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Load Characterization and Prediction of Entry into Perpetual Construction Domain for Highway Pavement Structures by Truck Factor Study

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Abstract: This paper presents the results of pavement characterization study of a highway by Truck Factor and Axle Load Factor. The study highway is one of Nigeria's most important corridors linking the South and the North of the country. The Truck Factor obtained is 9.30 Equivalent Standard Axle Loads (ESALs) while the average Load Factor per axle is 3.25 ESALs. These values particularly the Truck Factor are on the very high side in comparison to published figures in other countries. In the United States of America, published figures for Truck Factors for the rural Interstate highway system and rural principal arterials are 0.52and 0.38 respectively. That for the United Kingdom for similar roads is 2.75. Truck axle overload could therefore be one of the sources of prevalent premature pavement failures on this and similar highways in the country. Also, while single axles in the trucks carried a load of 2.29 ESALs each, tandem and tridem axles impacted the pavement with loads of 3.59 and 6.4 ESALs per axle respectively. If the study pavement were to be reconstructed for a design life of 20years, 66.05 million ESALs from truck axles would cumulate in this period as obtained from this study. This figure is more than double the 30million ESALs stipulated as the trigger load for perpetual or long life pavement construction. Therefore, the study highway should be reconstructed as such.

Keywords: Equivalent Standard Axle Loads, Truck Factor, Axle Load Factor, Perpetual Pavement, Annual Daily Truck Traffic, Load Equivalency Factor, AASHTO, Asphalt Institute

1. Introduction

Attendant to the growth of any nation's economy is the growth of commercial traffic on highways between industrial and commercial cities. In the developing countries, such growth has led to the proliferation of heavy truck axles in both their weights and numbers. This has for long constituted a main source of structural damage to highway pavements in developing countries, a situation which has disrupted the promotion of socio-economic growth as well as political stability [1] and unity of such countries. Growth of the axle loads has overtaken capture of their amounts, frequency and consequent pavement damaging factors. To wit is also the fact that the numbers and weights of these axles are primary inputs for the structural design of modern highway pavements as exemplified in the American Association of State Highway and Transportation Officials, AASHTO, [2], Asphalt Institute [3], Road Notes 29 [4] and 31 [5] methods, to mention but these few. The need therefore also exists for the capture of these truck axle loads in their weights and numbers on different national highways for input into the pavement structural design process.

The present study focuses on the Lokoja-Abuja-Kaduna highway in the carriageway headed for Abuja and Kaduna. At the present instant, newly reconstructed asphaltic concrete pavement sections of this highway usually fail prematurely, often after only three years of construction or reconstruction for a design life of some twenty years. Worse still, when such pavements fail, there are no adequate traffic load data for input into design for reconstruction or maintenance.

The aim of this study therefore is to characterize the Lokoja to Abuja carriageway by determining the truck traffic pavement-damaging factor, also called truck factor, resulting from the proliferation in sizes, numbers and frequency of axle loads of truck traffic impacted on the pavement of the highway. Therewith, cumulative Equivalent Standard Axle Loads (ESALs) required for pavement design for new construction, reconstruction or maintenance will be predicted. The size of the ESALs so predicted will then indicate the appropriate construction interms of either a standard pavement cross-section or a perpetual pavement, which is also called long-life pavement.

The Standard Axle Load: It is the load to which all axle loads are referred to in order to calculate the level of damage done to the pavement by the axle loads of vehicles. It has been chosen as the 81.6KN. load. Sometimes this figure is rounded to 82KN., but often for simplification purposes taken as 80KN., this being the most popular of all approximations of the Standard Axle Load.

Load Equivalency Factors (LEFs) and Equivalent Axle Loads (EALS) on Road Pavements: The level of traffic induced structural damage to the road pavement depends on the magnitude and number of repetitions of the different axles that have operated from the time the road was opened to traffic up until the present moment, during the design life of the pavement. To these a third factor viz: the strength of the subgrade on which the pavement is built will be added. The avoidance of the tedium and inaccuracies consequent on separate calculations of damage done by each type of axle has necessitated the reference of the damage done by any type and weight of axle to the equivalent done by the Standard Axle Load. Factors called Load Equivalency Factors were therefore defined as the number of passes required to be made over the pavement by the standard axle load in order to do the same structural damage to the pavement as one pass of the axle load, L in question. One of the results of the American Association of State Highway Officials, AASHO (now AASHTO) Road Test [6] was the establishment of these factors.

