



DEVELOPMENT OF AXLE LOAD SPECTRA FOR INTEGRATION IN TRAFFIC CHARACTERIZATION FOR NIGERIAN EMPIRICAL MECHANISTIC PAVEMENT ANALYSIS AND DESIGN SYSTEMS

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Design traffic is employed in this research to estimate the expected load repetitions for a given axle load spectrum during the pavement life. In changing traffic characterization in mechanistic-empirical (M-E) design procedure, the process does away with the equivalent single axle load (ESAL) concept and traffic analysis implementation was done by directly using axle load. Comparison of predicted Number of Axle load range repetitions determined by equivalent axle load factor (EALF) and general axle load equivalency factors (GAF), is the main objective. In this study, axle load spectrum by Weigh-In-Motion (WIM) data and parametric standard axle loads which cause equal damage were collected and utilized. Determination of the axle load distribution factor (ALDF) from the WIM data. It is a critical input in the method based on different axle load groups for the estimation of the predicted number of axle load repetitions during the pavement design period. The results that the marked difference on the estimated predicted axle load predictions with the determination of EALF and GAF 63.95% of GAF value for SAST. Similarly, 10.14% for SADT; 30.24% for TADT and 21.43% for TRDT. This indicates the inherited error in the empiricism content in the empirical approach of handling traffic, for the determination of EALF. The estimated traffic prediction value increases as the captured axle load magnitude increased, as a resultant of the type of commodities and goods carried on the roadway pavement.

1.0 Introduction

The characterization of traffic is one of the significant elements in the analysis and design of pavements (flexible, rigid, and composite), (Buch *et al.*, (2009), Timm and Newcomb (2002) observed that the primary change in traffic analysis when using mechanistic -empirical (M-E) design is the elimination of the load equivalency factors and calculation of equivalent single axle load (ESALs), and determines the expected number of repetitions of each load during the pavement life directly using axle load spectra. In this approach, the anticipated truck traffic is classified by axle type (steering, single, tandem, and tridem), and within each axle type, the distribution of axle weights is calculated. This is a more precise characterization of truck traffic loads, and it allows for more detailed and nuanced damaged investigations (Salama and Chatti, 2011). Pavement engineering calculations using axle load spectra are generally more complex than those using ESALs or Traffic Index (TI) because loading cannot be reduced to one equivalent number. However, the load spectra approach of quantifying traffic loads offers a more practical and realistic representation of traffic loading than using TI or ESALs (Highway Design Manual, 2012).

The load input to (M-E) methods in changing of traffic characterization is in terms of axle load distributions (i.e., load spectra) by axle configuration. This approach is a significant improvement over the aggregate ESAL-based method described previously, because it allows a

mechanistic pavement design approach. (Papagianakis and Massad, 2008). Axle load distribution factors (ALDF) represent the percentage of the total number of truck axle repetitions within each load interval (which varies with axle type) for each axle type. ALDF constitute a major change from the current 1993 AASHTO pavement design guide that requires only the total number of 18-kip ESALs as input (Kim et al., 2011)

In characterizing effects of applied loads of mixed-traffic stream, the combined loading effects of different axle types in the design traffic must be considered when designing a pavement. There are two common approaches by which the combined effects are evaluated: one based on the hypothesis of cumulative damage, and the other by the method of equivalent load. Under the hypothesis of cumulative damage, where the design repetitions of load for each axle type is a critical input whereby the total amount of damage caused by the mixed traffic is computed as the sum of damage ratios of all load types. (Oguara, 2004, Fwa et al., 2006; Huang, 2007; and Timm and Newcomb, 2002)

Method based on different axle load groups in traffic analysis is when the design is based on a number of axle load groups, as characterized by the ALDF, whereby, the predicted number of repetitions for each axle load group during the design period is determined. The procedure for predicting the predicted number of repetitions for each axle load group during the design period is similar to the method based on ESAL, except that each load group is considered separately. The initial repetitions of each axle type, growth factor, directed distribution factor (DDF), and lane distribution factor (LDF) are determined. These are critical variables required for the computation of repetitions of each axle type for a period of 20 years for a flexible pavement.

Nigerian Empirical Mechanistic Pavement Analysis and Design System is a framework for Mechanistic- Empirical Pavement Design for tropical climate developed by Olowosulu, (2005). Two major components in NEMPADS that required to be refine, that were (1) traffic data are required in the M-E pavement design procedure. It is expressed in terms of 8, 200 kg (80 kN) equivalent single axle loads (ESALs) and secondly, simplified procedure for prediction of pavement response in the prediction pavement performance. The focus on changes in traffic characterization is the main interest in this research study, for transition from using equivalency factors to determine the number of equivalent single axle loads (ESALs) to a push toward using load spectra in NEMPADS.

Report I-26 recommended that traffic should be divided into a number of load groups, each with different load magnitudes and configurations and different numbers of load repetitions (Huang, 2007).

The main objective of this study is to compare the estimated number of repetitions of each axle load range for each axle type during the pavement life using EALF determined from the empirically based approach and determined GAF from the (M-E) methods, respectively, and then to recommend the most accurate and reliable estimated predicted number of load repetitions This is achieving with following objectives: (1) Determination of axle load damage factor with the same traffic composition with either of these pavement design approaches: Computation of EALF based on empirical based method and GAF based on (M-E) method. (2) Estimation of the expected number of repetitions of each axle load range during the pavement life by either utilizing EALF or GAF.

The scope of this study, includes the (1) the collection of traffic information that includes the axle load spectrum by portable WIM data and loading on the axle configurations considered in this study, that cause the same amount of damage at the standard axle. The determination of ALDF is from the analysis of the traffic data. Traffic analysis using the method based on different axle load groups technique has been used to estimate the predicted number of load repetitions.

Axle load damage factors were computed on the basis of the pavement design approach. EALF was computed on the basis of handling traffic on empirically based approach and GAF was computed on the basis of handling traffic in (M-E) methods. Both axle load damage factors were the critical tools with the ALDF were the determined traffic inputs utilized to estimate the predicted number of load repetitions within the two considered approaches respectively, and then compared with each other.

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2. Materials and Methods.

To determine the number of load repetitions of each axle type for a period of 20 years on a flexible pavement, the required transport information and the analysis of the traffic data are utilized in the following considerations:

2.1 Input Data Characterization and Axle Load Spectra

This includes truck traffic load data; axle configuration and equivalencies; ALS records; analysis of ALS data of the independent axle load surveys; and **truck** traffic information.

2.1.1 Truck Traffic Load Data

Truck traffic information is used for estimating pavement loading known as Axle Load Spectra, incorporated into the (ME) design procedure. This information involves the independent axle load surveys and loads on the axle configurations that cause the same amount of damage as the standard axle

2.1.2 Axle Configuration and Equivalencies

The damage due to different axle groups is dependent on the axle spacing, the number of types per axle, the load on the group and the suspension. For design purposes, it is generally appropriate to consider axle groups in terms of the following four types:

- Single axle with single wheels; (SAST);
- Single wheels single axle with dual wheels; (SADT);
- Tandem axles both with dual wheels; (TADT);
- Tridem axles all with dual wheels; (TRDT).

Table 1: Axle Loads which cause Equal Damage

Axle Configuration	SAST	SADT	TADT	TRDT
Load (kN)	53	80	135	181

Source: Road Design Part 2- Pavement, CAMPWO3-102-99; Austroads (2004b) and 2012

The standard axle is defined as a defined as a single axle with dual wheels that carries a load of 8.2 tonnes (80kN). Loads on the axle configurations given above that cause the same amount of damage as the standard axle are given in Table 1.

