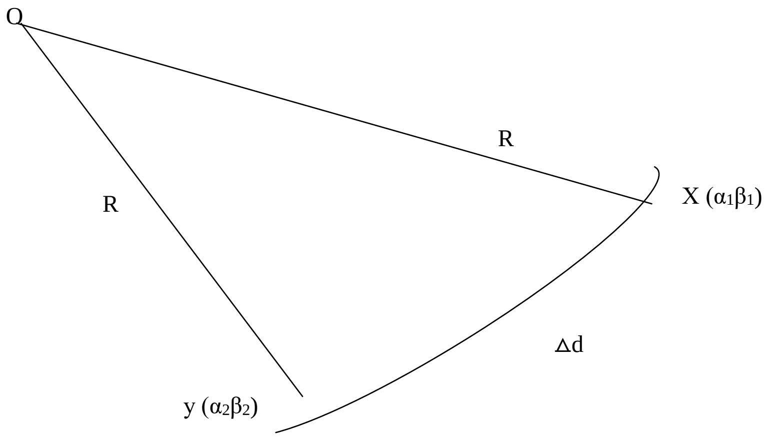

Fig. 3: XY projection

$$hav\left(\frac{\Delta d}{R}\right) = hav(\Delta\alpha) + \cos\alpha_1 \cos\alpha_2 \, hav(\Delta\beta) \quad (1)$$

where, Δd is the distance between point X and point Y on the earth's surface; R is the radius of the earth, approximately 6370km; α_1 is the latitude of reference point location X, (Warri); α_2 is the latitude of a point location Y, (where excessive speed occurred); β_1 the longitude of reference point location X, (Warri); β_2 is the longitude of a point location Y, (where excessive speed occurred). Note,

$$havesine\ (hav)\ \phi = sin^2\ \phi/2 \quad (2)$$

$\Delta\alpha = \alpha_2 - \alpha_1$

$\Delta\beta = \beta_2 - \beta_1$

therefore,

$$\Delta d = 2R\arcsin\left(sin^2\left(\frac{\Delta\alpha}{2}\right) + cos\alpha_1 cos\alpha_2 sin^2\left(\frac{\Delta\beta}{2}\right)\right)^{\frac{1}{2}} \quad (3)$$

3.3. Model for dangerous speed detection

Speed has an effect on accident rate and its severity which is quantified the relationship on the basis of kinetic laws presented in Eq. 4 (Nilsson, 1981).

$$Q_1 = Q_0\left(\frac{V_1}{V_0}\right)^N \quad (4)$$

where, V_1 is the average speed after; V_0 is the average speed before; Q_1 is the number of injury crashes after a change in speed; Q_0 is the initial number of injury crashes before the change in speed; N is the number that conforms to injury crashes.

Eq. 5 is Newton's law of motion that determines the change in vehicular accelerating speed with respect to the distance covered which can also be linked to the accident as in Eq. 4 and also to vehicle location defined by coordinates of Eq. 3.

$$\Delta d = \frac{V_1^N - V_0^N}{2a} \quad (5)$$

where a=vehicular acceleration

$$V_0^N = V_1^N - 2a\Delta d \quad (6)$$

Eq. 7 is the substitution of Eq. 6 in 4

$$\frac{Q_1}{Q_0} = \frac{V_1^N}{V_1^N - 2a\Delta d} \quad (7)$$

Eq. 8 is the further computation of Eq. 7.

$$V_1^N = \frac{2a\Delta d}{1 - \frac{Q_0}{Q_1}}. \quad (8)$$

Eqs. 9 and 10 are obtained by taking a log of both sides of Eq. 8 and solving for N.

$$N log V_1 = \log\left(\frac{2a\Delta d}{1 - \frac{Q_0}{Q_1}}\right) \quad (9)$$

$$N = \frac{\log\left(\frac{2a\Delta d}{1 - \frac{Q_0}{Q_1}}\right)}{log V_1} \quad (10)$$

N=2 conforms to a mild injury crash, N=3 conforms to a severe injury crash and N=4 conforms to a fatal injury crash. The exponents of 2, 3, and 4 cannot all be true at the same time for the same category of accidents. Therefore, the power model caters to the various levels of accident or injury severity to avoid overlapping and is treated as mutually exclusive (Elvik et al., 2004). Table 1 is the evaluated model values of N for various categories of accidents and their levels of fatalities in conformity with the best estimate of 96% confidence (Elvik, 2009).