The Exponential Power Law: It was during the AASHTO road tests [6] that the exponential Power Law was established viz:

$$\text{LEF}=\left[\frac{\text{L KN}}{80\ KN}\right]^{n} \quad (1)$$

where LEF is the Load Equivalency Factor or the pavement damaging power of the axle carrying LKN, 80KN is the standard axle load and n is an exponent whose value may vary between 3.8 and 5; rarely below 4 or above 5 for single axle loads.

In the developing countries where the growth and proliferation of axle loads are hardly checked, the exponent n is recommended as 4.55 by the Transport Research Laboratory, TRL [5].

Tables A1 and A2 of the Appendix show AASHTO Load Equivalency Factors for single, tandem and tridem axles, while Table A3 shows Load Equivalency Factors established for developing countries by the Transport Research Laboratory [5].

Hutchinson et. al [9] have proposed equations for the calculation of the Equivalency Factors, which they called Truck Load Factors, TLFs for different types of axles as follows:

$$\text{Single axles: TFL}=\left[\frac{W_1}{8200}\right]^{3.8} \quad (2)$$

$$\text{Tandem axles: TFL}=\left[\frac{W_2}{14500}\right]^{3.8} \quad (3)$$

$$\text{Tridem axles: TFL}=\left[\frac{W_3}{19100}\right]^{3.8} \quad (4)$$

Where:

W_1=mean axle weight in Kg of single axle truck types,

W_2=mean axle weight in Kg of tandem axle truck types and

W_3=mean axle weight in Kg of tridem axle truck types.

Theoretical Method: This method selects one of the critical response parameters of the loaded pavement. Examples are the horizontal tensile strain at the bottom of the asphalt bound layer, which has a relationship to fatigue damage and the vertical compressive strain on the top of the pavement subgrade, which relates to permanent deformation or rutting. The magnitude of the selected response when the pavement is carrying a given axle load or axle load group is calculated usually by application of the elastic theory. This is divided by the same type of response caused by the standard axle load, also obtained by the elastic theory. The quotient, raised to an appropriate power n, yields an estimate of the Load Equivalency Factor (LEF).

Mechanistic Method: In this case, the response parameter selected for example, strain or deformation is measured in the field at instrumented sections of the highway, instead of being calculated as in the theoretical method. The steps in calculating the LEF from now become the same as in the former method.

Published Truck Factors: These are shown in Tables A4, A5 and A6 of the Appendix.

Perpetual Pavement: This has been defined as 'an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction and needing only periodic surface renewal in response to distresses confined to the top of the pavement' [10-12]. The Texas Department of Transportation [13] stipulates that when the cumulative truck traffic in one direction exceeds thirty million ESALs over a design life of 20 to 30 years, then a perpetual pavement is demanded. Figure 1 shows layer details of a perpetual pavement design concept [10-12]. Table A1 of the appendix shows the AASHTO load equivalency factors for single and tandem axles [7] while Table A2 includes equivalency factors for tridem axles [8]. Table A3 shows load equivalency factors for single axles as established by the Transport Research Laboratory of the UK for tropical and sub-tropical developing countries [5].