2.1.3 ALS records

According to Ahmed and Erlingsson, (2015), ALS is one of the key inputs for M-E design of pavement structures (Lu and Harvey 2006). Swan et al. (2008) have also indicated that the ALS was one of the most significant factors in the M-E pavement design. In this paper, the axle loads and configurations from WIM instruments are usually presented in the form of the ALS or frequency distribution of the axle load groups of a given axle configuration. Therefore, raw WIM data must be analyzed to produce the ALS. This traffic data was captured by a portable weigh-in-motion (WIM) System on Kaduna - Zaria Roadway with the following details: (i) Number of axles; (ii) Gross Vehicle Mass (GVM); and (iii) Individual axle weights, recorded in "tons". The data are grouped into different axle loads for each axle configuration (steering, single, tandem, tridem and quad). Usually, the axle load interval or bin width of 10 kN is used to group the axle loads for SAST and SADT; bin width of 20kN for TADT and bin width of 30kN for TRDT. The frequency for each load group is then calculated to derive the ALS.

2.1.4 Analysis of ALS data of the independent axle load surveys

The independent axle load surveys have become the main source of up-to-date vehicle weight data, as there have no recent data on weighbridge operations is available. The WIM Data contains Vehicle Classification and axle group load data. Traffic survey conducted as secondary data by (Stewart Scott International, 2007) on Kaduna - Zaria Northbound and Zaria - Kaduna Southbound. ALS data captured on the Kaduna -Zaria Roadway was used for the study. Measurements were made on the Northbound Axis (Kaduna-Zaria) on 5th March, during the 9.am and 3.00PM (About 6hrs) and similar exercise was conducted on the Southbound Axis (Zaria-Kaduna) on 6th of March, 2007. The ALS for the Roadway have been developed which provide the load distribution of steering axles, other single axles, tandem axles and tridem representative ALS for the roadway. The ALS for the sites has been developed which provide the load distribution of steering axles, other single axles, tandem axles and tridem axles (Awosanya et al., 2021). ALS data from the independent axle load surveys was used for the study.

2.1.5 Truck Traffic Information

Truck traffic information adopted from the secondary data of the work of S.S.I (2007) includes:

Results of Independent Axle Load Surveys for Kaduna-Zaria Roadway

Traffic Volume: ADT (2006) = 11,000; Percent Truck =8%: ADT (1983) =7402

Defaults = DDF = (1.0); LDF (0.5); Design Period=20yrs

2.2 Methods

2.2.1 Axle Load Information from the truck traffic information.

Axle load information includes axle configurations, average number of axles per truck, and axle load distribution factors.

2.2.1.1 Axle Configuration

Axle configuration is defined by the number of axles sharing the same suspension system and the number of tires in each axle. Multiple axles involve two, three, or four axles spaced 1.2 to 2.0 meters apart, and are referred to as tandem, triple, or quad, respectively. They are treated differently from single axles because they impose pavement stresses/strains that overlap (Papagiannakis and Massad, 2008).

2.2.1.2 Average number of axles per truck

This input represents the average number of axles for each truck class (classes 5 to 13) for each axle type (steering, single, tandem, and tridem). M-E procedure allows for dividing the single axle category into steering single axle (Single tire) and other single axle (dual tires). A is the average number of axles per truck, is the ratio between the cumulative number of all the axles from the total weighed trucks and the cumulative vehicle weighed on the roadway, which is computed for each of the axis on the roadway. This variable is as presented in Equation 1.

$$A = \frac{\text{Total number of all the normalized axle number from the measured data}}{\text{Total number of all the trucks weighed by the W.I.M}} \quad (1)$$

2.2.1.3 Axle Load Distribution Factors

The axle load distribution factors (ALDF) simply represent the percentage of the total axle applications within each load interval for a specific axle type (steering, single, tandem, and tridem) and vehicle class (Classes 5 through 13). A definition of load intervals for each axle type is provided below: Single (steering Single or other single) – 0-250KN, at 10KN intervals; Tandem – 0 to 500KN at 20KN intervals; Tridem -0 to 750 KN at 30KN intervals. The percentage (decimal) of axles for each axle load group (The frequency of axle load ranges determined in the ALDF), is defined by:

$$P_i = \frac{\text{Number of axles in load range}}{\text{Total no.of axles in load range of the bound axis of each roadway.}} \quad (2)$$

ALDF constitute a major change from the current 1993 AASHTO pavement design guide that requires only the total number of 18-Kip ESALs as input.

2.2.1.4 Traffic Growth Factors

ADT growth rate was predicted by using the statistically based growth models built on historical trends, whereby, conversion to Linear or Exponential Annual Growth Rates was employed in which the current process uses one growth rate (ADT growth rate) for all truck classes, was determined using Equation 3.

$$r = \left(\frac{T_f}{T_o}\right)^{\frac{1}{Y_f - Y_o}} - 1 \quad (3)$$

where: Y_o is the base year, Y_f is the future year, T_o and T_f are the corresponding estimates of ADT, and r is the estimated exponential growth rate (NCHRP 538, 2005)

Traffic growth factors are the yearly growth rates for each truck class. The growth function can be either linear growth or compound growth. G is the growth factor: One simple way to project the growth factor is to assume a yearly rate of traffic growth and use the average traffic at the start and end of the design period as the design traffic:

$$G = \frac{1}{2} [1 + (1 + r)^Y] \quad (4)$$

In which r is the growth rate (decimal) per year (Huang, 2007)

2.3 Axle Load Damage Quantification Factors

The key parameter needed in the comparison of the predicted of repetitions for each axle load group depends mainly on how the traffic is being handled. In handling the traffic by the empirically based methods, the equivalent axle load factor (EALF) for each axle load group is being determined by the AASHTO ESAL equation. However, handling the traffic by the M-E methods, it is useful to define a companion summary measure-a general axle load equivalency factor (GAF) is being employed. The key link in this comparison is that the same developed Axle load distribution factor (ALDF) is being utilized in both computations, between the empirical methods and M-E methods. The two detail descriptions are presented below:

2.3.1 Determination of Equivalent Axle Load Factor (EALF)

In handling of traffic in empirically based methods, the method of analysis was based on the AASHTO Equivalency Factors in which the AASHTO equations for computing Equivalent Axle Load Factor (EALF) for each of the generated axle load ranges for each axle type as contained

$$\text{Log} \left(\frac{W_{tx}}{W_{t18}} \right) = 4.79 \log (18+1) - 4.79 + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}}$$

in the developed axle load distribution factor required in M-E design procedure. The following regression equations based on the results of road tests can be used for determining EALF:

$$\beta_{18} = \log \left(\frac{4.2 - P_t}{4.2 - 1.5} \right) ; \quad \beta_x = 0.4 + \frac{0.082(L_x + L_2)^{3.23}}{(SN+1)^{5.19} (L_2)^{3.23}} \quad (5)$$

Where, W_{tx} = the number of x-axle load application at the end of time t; W_{t18} = the number of 18kip (80KN) single axle load application to time t; ; L_x = the load in kip on one single axle, one set of tandem axles, or one set of tridem axles; ; L_2 is the axle code = 0 for steering axle; 1 for single axles, 2 for tandem axles, and 3 for tridem axles (Huang, 2007).; SN = structural number - a function of thickness, modulus of each layer, and drainage condition of base and sub-base.; P_t = terminal serviceability – which indicates the pavement conditions to be considered as failures, β_{18} = the value of β_x when $L_x = 18$ and $L_2 = 1$, Hence,

$$EALF = \frac{W_{t18}}{W_{tx}} \quad (6)$$

Practically, EALF is not very sensitive to pavement thickness and SN equal to 5 may be used for most cases and a P_t value of 2.5 can be used (AASHTO, 1986, 1993 and Huang 2007).