Table 1: Evaluation of power model for speed and road accidents

Accident or injury severity	Exponent (N)	Interval
Fatalities (Fatal)	4.5	(4.1–4.9)
Seriously injured road user (Severe)	3.0	(2.2–3.8)
Slightly injured road user (Mild)	1.5	(1.0–2.0)
Property-damage-only accidents	1.0	(0.2–1.8)

3.4. Relevant data for simulation

Table 2 is the summarized analysis of road accidents in Nigeria for the years 2014 and 2015 (FRSC, 2015). These data were adopted for Warri-Sapele road for the purpose of simulation and with further assumption that the accident occurred at thirty-six (36) different locations along the road and that speed was responsible for the crashes.

Table 2: Summarized analysis of road accidents in Nigeria for the years 2014 and 2015 (FRSC, 2015)

State	Total cases	
Year	2014	2015
ABIA	87	86
ADAMAWA	288	163
AKWA IBOM	57	50
ANAMBRA	272	255
BAUCHI	493	226
BAYELSA	95	69
BENUE	290	388
BORNO	14	9
CROSS RIVER	197	138
DELTA	90	200
EBONYI	248	287
EDO	239	274
EKITI	60	55
ENUGU	263	250
FCT ABUJA	1395	1342
GOMBE	179	189
IMO	241	170
JIGAWA	101	149
KADUNA	525	502
KANO	404	269
KATSINA	159	225
KEBBI	149	143
KOGI	254	331
KWARA	199	207
LAGOS	321	403
NASARAWA	878	798
NIGER	602	523
OGUN	298	428
ONDO	285	211
OSUN	266	266
OYO	272	270
PLATEAU	245	236
RIVERS	137	96
SOKOTO	158	164
TARABA	83	106
YOBE	70	53
ZAMFARA	266	203

Additionally, Table 3 presents names of locations with their equivalent coordinates, signal strengths (SS) of three cellular service providers designated as SS_1 (AIRTEL), SS_2 (MTN), SS_3 (GLO), and assumed crashes for the year 2014 as a number of the accident before (Q_0) while the year 2015 as the number of the accident after (Q_1) for various locations along Warri-Sapele road in Delta State, Nigeria.

Table 3: Locations with their equivalent coordinates, signal strengths of three cellular service providers, and assumed crashes for the year 2014 as the number of the accident before (Q_0) while the year 2015 as the number of the accident after (Q_1)

Location	Accident Before (Q_0)	Accident After (Q_1)	Latitude (α^0)	Longitude (β^0)	SS_1 dBm	SS_2 dBm	SS_3 dBm
Effurun RoundAbout Warri	87	86	5.788111111	5.582823333	-75	-61	-101
Between RoundAbout / Motor Park	288	163	5.780783333	5.589987333	-57	-83	-81
Effurun Motor Park	57	50	5.780916667	5.596966777	-71	-85	-95
MercyLand Church Effurun	272	255	5.781999977	5.601000111	-86	-94	-96
Army Check Point Effurun	493	226	5.778916667	5.605555550	-90	-96	-106
Kolanut Garden Effurun	95	69	5.778333333	5.613733330	-96	-90	-88
Ugono Junction	290	388	5.777216667	5.618566667	-94	-87	-85
Ohorho Junction	14	9	5.775550000	5.626216667	-95	-85	-83
Water Oils Petrol Station Ohorho	197	138	5.771111111	5.635900000	-80	-77	-77
Rure Oil and Gas Otomewo	90	200	5.768750000	5.640933333	-77	-87	-80
High Tension Line Otomewo	248	287	5.765133333	5.651066667	-83	-101	-91
Lym Co Consult Otomewo	239	274	5.762551110	5.658683333	-86	-107	-94