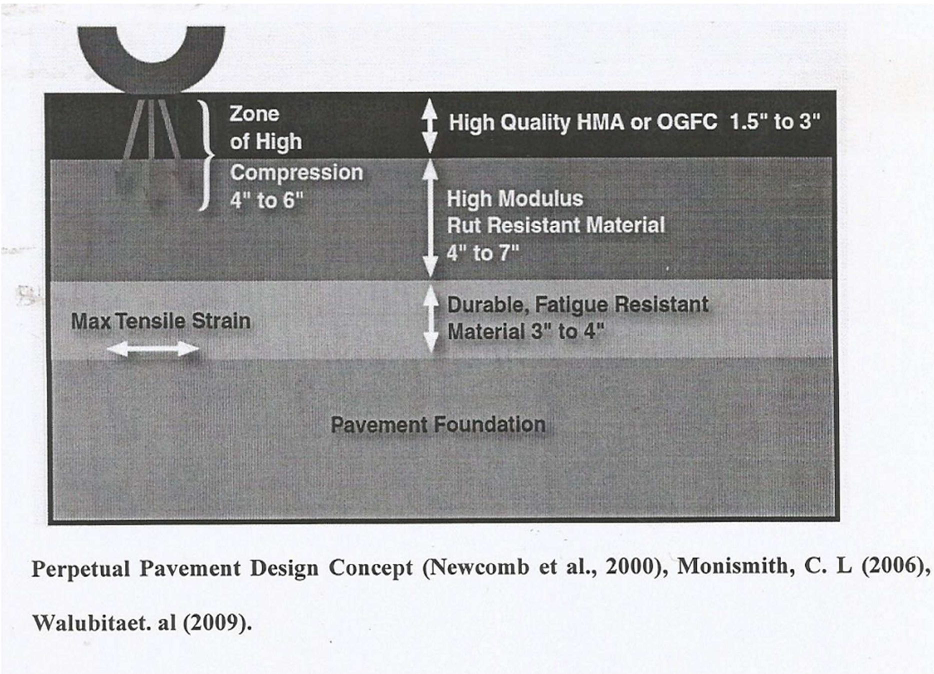

Figure 1. *Perpetual Pavement Design Concept.*

2. Materials and Methods

Portable truck axle weighing scales were used for weighing the trucks, axle-by-axle in a static mode. The system has two scales, which with their accompanying CPUs are powered by rechargeable batteries. These heavy duty pads have a rugged design to accommodate the weight of large vehicles viz: trucks, tankers, vans and multi-wheel trailers. They are configured to suite any axle group and wheel spacing and are wide enough for dual tyres. They are made of cast aluminum and are light enough to be portable. Their construction includes built-in read-out display, built-in printer, roll off printer paper and cables.

Field Experience/ Limitations: Truck drivers are often in a hurry and are usually not patient to halt for axle load capture. Some drive dangerously in order to avoid the capture since they are mindful of possible punitive measures should the axles of their vehicles be overloaded. Due to the momentary zero speed required, a long queue of trucks will soon build up and cause delays to other road traffic. Another limitation of the use of portable scales is that police authorization will be required as well as police support for control of vehicles during the study.

Plate 1(a):
Equipment Layout.

Plate 1(b):
Equipment Layout (contd.)

Plate II:
Truck Axle Loads Capture.

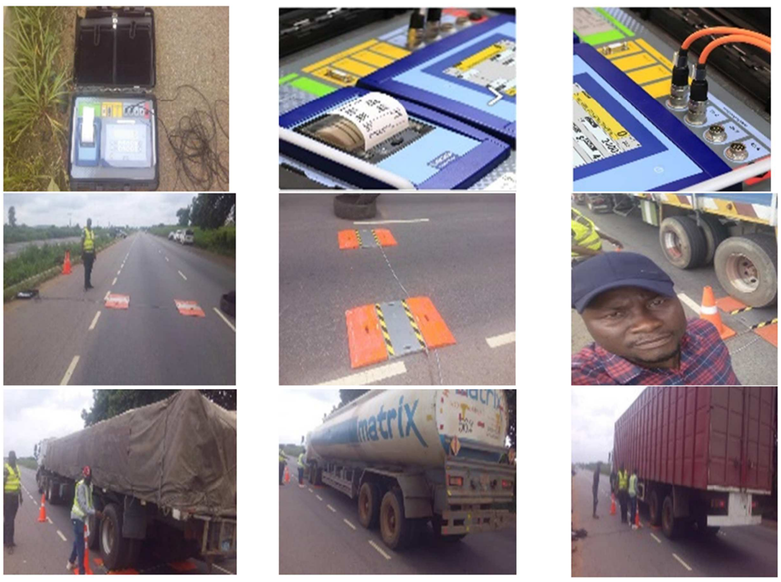

Figure 2. *On-site Equipment Layout and Truck Axle Loads Capture.*

3. Results and Analyse

Results:

Table 1. *Number of Axle Load Groups per 50 Trucks for Single Axles.*

Axle Load Group (KN)	No. of axles per 50 Trucks
<13.35	2
13.35 - 31.15	3
31.15 – 35.6	5
35.6 – 53.4	11
53.4 – 71.2	23
71.2 – 80.0	5
80.0 – 89.0	4
89.0 – 97.8	2
97.8 – 106.8	3
106.8 – 115.6	4
115.6 – 133.5	6
133.5 – 160.0	6
160.0 – 187.0	2
	76

Table 2. *Number of Axle Load Groups per 50 Trucks for Tandem Axles.*

Axle Load Group (KN)	No. of axles per 50 Trucks
<44.5	0
44.5 – 53.4	0
53.4 – 80.0	2
80.0 – 106.8	1
106.8 – 133.5	5
133.5 – 142.3	2
142.3 – 151.2	3
151.2 – 160.0	2
160.0 – 169.0	1
169.0 – 178.0	4
178.0 – 187.0	5
187.0 – 195.7	2
195.7 – 204.5	3
204.5 – 222.4	4
222.4 – 240.2	7
240.2 – 258.0	2
258.0 – 275.8	5
278.8 – 289.0	1
	49

Table 3. *Number of Axles Load Groups per 50 Trucks for Tridem Axles.*

Axle Load Group (KN)	No. of axles per 50 Trucks
<97.9	0
97.9 – 115.6	2
115.6 – 151.2	1
151.2 – 187.0	0
187.0 – 222.4	0
222.4 – 258.0	3
258.0 – 293.5	2
293.5 – 329.0	3
329.0 – 364.7	3
364.7 – 400.3	2
400.3 – 502.1	2
	18

Table 4. *Equivalent Standard Axle Loads (ESALs) from Single Axles.*

No. of axles per 50 Trucks (1)	Load Equivalency Factor (LEF) (2)	ESALs (3)=(1) x (2)
2	0.00018	0.00036
3	0.00500	0.015
5	0.0270	0.135
11	0.0877	0.965
23	0.360	8.28
5	0.796	3.98
4	1.24	4.96
2	1.83	3.66
3	2.58	7.74
4	3.53	14.12
6	5.39	32.34
6	9.98	59.88
2	19.14	38.28
76		Sum=174.41

Average Load per axle carried by single axles=$\frac{174.41}{76}$=2.29ESALs.

Table 5. *Equivalent Standard Axle Loads (ESALs) for Tandem Axles.*

No. of axles per 50 Trucks (1)	Load Equivalency Factor (LEF) (2)	ESALs (3)=(1) x (2)
0	0.00688	0
0	0.01008	0
2	0.0360	0.072
1	0.148	0.148
5	0.426	2.13
2	0.753	1.506
3	0.971	2.913
2	1.23	2.46
1	1.53	1.53
4	1.89	7.56
5	2.29	11.45
2	2.75	5.50
3	3.27	9.81
4	4.17	16.68
7	5.63	39.41
2	7.41	14.82
5	9.59	47.95
1	11.87	11.87
49		175.81

Average Load per axle carried by tandem axles=$\frac{175.81}{49}$=3.59 ESALs.