2.3.2 Determination of General Axle Equivalency Factor (GAF)

In handling of traffic in M-E methods, the method of analysis was based on the practical comparison of axle load spectra, through which statistical measures are needed that are related to the concept of pavement damage and are independent of pavement –related variables. General axle load equivalency factors (Dahlin 1994; AASHTO 1993) can fulfil this need. The

$$GAF = \left(\frac{W}{18,000} \right)^{3.8} = \left(\frac{L_i}{SL_i} \right)^{3.8} \quad (7)$$

(GAF) are defined as:

$W = L_i$ = Axle load of any type or spacing in pounds (or converted to kN) = Load

L_i = carried by axle group type i (KN), from the ALDF.: SL_i = Standard load for axle group type, that has a similar unity damage for each axle type: -Single axle with single tires: $SL = 53KN$; -Single axle with dual tires: $SL = 80KN = 18,000Pounds$; -Tandem group with dual tires: $SL = 135KN$; -Tridem group with dual tires: $SL = 181KN$.

Any changes in GAFs can be attributed directly to changes in traffic loads that is the focus of this study for the purpose of improving the pavement performance to be determined by NEMPADS (Hajek et al., 2000, Austroads 2004b and 2012; Moffatt et al., 2014).

2.4 Determination of the predicted number of load repetitions.

The considered method in this thesis for estimating pavement loading known as Axle Load Spectra for use with the Mechanistic-Empirical (ME) design procedure, whereby method based on different axle load groups is being employed. The procedure for predicting the predicted number of load repetitions for each axle load (for each axle load range) during the design life, is similar to the method based on ESAL, except that each load group is considered separately. Timm and Newcomb, (2002) studied the primary difference between how traffic is handled in empirically based methods versus Mechanistic-Empirical (M-E) Methods.

In estimating anticipated traffic loading, whereby, the design is based on the axle load spectra, then the initial number of repetitions per day for the i th load group can be computed from

$$(n_o)_i = (P_i F_i) (ADT)_o (T) (A) \quad (8)$$

in which P_i is the percentage (decimal) of axles in the i th load group (The frequency of axle load ranges determined in the ALDF), determined according to equation 2 above.

The predicted number of load repetitions n_i for load group i during the design period is

$$n_i = 365 (n_o)_i (G) (D) (L) (Y) \quad (9)$$

in which $(n_o)_i$ is the initial number of repetitions per day for the i th load group, determined above in Equation 8, G is the growth factor, D is the directional distribution factor, which is usually assumed to be 0.5 unless the traffic in two directions is different, L is the lane distribution factor which varies with the volume of traffic and the number of lanes, and Y is the design period in years.

2.4.1 Predicted number of repetitions in empirically based approach.

In handling traffic in empirically based approach, EALF was used as a key axle damage factor parameter in calculating the predicted number of repetitions for the empirical approach, using Equations 8 and 9.

2.4.2 Predicted number of repetitions in mechanistically–empirical methods.

In handling traffic in M-E methods, GAF is used as a key axle damage factor variable in calculating the predicted number of repetitions for the empirical approach, using Equations 8 and 9. In these methods, empiricism was being eliminated.

2.4.3 Comparison of Predicted Number of Axle Repetitions Determined by EALF and GAF.

A comparison between handling traffic in an empirically based methods and the M-E methods can best be illustrated by the same traffic composition and the method based on different axle load groups, with a marked difference of the axle load damage factor computed for each of the same determined axle load ranges in the ALDF.

In this study, there is a need to compare the value of the predicted number of repetitions of each axle load group during the design period, using empirical and Mechanistic-Empirical methods. In handling traffic in empirically based approach, EALF was used as a key axle damage factor parameter in calculating the predicted number of repetitions for the empirical approach. In handling traffic in M-E methods, GAF is used as a key axle damage factor variable in calculating the predicted number of repetitions for the (M-E) methods This indicate the impact of empiricism content in the traffic projection in the axle applications and its effect on the elimination of empiricism content in the traffic projection in the axle applications.

3. Results and Discussion

Traffic elastic analysis is performed using the method based on different axle load groups. the different variables discussed in the previous section are considered. the investigation of the resulting estimate of predicted number of load repetitions by making comparison its value on the basis of the determination of EALF and GAF. the following sections discuss the outcomes of these results

3.1 Average number of axles per truck

Average number of axles on each of the axis of the roadway as calculated according to Equation 1, are presented in Table 2. From the analysis of results, obtained axle configuration from the surveyed truck configurations on the Kaduna-Zaria roadway. The average number of axles on the southbound axis (Zaria to Kaduna) was 2.66, and on the northbound axis (Kaduna to Zaria) it was 2.71. The results showed that the truck magnitude and the captured countered axles on the northbound axis are greater in number than the weighed truck number on the southbound axis.

Table 2: Average number of axles per truck for Kaduna-Zaria Roadway

Kaduna-Zaria Roadway Axle Configurations	Southbound Axis (SB) No of Axles counted for each BIN	Northbound Axis (NB) No of Axles counted for each BIN
SAST	86	99
SADT	68	76
TADT	75	90
TRDT	0	3
Total number of axles counted for each BIN	229	268
Total number of trucks counted	86	99
Average number of axles per truck	$229/86= 2.66$	$268/99= 2.71$

3.2 Axle Load Distribution Factor (ALDF)

Axle Load Distribution Factor (ALDF) as calculated according to Equation 2, are presented in Table 3. From the analysis of the results, the cumulative for each of the axle type, of the calculated frequencies is 100%. The frequencies of axle ranges is presented in Table 3, with the corresponding axle load ranges for each of the axle configurations. The captured axle load data on the Kaduna-Zaria roadway. It indicates generally that the captured surveyed and weight of the axles on the northbound (NB) axis are greater in magnitude than the weighted axle in the southbound (SB) axis. The reason behind the differentials was that construction and industrial commodities were carried on the NB axis, whereby, in the SBaxis, agricultural products were carried. The number of axles counted for each BIN has the greatest magnitude of axle load magnitude in the NBaxis are higher for SAST, TADT, and SADT respectively, than in the SB axis. For TRDT, not captured on the SBaxis, but very scanty on the NB axis, and the sample space is very minimum.

3.3 Growth Factor and Annual growth rate.

The ADT growth rate was calculated according to Equation 3, and the growth factor was calculated according to Equation 4, and are both presented in Table 4. From the analysis of results, obtained traffic volumes ADT values for the year 1983 and 2006, for the Kaduna-Zaria roadway. In percentage terms, the resulting exponential growth rate is 1.74 percent. The use of the obtained growth rate resulted in the growth factor that is 1.21%. The determined growth factor and growth rate were not both affected by the content of empiricism and therefore, had the same impact of the predicted number of axle load repetitions and pavement performance as implemented by Timm and Newcomb (2002).

3.4 Computation of Equivalent Axle Load Factor (EALF)

The regression equations based on the results of road tests is used for the determination of EALF for the four different axle types observed on the Kaduna-Zaria roadway. The axle load intervals are determined for each axle types from the result of the secondary data captured on the Kaduna-Zaria Roadway from the work of S.S.I (2007). The determined EALF from the same traffic composition for the four different axle types is presented in Table 5.

3.5 Computation of GAF.

General axle load equivalency factors (GAF) is computed from the same traffic composition using the statistical measures that are needed to the concept of pavement damage and are independent of pavement -related variables. The determined GAF is presented for the Kaduna-Zaria roadways in Table 6, for the four different axle types on the considered roadway.