Between Otomewo/Okuovo	60	55	5.761043111	5.664000000	-87	-107	-95
Between Otomewo/Okuovo	263	250	5.758816667	5.668583333	-89	-88	-97
Okwovo Junction	1395	1342	5.755700000	5.676000000	-90	-85	-99
Between Okwovo / NIFEST City	179	189	5.754116667	5.681033333	-109	-87	-101
NIFEST City	241	170	5.751633333	5.687766667	-89	-93	-102
Opuraja Community	101	149	5.751900000	5.690800000	-88	-93	-105
The Apostlic Church Opuraja	525	502	5.753466667	5.701816667	-87	-91	-109
Jakpa Mereje Junction	404	269	5.754350000	5.707150000	-71	-91	-99
Adeje Junction	159	225	5.755600000	5.714783333	-85	-95	-113
Okwobude Town	149	143	5.755283333	5.725600000	-101	-97	-105
Okuetolor Junction	254	331	5.751600000	5.732983333	-93	-97	-106
Okuotoma Junction	199	207	5.749066667	5.737383333	-90	-99	-106
Between Okuotoma / Elume	321	403	5.744516667	5.749866667	-80	-91	-107
Elume Junction	878	798	5.740233333	5.765533333	-70	-85	-105
Ibada-Elume	602	523	5.738516667	5.773283333	-74	-85	-101
Between Elume / Ikwewu-Sapele	298	428	5.734955555	5.789266667	-81	-91	-111
Between Elume / Ikwewu-Sapele	285	211	5.733366667	5.799933333	-82	-92	-113
Between Elume / Ikwewu-Sapele	165	266	5.734111111	5.810666670	-87	-107	-113
Ikwewu Sapele	272	270	5.730366667	5.824600000	-91	-81	-104
Drigas Nig. Ltd Sapele	245	236	5.731766330	5.831216667	-90	-81	-102
Godstime Petrol Sapele	137	96	5.731483333	5.835983333	-89	-81	-101
Dums Petrol Station Sapele	158	164	5.732716667	5.841950000	-63	-89	-107
Sapele RoundAbout	83	106	5.732933333	5.849300000	-61	-85	-101
NTA Sapele	70	53	5.731950000	5.854533333	-74	-84	-101
Sapele Bridge	266	203	5.730633333	5.870500000	-105	-85	-113

3.5. Simulink model for vehicle location and signal transmission (VLST)

The developed models in Eqs. 1-10 were employed in simulation for different levels of vehicular speed and highest signal strength at different locations in the MATLAB 2019 environment. Fig. 4 presents the developed Simulink model referred to as vehicle location and signal transmission (VLST). GSM network was employed for reporting speed levels at defined or specific locations along Warri-Sapele road. Signal strengths of chosen three GSM service providers (AIRTEL, MTN, and GLO) were also employed in the simulation.