Table 6. *Equivalent Standard Axle Loads (ESALs) for Tridem Axles.*

No. of axles per 50 Trucks (1)	Load Equivalency Factor (LEF) (2)	ESALs (3)=(1) x (2)
0	0.0400	0
2	0.057	0.114
1	0.145	0.145
0	0.393	0
0	0.868	0
3	1.66	4.98
2	2.85	5.70
3	4.52	13.56
3	6.78	20.34
2	9.80	19.60
2	25.48	50.90
18		115.34

Average Load per axle carried by tridem axles=$\frac{115.34}{18}$=6.4 ESALs.

$$\sum ESALs = 174.41 + 175.81 + 115.34 = 465.56.$$

$$Truck\ Factor = \frac{\Sigma(ESALs)}{No.of\ Truks\ sampled} = \frac{465.56}{50} = 9.30 \quad (5)$$

$$\text{Axle Factor} = \frac{\Sigma(ESALs)}{Total\ No.of\ Axles\ in\ Sampled\ Trucks} = \frac{465.56}{143} = 3.25 \quad (6)$$

Table 7. *Summary of Truck and Axle Factors.*

Truck Factor	9.30 ESALs
Average load from each axle=Axle Factor	3.25 ESALS
Average Load from single axles only	2.29 ESALs
Average load from tandem axles only	3.59 ESALs
Average load from tridem axles only	6.40 ESALs
No. of axles in 50 trucks	143 Axles
Total load from all axles	465.56 ESALs
Design load for reconstruction for a 20-year life	66.05×10^6 ESALs

Table 8. *Truck and Axle Factors for Different Countries.*

Country	Truck Factor (ESALs)	Axle Factor (ESALs)
USA	0.52 (I-route), 0.38 (Principal arterials)	-
UK	2.75	-
Nigeria	-	3.89*
This Study	9.30	3.25**

* 1979 Study [14].
** October 2019 Study.

Truck Traffic Data: Mbaezue [15] in 2013 was able to count the truck traffic in two directions for this highway section. He performed a 24-hour study for three days and by taking the average he obtained an Annual Daily Truck Traffic, ADTT of 2,381 trucks for that year. An iterative forward calculation is applied to this figure in intervals of 3 years as suggested by the Federal Ministry of Works [16], up until 2019 as follows:

For year 2016, using a base figure of 2381, we have:

2381 x [1+(3.5÷100)]=2464.3 trucks (using a truck traffic growth rate of 3.5%).

For year 2019, using a base figure of 2464.3 and traffic growth rate of 4%, we have:

2464.3 x [1+(4.0÷100)]=2,562.9 trucks

Thus in the study year of 2019:

$$ADTT_o = 2562.9 \times DDF \times LDF \quad (7)$$

Where DDF=Directional Distribution Factor, LDF=Lane Distribution Factor (in the direction and lane of the Study), $ADTT_o$ is Annual Daily Truck Traffic at the year and time of study.

=2562.9 x 0.5 x0.5=640.7 trucks per lane.

However, from the Axle Load Study, Truck Factor=9.30

Therefore,

$$\text{Initializing } ESAL = ESAL_0 = ADTT_0 \times \text{Truck Factor} \quad (8)$$

=640.7 x 9.30=5,958.51 Equivalent Standard Axle Loads.

Table 9. *Results of Forward Iteration of Truck Traffic from 2013-2019.*

Year	2013	2016	2019
$ADTT_n$	2,381	2,464.3	2,562.9

Prediction of Entry into Perpetual Pavement Construction Domain: If this pavement were to be reconstructed to last for 20 years, then terminal

$$ESAL = ESAL_{20} = ESAL_0 \times TGF \ [16] \quad (9)$$

Where TGF=Traffic Growth Factor, defined as:

$$TGF = 365 \times \frac{[(1+i)^n - 1]}{log_e(1+i)} \ [16] \quad (10)$$

Where i=Truck traffic growth rate=$\frac{r}{100}$=4%,n=pavement design life in years=20.

Therefore

$$ESAL_{20} = TGF \times ESAL_O = 365 \frac{[(1+0.04)^{20} - 1]}{log_e\left(1+\frac{4}{100}\right)} \times 5958.51$$

$$= 5958.51 \times 365 \times \frac{1.19112}{log_e(1.04)} = \frac{1.19112}{0.03922} \times 365 \times 5958.51$$

$=66,050,858.17=66.05 \times 10^6$ ESALs.

Therefore 66.05 million ESALs will cumulate from truck axles twenty years from the time of this study. This is more than double the 30 million ESALs recommended by the Texas Department of Transportation [13]as the trigger point into the requirement for perpetual pavement construction.