Table 3: Results of the calculated axle load distribution factor (ALDF) for the four different axle configurations

Single Axle with Single Tire (SAST)						Single Axle with Dual Tires (SADT)					
Southbound Axis (Sb) Axis			Northbound Axis (Nb) Axis			Southbound Axis (Sb) Axis			Northbound Axis (Nb) Axis		
S/N	BIN	Count (No of Axles Counted for Each Bin) for Southbound Axis	Percentage of Occurrence (Frequency) %for Sb-Axis	Count (No of Axles Counted for Each Bin) for Northbound Axis	Percentage of Occurrence (Frequency) % for Nb-Axis	S/N	Bin	Count (No of Axles Counted for Each Bin) for Southbound Axis	Percentage of Occurrence (Frequency) % for Sb-Axis	Count (No of Axles Counted for Each Bin) for Northbound Axis	Percentage of Occurrence (Frequency) %for Nb-Axis
1	0	0	0	0	0	1	0	0	0	0	0
2	10	2	2.33	4	4.04	2	10	1	1.47	1	1.32
3	20	3	3.49	3	3.03	3	20	1	1.47	2	2.63
4	30	9	10.47	8	8.08	4	30	8	11.76	6	7.89
5	40	16	18.60	9	9.09	5	40	31	45.59	6	7.89
6	50	39	45.35	18	18.18	6	50	10	14.71	5	6.58
7	60	3	3.49	32	32.32	7	60	2	2.94	0	0
8	70	8	9.30	15	15.15	8	70	1	1.47	2	2.63
9	80	1	1.16	5	5.05	9	80	5	7.35	1	1.32
10	90	0	0	2	2.02	10	90	1	1.47	4	5.26
11	100	2	2.33	0	0	11	100	2	2.94	6	7.89
12	110	2	2.33	2	2.02	12	110	1	1.47	6	7.89
13	120	1	1.16	1	1.01	13	120	1	1.47	11	14.47
14	130	0	0	0	0	14	130	2	2.94	9	11.84
15	140	0	0	0	0	15	140	1	1.47	2	2.63
16	150	0	0	0	0	16	150	0	0	3	3.95
17	160	0	0	0	0	17	160	0	0	5	6.58
18	170	0	0	0	0	18	170	1	1.47	1	1.32
19	180	0	0	0	0	19	180	0	0	1	1.32
20	190	0	0	0	0	20	190	0	0	1	1.32
21	200	0	0	0	0	21	200	0	0	3	3.95
22	210	0	0	0	0	22	210	0	0	1	1.32
23	220	0	0	0	0	23	220	0	0	0	0
24	230	0	0	0	0	24	230	0	0	0	0
25	240	0	0	0	0	25	240	0	0	0	0
26	250	0	0	0	0	26	250	0	0	0	0
Total		86	100.00	99	100.00	Total		68	100.00	76	100.00
Number of Axles Counted						Number of Axles Count					

TABLE 3 CONT'D: Results of the calculated axle load distribution factor (ALDF) for the four different axle configurations

Tandem Axle with Dual Tire (TADT)				Tridem Axle with Dual Tires (TDT)							
		Southbound Axis (Sb) Axis		Northbound Axis (Nb) Axis				Southbound Axis (Sb) Axis		Northbound Axis (Nb) Axis	
S/N	BIN	Count (No of Axles Counted for Each Bin) for Southbound Axis	Percentage of Occurrence (Frequency) % for Sb-Axis	Count (No of Axles Counted for Each Bin) for Northbound Axis	Percentage of Occurrence (Frequency) % for Nb-Axis	S/N	Bin	Count (No of Axles Counted for Each Bin) for Southbound Axis	Percentage of Occurrence (Frequency) % for Sb-Axis	Count (No of Axles Counted for Each Bin) For Northbound Axis	Percentage of Occurrence (Frequency) % for Nb-Axis
1	0	0	0	1	1.11	1	0	0	0	0	0
2	20	4	5.33	1	1.11	2	30	0	0	0	0
3	40	11	14.67	3	3.33	3	60	0	0	0	0
4	60	31	41.33	6	6.67	4	90	0	0	0	0
5	80	13	17.33	4	4.44	5	120	0	0	0	0
6	100	2	2.67	6	6.67	6	150	0	0	0	0
7	120	2	2.67	4	4.44	7	180	0	0	0	0
8	140	1	1.33	2	2.22	8	210	0	0	0	0
9	160	0	0	7	7.78	9	240	0	0	0	0
10	180	0	0	8	8.89	10	270	0	0	2	66.67
11	200	3	4.00	8	8.89	11	300	0	0	0	0
12	220	2	2.67	15	16.67	12	330	0	0	0	0
13	240	2	2.67	11	12.22	13	360	0	0	0	0
14	260	0	0	1	1.11	14	390	0	0	1	33.33
15	280	0	0	6	6.67	15	420	0	0	0	0
16	300	2	2.67	3	3.33	16	450	0	0	0	0
17	320	1	1.33	1	1.11	17	480	0	0	0	0
18	340	1	1.33	1	1.11	18	510	0	0	0	0
19	360	0	0	0	0	19	540	0	0	0	0
20	380	0	0	2	2.22	20	570	0	0	0	0
21	400	0	0	0	0	21	600	0	0	0	0
22	420	0	0	0	0	22	630	0	0	0	0
23	440	0	0	0	0	23	660	0	0	0	0
24	460	0	0	0	0	24	690	0	0	0	0
25	480	0	0	0	0	25	720	0	0	0	0
26	500	0	0	0	0	26	750	0	0	0	0
Total		75	100.00	90	100.00	Total		0	0	3	100.00
Number of Axles Counted						Number of Axles Count					

Table 4: Traffic Growth Factors

Future ADT	Future Year
11,000.00	2006
Base ADT	Base Year
7402	1983
Growth rate (r) %	1.74%
Equation 3 Utilized	
Design Period	20Years
Growth Factor (G)	1.21%
Equation 4 Utilized	

Table 5: Results of the Determined EALF for each axle load range of the axle load spectrum.

S/N	Axle Load Range for SAST (kN)	EALF For SAST	Axle Load Range for SADT (kN)	EALF For SADT	Axle Load Range for TADT (kN)	EALF For TADT	Axle Load Range for TRDT (kN)	EALF For TRDT
1	0	0.0000	0	0.0000	0	0	0	0.0000
2	10	0.0001	10	0.0003	20	0.0004	30	0.0004
3	20	0.0013	20	0.0033	40	0.0045	60	0.0054
4	30	0.0089	30	0.0169	60	0.0233	90	0.0271
5	40	0.0352	40	0.0562	80	0.0773	120	0.0865
6	50	0.1024	50	0.1441	100	0.1983	150	0.2096
7	60	0.2452	60	0.3095	120	0.4258	180	0.4217
8	70	0.5132	70	0.5843	140	0.8037	210	0.7478
9	80	0.9728	80	1.000	160	1.3755	240	1.2177
10	90	1.7102	90	1.5871	180	2.1832	270	1.8722
11	100	2.8329	100	2.3764	200	3.2689	300	2.7668
12	110	4.4720	110	3.4024	220	4.6801	330	3.9723
13	120	6.7843	120	4.7068	240	6.4744	360	5.5754
14	130	9.9545	130	6.3417	260	8.7232	390	7.6785
15	140	14.1965	140	8.3709	280	11.5145	420	10.4005
16	150	19.7563	150	10.8707	300	14.9531	450	13.8773
17	160	26.9131	160	13.9303	320	19.1618	480	18.2628
18	170	35.9815	170	17.6516	340	24.2905	510	23.7257
19	180	47.3134	180	22.1493	360	30.4673	540	30.4705
20	190	61.2998	190	27.1493	380	37.8983	570	38.6986
21	200	78.3723	200	33.9998	400	46.7682	600	48.6488
22	210	79.0055	210	41.6493	420	57.2904	630	60.5788
23	220	123.7182	220	50.6698	440	69.6985	660	74.7697
24	230	153.0754	230	61.2458	460	84.2462	690	91.5270
25	240	187.6899	240	73.5770	480	101.2082	720	111.1817
26	250	228.2242	250	87.8790	500	120.8813	750	134.0910