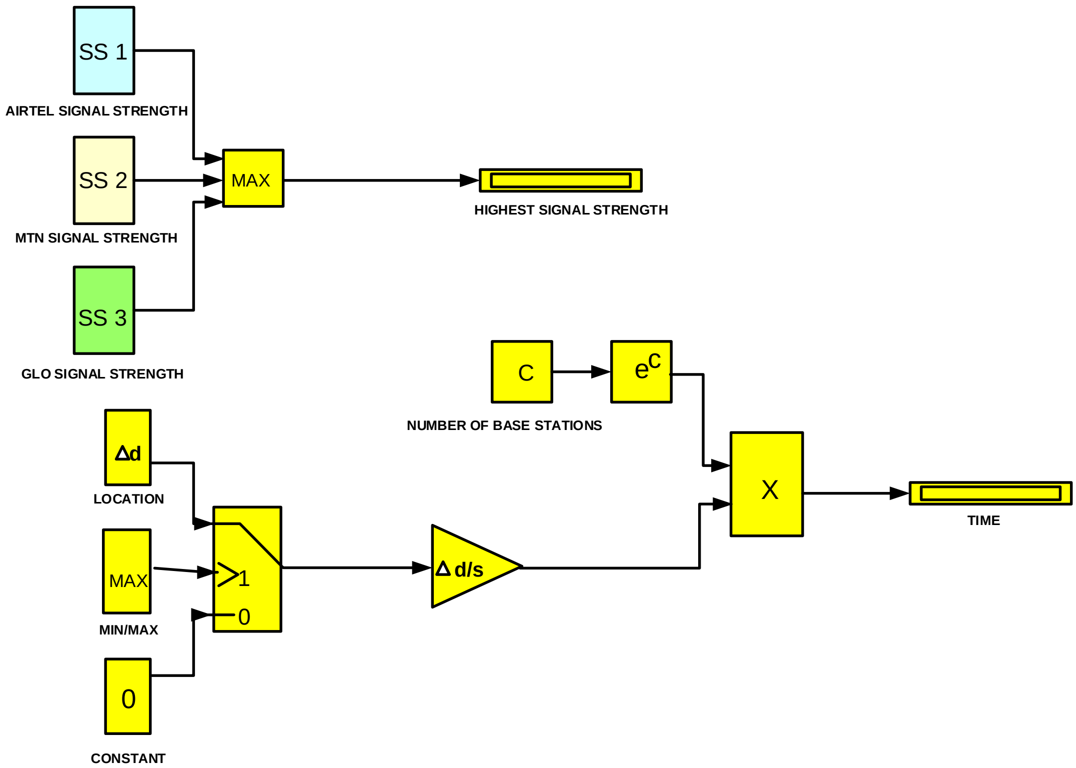

Fig. 4: Simulink model for vehicle location and signal transmission (VLST)

4. Simulation results and discussions

Table 4 is the simulated results performed for forty (40) locations along Warri-Sapele road. The analysis of Table 4 led to the formation of Figs. 5 and 6.

Shown in Fig. 5 is the total of thirteen (13) locations along Warri-Sapele road that were registered at a dangerous fatal speed that could lead to fatal accidents which were transmitted by the three service providers of AIRTEL, GLO, and MTN networks. In addition, a total of thirteen (13) severe speeds that could lead to severe accidents were also recorded that were transmitted by the three networks while a total of eight (8) mild speeds that could lead to mild accidents were recorded that were transmitted by two service providers of AIRTEL and MTN networks.

Furthermore, observations also showed that the AIRTEL service provider had the strongest signal strength along the road, compared to MTN and GLO as it was able to transmit a total of sixteen (16) various speeds compared to MTN which was six (6) and GLO that was two (2).

The distances at various locations from Warri to Sapele with their respective vehicular speeds are shown in Fig. 6. The simulated result reported that at a location that conformed to 8km, the vehicle was running at least a speed of 50km/h while at a distance of 33km, the vehicle was running at the highest speed of 350km/h. The vehicle's average speed, therefore, is 200km/h.

5. Conclusion

Simulative analysis of vehicular speed at defined locations was successfully realized for the Warri-Sapele road as a case study. Various speed levels at different locations were simulated on Math Lab 19 environment to be applied in the design of an automated speed-detecting and alerting device.

The application of this work in design is an enhancement to the manual method of informing vehicle owners of drivers over-speeding to avoid the possible accident was realized. The results obtained from the simulated model were successful for various locations and speeds. The present manual method of informing vehicle owners about dangerous speeds was unsatisfactory and had led to the loss of many lives in Nigeria due to accidents that would have been avoided.