4. Discussion of Results

A Truck Factor of 9.30 obtained in this Study means that on the average one application or passage of each of the trucks plying the road in the direction of Study does the same damage to the pavement as 9.30 applications of the 80KN single-axle load, called the Standard Axle Load. This figure therefore characterizes the pavement under study. Also, the number of Equivalent Standard Axle Loads carried by each truck axle was obtained as 3.25 ESALs. Thus while the average damaging power of each truck on the study pavement is 9.30 that for each axle is 3.25. These figures become necessary against the backdrop of earlier studies in both this country and some foreign nations. As shown in table 8 and displayed fully in Tables A4, A5 and A6, Road Note 29 of the UK. Prescribes a commercial truck factor of 2.75 for roads designed to carry over 2000 commercial vehicles per day in each direction at the time of construction, while the figure of 0.52 is published for all trucks on the rural Interstate routes of the USA. These two figures when compared to 9.30 obtained in this Study show that the pavement under study is relatively highly overloaded. This makes a strong case for the use of results of axle load studies for the structural design of road pavements. Presently the Federal Ministry of Works recommends the use of number of vehicles per day exceeding 3 tonnes loaded weight versus the CBR of subgrade to design pavement thicknesses. Notice is also taken of the fact that for a Study conducted in the late nineteen seventies [14] the Load Equivalency Factor per axle was 3.89 while in this study, the figure is 3.25. This could be explained by the fact that today's trucks carry many moreaxles for the same gross weight of truck so that loads are more widely distributed and therefore lighter per axle compared to the trucks of the late 1970's. Also of further interest is the fact that the initializing ESALs for the 3rd quarter of 2019, called $ESAL_0$ in this study is 5,958.51. If the pavement were to be reconstructed, it would be designed for a load of 66.05x 10^6 ESALs for a life of 20 years. This exceeds the 30 million ESALs limit or trigger point for implementation of a perpetual pavement. Therefore, such should be implemented if premature pavement failures as presently observed should be avoided.

A perpetual pavement is presently being implemented on the Lagos to Ibadan expressway since 2014 [17], thus heralding the construction of such pavements in Nigeria. A perpetual pavement section is shown in Figure 1.

5. Conclusion

This study indicates that the highway understudy has a Truck Factor of 9.30 while each axle carries an average of 3.25ESALs. The pavement sustains loads of 2.29, 3.59 and 6.4ESALs from each axle of the constituent single, tandem and tridem axles respectively. The truck traffic loading has entered the domain for perpetual pavement construction. Therefore, reconstruction of this pavement demands implementation of a perpetual or long life construction if usual premature failures are to be avoided.

6. Recommendations and the Future

The very high Truck Factor would signify the need to install axle load weigh-stations on this and other highways similar in terms of truck traffic to the one under study. The Federal Ministry of Works, the owner of such highways should also investigate the need for a change of pavement design method for such highways to the use of cumulative axle loads to the end of the pavement design life. These suggestions are borne out of the numerous premature pavement failures on Federal Government highways. Some of the roads as exemplified by the study highway are due for reconstruction to the standard of perpetual pavements. The limitations pointed out under Materials and Methods will be highly improved if Weigh-In-Motion (WIM) technology is employed. WIM systems are designed to automatically capture and record the axle weight readings while the vehicle is in motion unlike axle load scales. WIM systems simply require that the trucks drive over the weighbridge steadily at a reduced and constant speed of up to 5Km/hr., thereby reducing unnecessary delays and downtime as well as police permit and intervention. This technology is therefore strongly recommended for this study.