Table 6: Determination of the GAF for each load range of the Axle Load Spectrum

S'N	AXLE LOAD RANGE FOR SAST	GAF FOR SAST=(AXLE LOAD RANGE/ 53) ^3.8	AXLE LOAD RANGE FOR SADT	GAF FOR SADT=(AXLE LOAD RANGE/ 80)^3.8	AXLE LOAD RANGE FOR TADT	GAF FOR TADT=(AXLE LOAD RANGE/ 80) ^3.8	AXLE LOAD RANGE FOR TRDT	GAF FOR TRDT=(AXLE LOAD RANGE/ 80) ^3.8
1	0	-	0	-	0	-	0	-
2	10	0.0018	10	0.0004	20	0.0007	30	0.0011
3	20	0.0246	20	0.0052	40	0.0098	60	0.0151
4	30	0.1150	30	0.0241	60	0.0459	90	0.0703
5	40	0.3432	40	0.0718	80	0.1369	120	0.2098
6	50	0.8014	50	0.1676	100	0.3197	150	0.4897
7	60	1.6022	60	0.3351	120	0.6392	180	0.9792
8	70	2.8782	70	0.6020	140	1.1482	210	1.7590
9	80	4.7807	80	1.0000	160	1.9072	240	2.9216
10	90	7.4795	90	1.5645	180	2.9838	270	4.5709
11	100	11.1622	100	2.3348	200	4.4529	300	6.8215
12	110	16.0341	110	3.3539	220	6.3964	330	9.7988
13	120	22.3172	120	4.6682	240	8.9030	360	13.6386
14	130	30.2508	130	6.3277	260	12.0679	390	18.4870
15	140	40.0902	140	8.3858	280	15.9931	420	24.5001
16	150	52.1073	150	10.8995	300	20.7870	450	31.8441
17	160	66.5898	160	13.9288	320	26.5645	480	40.6947
18	170	83.8412	170	17.5373	340	33.4466	510	51.2375
19	180	104.1807	180	21.7918	360	41.5605	540	63.6675
20	190	127.9427	190	26.7622	380	51.0398	570	78.1890
21	200	155.4768	200	32.5216	400	62.0240	600	95.0159
22	210	187.1479	210	39.1464	420	74.6585	630	114.3709
23	220	223.3356	220	46.7158	440	89.0947	660	136.4861
24	230	264.4341	230	55.3126	460	105.4900	690	161.6025
25	240	310.8525	240	65.0221	480	124.0076	720	189.9699
26	250	363.0143	250	75.9329	500	144.8164	750	221.8473

3.6 Determination of the predicted number of load repetitions using EALF

Predicted number of axle repetitions utilizing EALF is determined by utilizing the EALF as a primary input using the same traffic composition for the four different axle types in Empirical approach with the empiricism contents not eliminated. This is presented between Figures 1 and Figures 4.

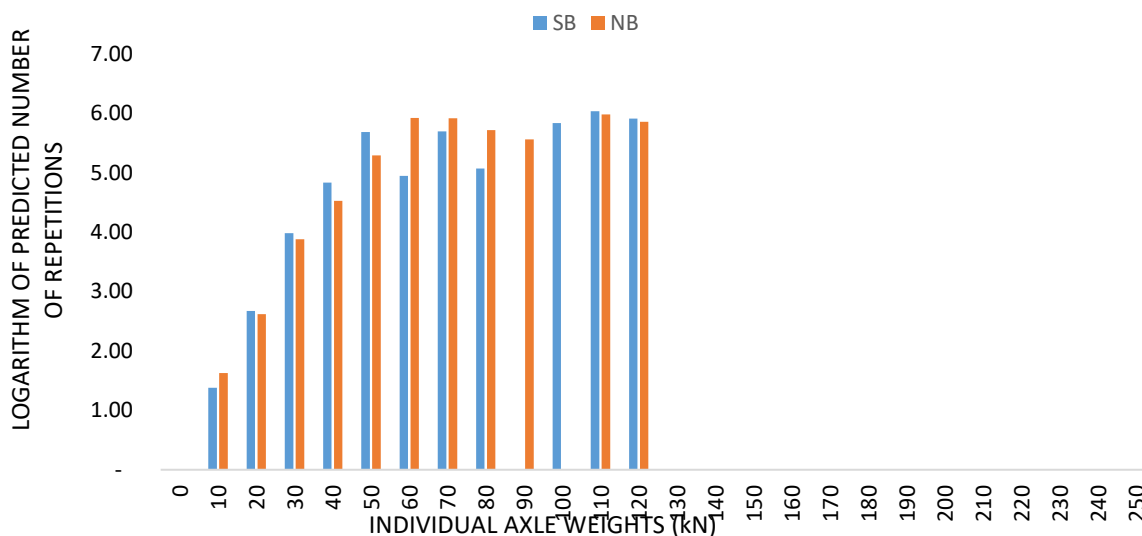


Figure 1: Predicted Number of Repetitions using EALF for Single Axle with Single Tire Loads during 20-year Design Period at Kaduna-Zaria Roadway

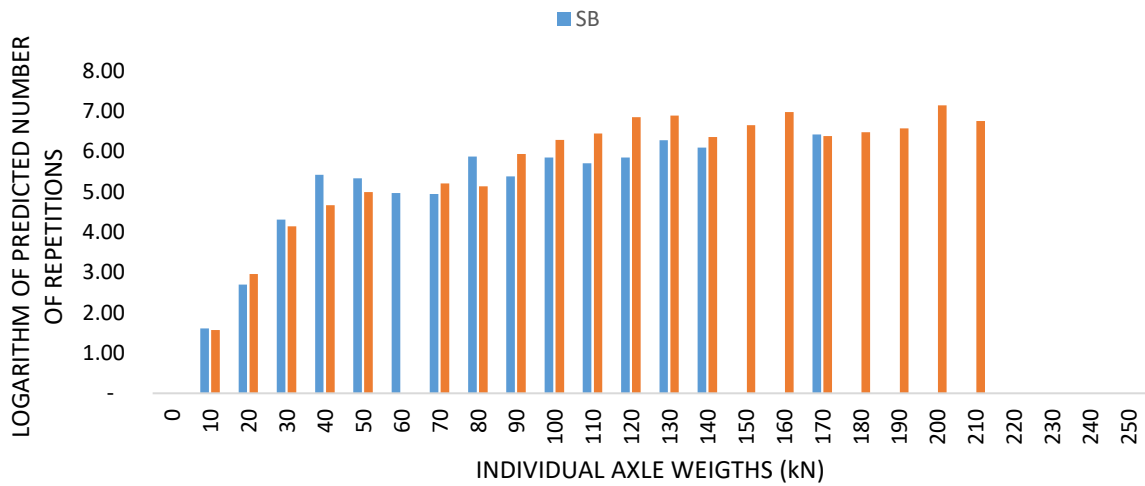


Figure 2: Predicted Number of Load Repetitions using EALF for Single Axle with Dual Tires Loads during 20year Design Period at Kaduna-Zaria Roadway.