Table 4: Simulated result

Speed (km/h)	Nature of speed 'N'	Name of location	Distance from Warri (km)	Highest signal strength
242	Fatal speed	NTA sapele	32.1820	AIRTEL
198	Severe speed	Okuotoma Junction	19.2250	AIRTEL
82	Mild speed	Between Okuotoma / Elume	20.7160	AIRTEL
187	Severe speed	Between Okuotoma / Elume	21.0080	AIRTEL
212	Severe speed	Ikwewu Sapele	28.7330	MTN
312	Fatal speed	Ibada-Elume	23.7230	AIRTEL
57	Mild speed	Between Okuotoma / Elume	20.3840	AIRTEL
248	Fatal speed	Between Elume / Ikwewu-Sapele	27.4040	AIRTEL
96	Severe speed	Rure Oil and Gas Otomewo	7.8760	AIRTEL
208	Severe speed	Elume Junction	21.9150	AIRTEL
323	Fatal speed	Sapele Bridge	33.7230	MTN
298	Fatal speed	Kolanut Garden Effurun	3.6740	MTN
211	Severe speed	Lym Co Consult Otomewo	9.4010	AIRTEL
307	Fatal speed	Dums Petrol Station	30.7650	AIRTEL
233	Severe speed	Between Okwovo / NIFEST City	12.5660	MTN
199	Severe speed	Between Otomewo/Okuovo	10.0390	AIRTEL
222	Severe speed	Army Check Point Effurun	3.0650	AIRTEL
91	Mild speed	Adeje Junction	16.8490	AIRTEL
188	Severe speed	Ohorho Junction	5.6950	GLO
86	Mild speed	Kolanut Garden Effurun	3.9860	MTN
94	Mild speed	Rure Oil and Gas Otomewo	7.8760	AIRTEL
285	Fatal speed	Adeje Junction	15.9290	AIRTEL
216	Severe speed	Egbinaka Community	76.2280	AIRTEL
316	Fatal speed	Ohorho Junction	5.6950	GLO
333	Fatal speed	Between Elume / Ikwewu-Sapele	26.7320	AIRTEL
203	Severe speed	Between RoundAbout / Motor Park	1.6880	AIRTEL
69	Mild speed	Jakpa Mereje Junction	15.3410	AIRTEL
77	Mild speed	Sapele Bridge	34.2480	MTN
174	Severe speed	Between Ugono/Ohorho	5.1880	GLO
252	Fatal speed	Between Elume / Ikwewu-Sapele	24.6270	AIRTEL
75	Mild speed	Adeje Junction	16.5460	AIRTEL
347	Fatal speed	Army Check Point Effurun	3.0650	AIRTEL
299	Fatal speed	Okwobude Town	17.4430	MTN
177	Severe speed	The Apostlic Church Opuraja	14.4670	AIRTEL
284	Fatal speed	Okwobude Town	17.7380	AIRTEL
307	Fatal speed	Sapele Bridge	35.1850	MTN
322	Fatal speed	Ibada-Elume	23.0930	AIRTEL
73	Mild speed	Jakpa Mereje Junction	15.0680	AIRTEL