Appendix

Table A1. *AASHTO Load Equivalency Factors for Single and Tandem Axles [7].*

Gross axle load		Load equivalency	factors	Gross axle load		Load equivalency	factors
kN	**1b**	**Single axles**	**Tandem axle**	**kN**	**1b**	**Single axles**	**Tandem axle**
4.45	1,000	0.00002		182.5	41,000	23.27	2.29
8.9	2,000	0.00018		187.0	42,000	25.64	2.51
13.35	3,000	0.0072		1913	43,000	28.22	2.75
17.8	4,000	0.00209		195.7	44,000	31.00	3.00
22.25	5,000	0.00500		200.0	45,000	34.00	3.27
26.7	6,000	0.01043		204.5	46,000	37.24	3.55
31.15	7,000	0.0196		209.0	47,000	40.74	3.85
35.6	8,000	0.0343		213.5	48,000	44.50	4.17
40.0	9,000	0.0562		218.0	49,000	48.54	4.51
44.5	10,000	0.0877	0.00688	222.4	50,000	52.88	4.86
48.9	11,000	0.1311	0.01008	226.8	51,000		5.23
53.4	12,000	0.189	0.0144	231.3	52,000		5.63
57.8	13,000	0.264	0.0199	235.7	53,000		6.04
62.3	14,000	0.360	0.0270	240.2	54,000		6.47
66.7	15,000	0.478	0.0360	244.6	55,000		6.93
71.2	16,000	0.623	0.0472	249.0	56,000		7.41
75.6	17,000	0.796	0.0608	253.5	57,000		7.92
80.0	18,000	1.000	0.773	258.0	58,000		8.45
84.5	19,000	1.24	0.0971	262.5	59,000		9.01
89.0	20,000	1.51	0.1206	267.0	60,000		9.59
93.4	21,000	1.83	0.148	271.3	61,000		10.20
97.8	22,000	2.18	0.180	275.8	62,000		10.84
102.3	23,000	2.58	0.217	280.2	63,000		11.52
106.8	24,000	3.03	0.260	284.5	64,000		12.22
111.2	25,000	3.53	0.308	289.0	65,000		12.96
115.6	26,000	4.09	0.364	293.5	66,000		13.73
120.0	27,000	4.71	0.426	298.0	67,000		14.54
124.5	28,000	5.39	0.495	302.5	68,000		15.38
129.0	29,000	6.14	0.572	307.0	69,000		16.26
133.5	30,000	6.97	0.658	311.5	70,000		17.19
138.0	31,000	7.88	0.753	316.0	71,000		18.15
142.3	32,000	8.88	0.857	320.0	72,000		19.16
146.8	33,000	9.98	0.971	325.0	73,000		20.22
151.2	34,000	11.18	1.095	329.0	74,000		21.32

Gross axle load		Load equivalency	factors	Gross axle load		Load equivalency	factors
kN	**1b**	**Single axles**	**Tandem axle**	**kN**	**1b**	**Single axles**	**Tandem axle**
155.7	35,000	12.50	1.23	333.5	75,000		22.47
160.0	36,000	13.93	1.38	338.0	76,000		23.66
164.5	37,000	15.50	1.53	342.5	77,000		24.91
169.0	38,000	17.20	1.70	347.0	78,000		26.22
173.5	39,000	19.06	1.89	351.3	79,000		27.58
178.0	40,000	21.08	2.08	356.0	80,000		28.99

Table A2. *AASHTO Load Equivalency Factors for Single, Tandem and Tridem Axles [8].*