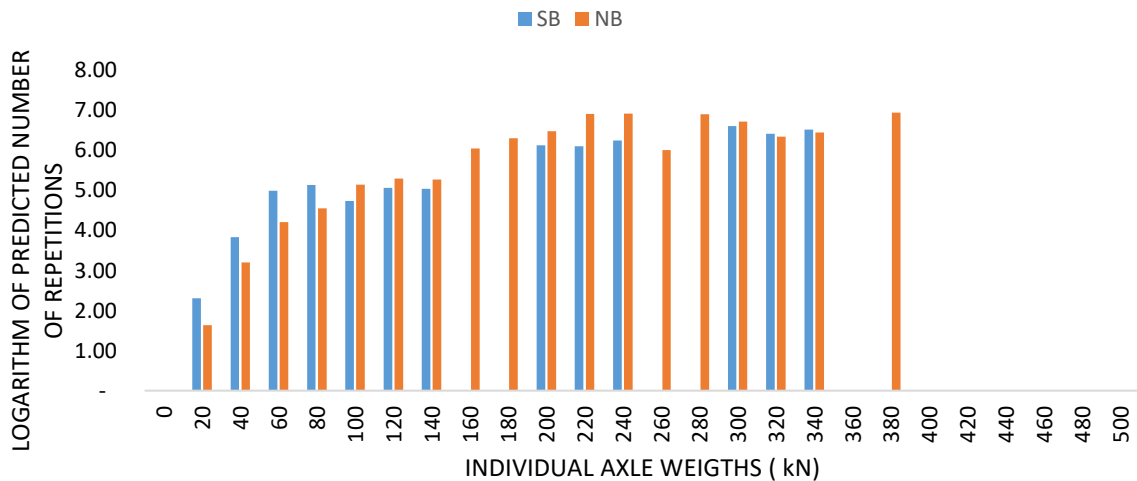


Figure 3: Predicted Number of Load Repetitions using EALF for Tandem Axle with Dual Tires Loads during 20-year Design Period at Kaduna -Zaria Roadway

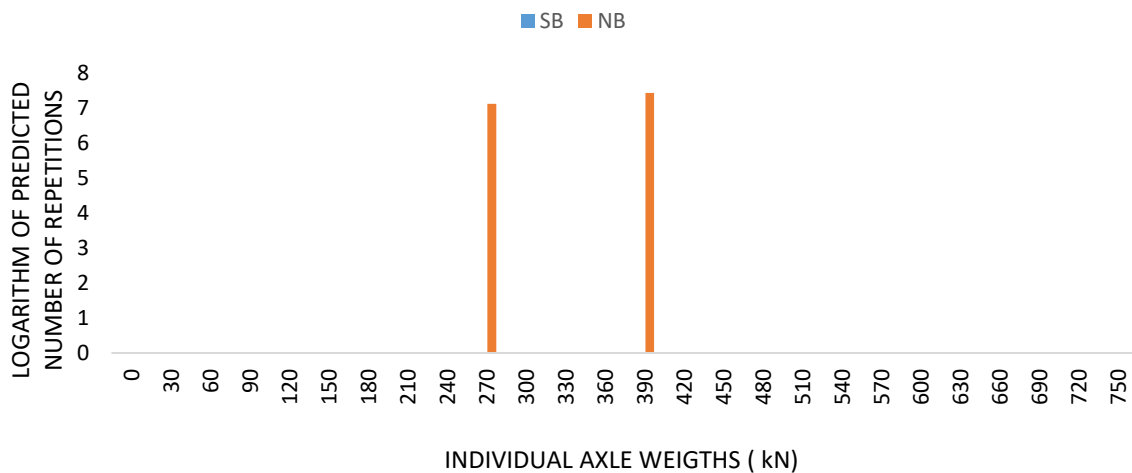


Figure 4: Predicted Number of Load Repetitions using EALF for Tridem Axle with Dual Tires Loads during 20-year Design Period at Kaduna-Zaria Roadway.

3.7 Determination of the predicted number of load repetitions using GAF

Predicted number of axle repetitions utilizing GAF is determined by utilizing the GAF as a primary input using the same traffic composition for the four different axle types in Mechanistic –Empirical Procedures without the empiricism contents that has been eliminated. This is presented between Figures 5 and Figures 8.

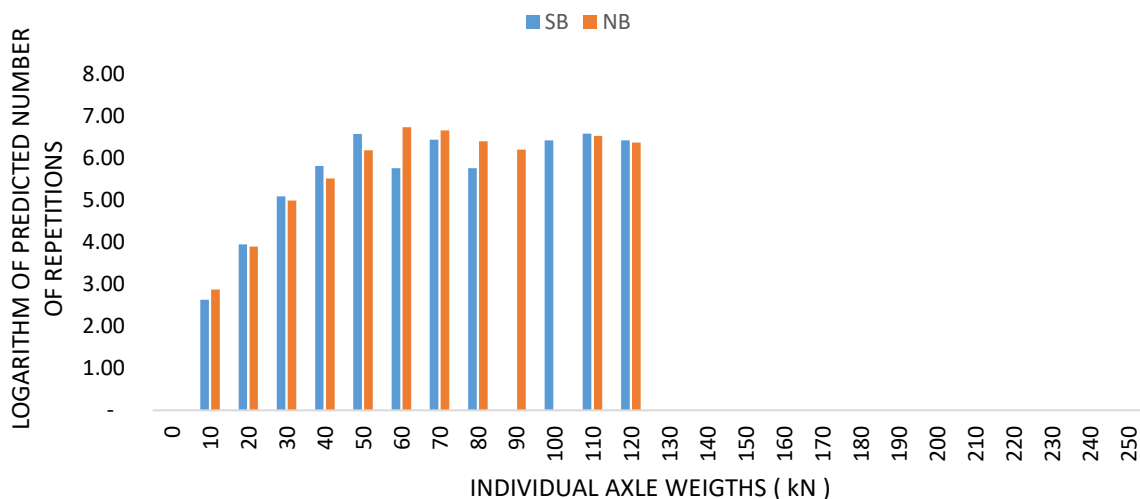


Figure 5: Predicted Number of Load Repetitions using GAF for Single Axle with Single Tires Loads during 20year Design Period at Kaduna-Zaria Roadway

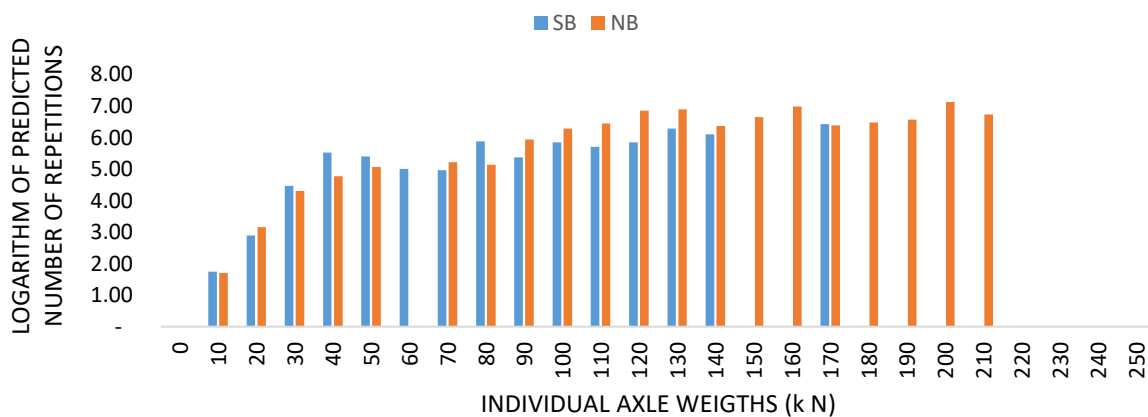


Figure 6: Predicted Number of Load Repetitions using GAF for Single Axle with Dual Tires Loads during 20-year Design Period at Kaduna -Zaria Roadway