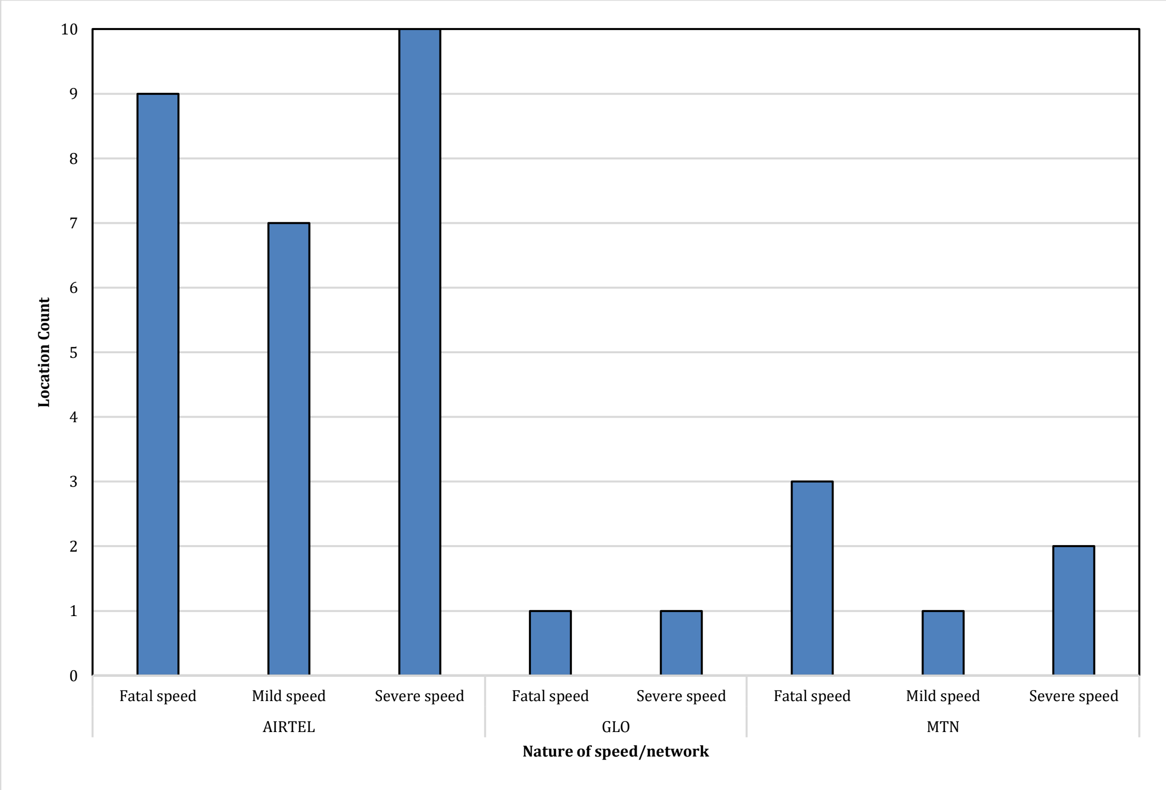

Fig. 5: Location count versus nature of speed and mode of transmission

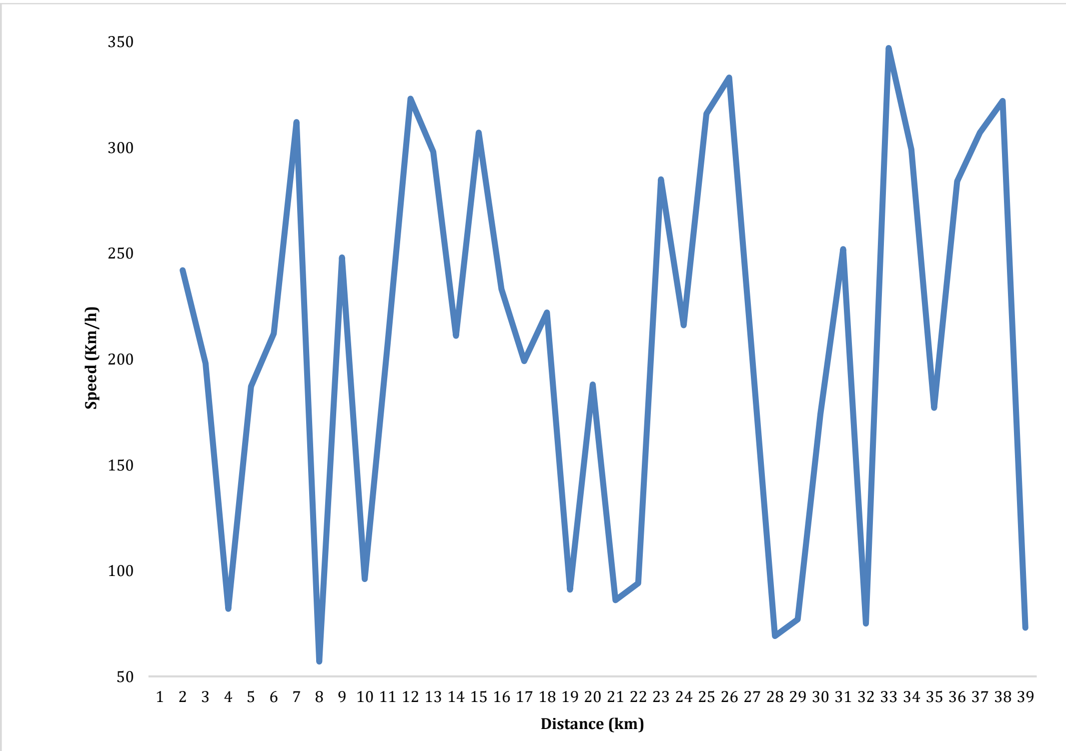

Fig. 6: Locations versus nature of speed along Warri-Sapele road

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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