Gross Axle Load		Load Equivalency Factors		
kN	**1b**	**Single Axles**	**Tandem Axles**	**Tridem Axles**
4.45	1,000	0.00002		
8.9	2,000	0.00018		
17.8	4,000	0.00209	0.0003	
26.7	6,000	0.01043	0.0001	0.0003
35.6	8,000	0.0343	0.003	0.001
44.5	10,000	0.0877	0.007	0.002
53.4	12,000	0.189	0.014	0.003
62.3	14,000	0.360	0.027	0.006
71.2	16,000	0.623	0.047	0.011
80.0	18,000	1.000	0.077	0.017
89.0	20,000	1.51	0.121	0.027
97.9	22,000	2.18	0.180	0.040
106.8	24,000	3.03	0.260	0.057
115.6	26,000	4.09	0.364	0.080
124.5	28,000	5.39	0.495	0.109
133.4	30,000	6.97	0.658	0.145
142.3	32,000	8.88	0.857	0.191
151.2	34,000	11.18	1.095	0.246
160.1	36,000	13.93	1.39	0.313
169.0	38,000	17.20	1.70	0.393
178.0	40,000	21.08	2.08	0.487
187.0	42,000	25.64	2.51	0.597
195.7	44,000	31.00	3.00	0.723
204.5	46,000	37.24	3.55	0.868
213.5	48,000	44.50	4.17	1.033
222.4	50,000	52.88	4.86	1.22
231.3	52,000		5.63	1.43
240.2	54,000		6.47	1.66
249.0	56,000		7.41	1.91
258.0	58,000		8.45	2.20
267.0	60,000		9.59	2.51
275.8	62,000		10.84	2.85
284.5	64,000		12.22	3.22
293.5	66,000		13.73	3.62
302.5	68,000		15.38	4.05
311.5	70,000		17.19	4.52
320.0	72,000		19.16	5.03
329.0	74,000		21.32	5.57
338.0	76,000		23.66	6.15
347.0	78,000		26.22	6.78
356.0	80,000		29.0	7.45
364.7	82,000		32.0	8.2
373.6	84,000		35.3	8.9
382.5	86,000		38.8	9.8
391.4	88,000		42.6	10.6
400.3	90,000		46.8	11.6

Table A3. *Load Equivalency Factors for Different Axle Loads [5].*

Wheel load (single & dual) (10^3 kg)	Axle load (10^3 kg)	Equivalence Factors
1.5	3.0	0.01
2.0	4.0	0.04
2.5	5.0	0.11
3.0	6.0	0.25
3.5	7.0	0.50

Wheel load (single & dual) (10^3 kg)	Axle load (10^3 kg)	Equivalence Factors
4.0	8.0	0.91
4.5	9.0	1.55
5.0	10.0	2.50
5.5	11.0	3.83
6.0	12.0	5.67
6.5	13.0	8.13
7.0	14.0	11.3
7.5	15.0	15.5
8.0	16.0	20.7
8.5	17.0	27.2
9.0	18.0	35.2
9.5	19.0	44.9
10.0	20.0	58.5

Table A4. *Conversion Factors for Obtaining the Equivalent Number of Standard Axles (Dept. of Transport, 1978) [4]*

Traffic Loading	Equivalent Number of Standard Axles per Commercial Vehicle
Roads designed to carry over 2,000 commercial vehicles per day in each direction at the time of construction	2.75
Roads designed to carry between 1,000 and 2,000 commercial vehicles per day in each direction at the time of construction	2.25
Roads designed to carry between 250 and 1,000 commercial vehicles per day in each direction at the time of construction	1.25
All other public roads	0.75

Table A5. *Distribution of Truck Factors for Interstate, Principal and Minor Arterials in the USA [8].*

Vehicle Type	Interstate	Other Principal Arterials	Minor Arterials
All Trucks	0.52	0.38	0.21

Table A6. *Summary of Axle-Load Studies in Some Countries [14].*

			Relative damaging power	
Year	Country	Legal axle Limit (tonne)	Numbers of ESA per 100 Commercial axles	Estimated average ESA / tonne of payload
1961	Malawi	7	3.6	-
1961	Rhodesia	7	5.9	-
1963	Jamaica	7	36	0.33
1967	Malaysia	7	19	0.15
1970	Abu Dhabi	No limit	64	0.33
1971	Abu Dhabi	No limit	127	0.49
1970-71	Qatar (overall)	No limit	109	0.50
1970-71	Qatar (selected route)	No limit	452	1.08
1964	United Kingdom (MI Motorway)	10	46	0.19
	France (RN 10 Motorway)	13	89	0.31
1974	Kenya Mombasa-Nairobi Rd	8	281 (336) *	(0.75) *
	Lunga-Lunga-Mobassa Rd.	8	92 (164) *	(0.37) *
1975	Nigeria	10	389	0.62
1975	Turkey	8.2	57	0.21
1976	Ethiopia (selected trunk route)	8.0	491	0.66
1976	Ethiopia (mean of five trunk route)	8.0	233	0.45
1978	Malaysia (mean of three trunk routes)	8.2	116	0.27

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