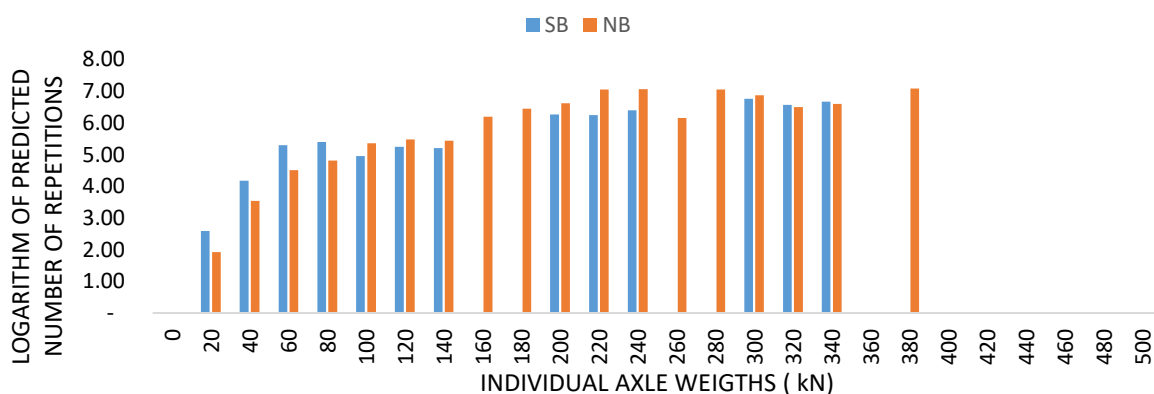


Figure 7: Predicted Number of Load Repetitions using GAF for Tandem Axle with Dual Tires Loads during 20-year Design Period at Kaduna-Zaria Roadway



Figure 8: Predicted Number of Load Repetitions using GAF for Tridem Axle with Dual Tires Loads during 20year Design Period at Kaduna -Zaria Roadway

3.8 Comparison of the expected number of repetitions of each axle load group during the pavement life Determined by EALF and GAF.

Comparison of the expected number of repetitions of each load group during the pavement life by traffic analysis, whereby, the results of the determined ALDF was utilized and presented in Table 3. The axle load ranges obtained and contained in Table 3, was used in the determination of EALF using Equations 5 and 6, that was presented in Table 5, and the same axle load ranges were used in the calculation of GAF using Equation 7 and presented in Table 6. The differences in the obtained results of EALF and GAF was presented in Table 7 for the axle load ranges for each of the different axle configurations. From the traffic analysis, the method based on different axle load groups was used for the determination of the predicted number of load repetitions by using Equations 8 and 9, and this is presented between Figures 9 and Figures 12. The marked difference is determined by using EALF or GAF individually in Equation 8 respectively, which is an input of Equation 9, and the results were compared. The obtained results indicate the effect of the empiricism content in EALF but that was eliminated in GAF. The projected traffic that was compared was plotted on the four different axle configurations for different axle load ranges was plotted between Figure 9 and Figure 12. The compared predicted number of repetitions for load group were presented in Figure 9 to Figure 12. The presentations are presented as follows: The predicted number of axle load repetitions for the SAST is presented in Figure 9. Similarly, Figure 10 is for SADT; Figure 11 is for Tandem Axles with dual tires and Figure 12 depicts the TRDT.

Table 7: Axle Load Damage Quantification Factors

S/N	Comparison of EALF and GAF for SAST.			Comparison of EALF and GAF FOR SADT.			Comparison of EALF and GAF for TADT.			Comparison of EALF and GAF FOR TRDT.		
	Axle load range for SAST (kN)	EALF for SAST	GAF for SAST	Axle load range for SADT (kN)	EALF for SADT	GAF for SADR	Axle load range for TADT (kN)	EALF for TADT	GAF for TADT	Axle load range for TRDT (kN)	EALF for TRDT	GAF for TRDT
1	0	0	0	0	0	0	0	0	0	0	0	0
2	10	0	0	10	0	0	20	0	0	30	0	0
3	20	0.001	0.02	20	0.003	0.01	40	0.005	0.01	60	0.005	0.02
4	30	0.009	0.12	30	0.017	0.02	60	0.023	0.05	90	0.028	0.07
5	40	0.035	0.34	40	0.056	0.07	80	0.077	0.14	120	0.093	0.21
6	50	0.102	0.8	50	0.144	0.17	100	0.198	0.32	150	0.239	0.49
7	60	0.245	1.6	60	0.31	0.34	120	0.426	0.64	180	0.513	0.98
8	70	0.513	2.88	70	0.584	0.6	140	0.804	1.15	210	0.968	1.76
9	80	0.973	4.78	80	1	1	160	1.376	1.91	240	1.658	2.92
10	90	1.71	7.48	90	1.587	1.56	180	2.183	2.98	270	2.631	4.57
11	100	2.833	11.16	100	2.376	2.33	200	3.269	4.45	300	3.939	6.82
12	110	4.472	16.03	110	3.402	3.35	220	4.68	6.4	330	5.64	9.8
13	120	6.784	22.32	120	4.707	4.67	240	6.474	8.9	360	7.807	13.64
14	130	9.954	30.25	130	6.342	6.33	260	8.723	12.07	390	10.512	18.49
15	140	14.197	40.09	140	8.371	8.39	280	11.514	15.99	420	13.875	24.5
16	150	19.76	52.11	150	10.371	10.9	300	14.953	20.79	450	18.019	31.84
17	160	26.913	66.59	160	13.93	13.93	320	19.162	26.56	480	23.091	40.69
18	170	35.982	83.84	170	17.652	17.54	340	24.28	33.45	510	29.259	51.24
19	180	47.313	104.18	180	22.149	21.79	360	30.467	41.56	540	36.714	63.67
20	190	61.3	127.94	190	27.552	26.76	380	37.898	51.04	570	45.669	78.19
21	200	78.372	155.48	200	34	32.52	400	46.768	62.02	600	56.358	95.02
22	210	99.006	187.15	210	41.649	39.15	420	57.29	74.66	630	69.037	114.4
23	220	123.718	223.34	220	50.67	46.72	440	69.698	89.09	660	83.99	136.5
24	230	153.075	264.43	230	61.246	55.31	460	84.246	105.49	690	101.52	161.6
25	240	187.69	310.85	240	73.577	65.02	480	101.208	124.01	720	121.96	190
26	250	228.224	363.01	250	87.879	75.93	500	120.881	144.82	750	145.667	221.9

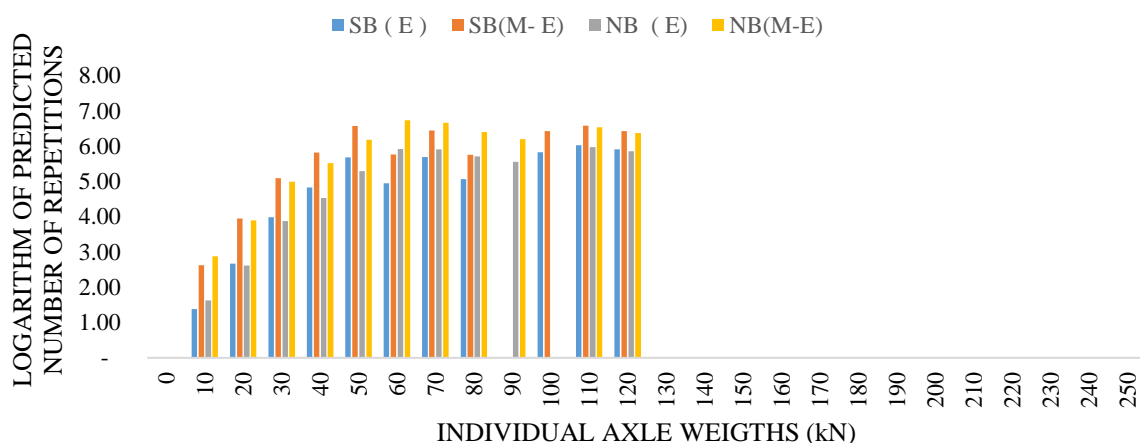


Figure 9: Comparison of the Expected Number of Load Repetitions for Single Axle with Single Tires Loads determined by EALF and GAF during 20year Design Period at Kaduna -Zaria Roadway.

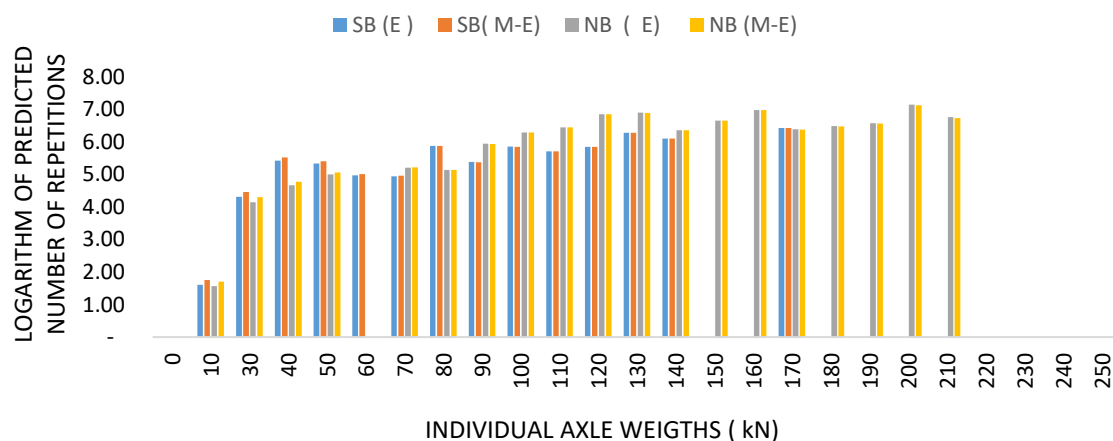


Figure 10: Comparison of the Expected Number of Load Repetitions for Single Axle with Dual Tires Loads determined by EALF and GAF during 20year Design Period at Kaduna -Zaria Roadway.

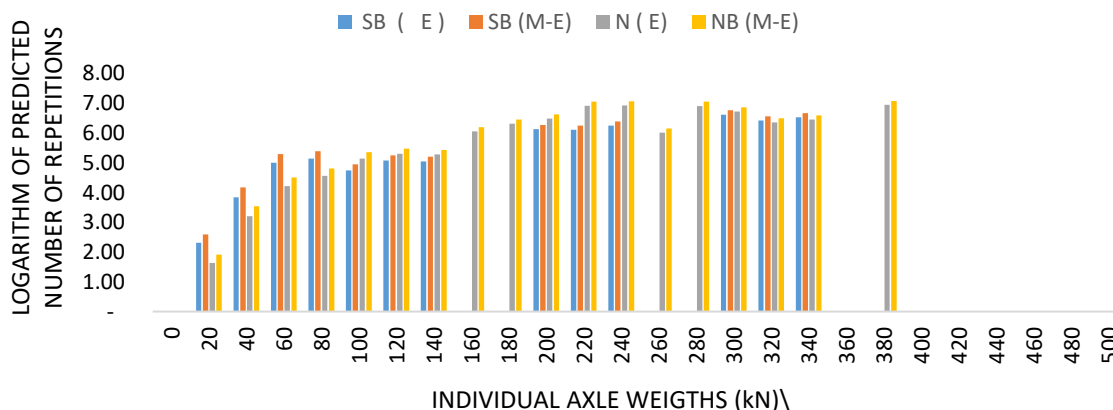


Figure 11: Comparison of the Expected Number of Load Repetitions for Tandem Axle with Dual Tires Loads determined by EALF and GAF during the 20year Design Period at Kaduna - Zaria Roadway.

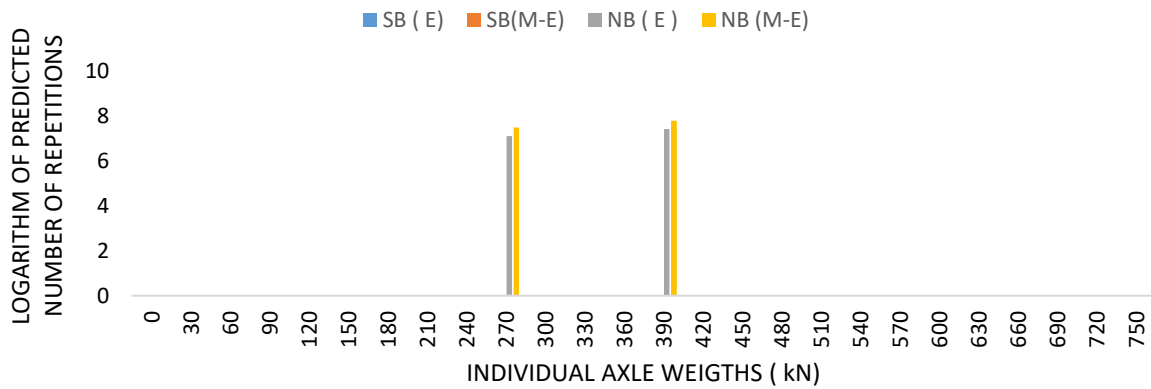


Figure 12: Comparison of the Expected Number of Load Repetitions for Tridem Axle with Dual Tires Loads determined by EALF and GAF during the 20year Design Period at Kaduna - Zaria Roadway.

4. Conclusion

The following conclusions were drawn from this study:

(i) The required traffic loading was characterized for the method based on different axle load groups, whereby, traffic loading was handled in a disaggregate fashion. The load input was in terms of axle load distribution by axle configuration.

(ii) Traffic loads were handled through a more complicated process called axle load spectra, in which all traffic loads were analyzed based on vehicle class, axle type, and axle load, and therefore, represented, the true distribution of traffic weights carried by the pavement under consideration. The axle load spectrum from the WIM data contains no empiricism content, therefore, it relied not on the equivalency factors.

(iii) The percentage of the total number of truck axle repetitions within each load interval (which varies with axle type) for each axle type was determined from the axle load spectrum of the WIM data, that shows the axle load distribution factors (ALDF). ALDF constitute a major change from the current 1993 AASHTO pavement design guide that requires only the total number of 18-kip ESALs as input.

(iv) A unique and rational way of handling volume changes and traffic growth was incorporated in this forecasting process in traffic analysis instead of the traditional approach of growth rate assumption. Careful consideration of current and historical traffic trends and the application of engineering was utilized to obtain an accurate prediction of traffic growth. The growth factor calculated was accurate based on the determined growth rate input and its significance influence on the estimated traffic. The growth factors have the same influence both on the load spectra and the same as using ESALs, because the empiricism content has no significant impact on the estimated traffic.

(v) The EALF was determined based on the empirical equations developed from the AASHTO Road Test, whereby, the regression equations based on the results of road tests was utilized. However, GAF was calculated for each load range of the axle load spectrum, whereby, the needed statistical measures that are related to the concept of pavement damage and are independent of pavement -related variables. The obtained values from the same traffic composition shows that the biggest different between the AASHTO EALF and the GAF, for the practical range for each load range of the axle load spectrum.

(vi) This finding confirms the comparison of the axle load number of repetitions determined by AASHTO EALF and the GAF, because its practical range of difference with the same traffic

composition was the same difference in output based on the primary inputs of the different axle load damage factors determined individually.

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