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Generation of traffic input for flexible pavement design

Fogue Richard *, Mamba Mpele

Department of civil Engineering; National Polytechnics Higher School, Yaounde , Cameroon ,P.O Box ,6449

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ABSTRACT

Layered elastic theory (LET) was performed by Burmister. It helped to build mechanistic – empirical (M-E) pavement design. In this study, three different approaches were used to predict Cumulative Equivalent single axle load (C-ESAL) over the design period. Two were based on M-E and one was empirical. In each of these cases, standard axle loads were used as well as weight limits and vehicle classification, according to their axle configurations (single, tandem, tridem). Traffic data came from annual traffic census campaigns over the past ten years. Gross vehicle weight (GVW) and axle weight (AW) data came from a fixed weighing station performed during 31 days in 2020. Two road axis were considered: One having a weighing station (reference road) and one under technical studies (specific road). Traffic road data were used to perform regression analyses and predictions. AW and GVW helped to calculate Axle load equivalency factors (ALEF) and Truck equivalency factors (TEF) on the reference road. These values were projected on the specific road. Frequency distribution, gross vehicle weight distribution, axle load distribution of heavy vehicles are applied on the reference road. We performed overload AW and overload GVW analyses. Comparisons were done for the three approaches and an evaluation of technical studies was proposed, including traffic and AW monitoring and management systems. This work came as a basis for the transposition of M-E calculation of traffic inputs, more accurate and used over the passed fifty years, in Higher Income countries, called AASHTO method for USA, LCPC-SETRA method for France, to Cameroon and Sub-sahara African countries, that have been using empirical generation of traffic inputs over the same period, called CEBTP method.

1. Introduction

The pavement is a land route designed for the flow of pedestrian traffic, two- or three-wheeled vehicles and cars. Also called multilayered linear system (MLLS), it is composed of the following layers: a subgrade (soil base), a sub-base, a base and a wearing course; the subgrade having an infinite thickness [1]. The American Association of State Highways and Transportation Officials (AASHTO) uses Structural Number (SN) in order to design MLLS. The SN is the sum of the products of the structural coefficient a_i of the layer, D_i of its thickness and of the drainage coefficient m_i as shown on Fig. 1 that follows.

For the design of MLLS, heavy vehicles are preferable than light vehicles because of the greater damages they create. A synopsis of heavy vehicles used to design MLLS is being proposed in Fig. 2 (a,b) that follows.

The preoccupation is how to move from a given road traffic to a cumulative simple loads. This research article brings out three

* Corresponding author.
E-mail address: fogue_richard@yahoo.com (F. Richard).

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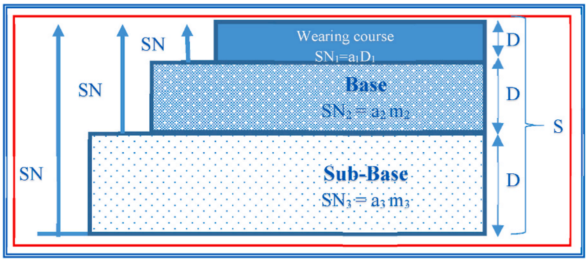

Fig. 1. Principle of a multilayered linear system according to American Association of State Highways and Transportation Officials (AASHTO) [1].

different approaches in order to come through the matter: AASTHO, SETRA - LCPC-[1] and CEBTP[2] methods, respectively for the United States of America, France and Sub-Sahara African countries. The latter includes Cameroon from where this synopsis study, that has never been performed before, was proposed. A scope of an axle load commonly used in the design of MLLS for SETRA – LCPC method is shown in Fig. 3 that follows.

Thus, the road traffic management system and weighting of the Ministry of Public Works of Cameroon will be brought forward. A cluster analysis will be performed as well from the national road n° 1 Yaounde – Obala which has a weighting station to the regional road n°33 Obout – Endom – Akonolinga which is under technical studies.

Possible highlights applications and advantages, as compared to conventional manual collection of traffic data fpr Perpetual pavement (PP) structural design concept in the state of Texas, of using detailed WIM traffic data information for future analyses of both highway operation and pavement structural design, were performed, based on two PP projects [4]. In order to develop state-wide axle load spectra data, the cluster analysis was conducted using vehicle classification distribution and the Class 9 tandem axle load spectra data to provide traffic input data for the Texas M-E flexible pavement design programm where the load spectra data are not available due to the absence of WIM stations [5]. Also, the use of WIM systems to characterize traffic loading in pavement design and performance prediction is the current state-of-the art. Evaluation of potential application of portable WIM systems as a means for bringing the WIM technology to high volume rural highways was performed in the state of Texas during three weeks [6]. As a means of addressing accuracy, reliability, and data quality, a field pilot study was undertaken to comparatively evaluate two different sensor installation methods: the pocket tape and metal platemethods. In this way, the latter method was more accurate [7]. It was demonstrated that developed multiple-choice default load spectra inputs have the advantages of considering various characteristics of Axle Load Distribution (ALD) and Vehicle Class Distribution (VCD) for different types of roads and allowing more accurate pavement design than the traditional ESAL input in the state of Texas [8].

2. Materials and methods

2.1. Road network and truck classifications

Cameroon road network is made up of motorways (under construction), national roads, regional roads and local roads. National roads link the national capital Yaounde to regional headquarters, economic poles of national importance, neighbouring countries or one regional headquarter to another. Regional roads link regional headquarters to divisional headquarters, economic poles of regional importance or a regional headquarter to another. Local roads are all other roads that are not previously mentioned [9].

The current practice in Tanzania requires that heavy vehicles be grouped into four different categories, namely Medium Goods Vehicles (MGVs; 2 axles trucks), Heavy Goods Vehicles (HGVs; 3 axles trucks), Very Heavy Goods Vehicles (VHGVs; 4 or more axles/ Trailers), and Buses [10]. The Federal highways (FHWA)'s vehicle classification system has 13 classes among which Classes 4 to 13 are identified as trucks [11]. In the province of British Columbia/Canada, Northern America, vehicle classification counts are done visually using four vehicle types [12].

A vehicle classification system was proposed and a prototype system installed on a relief road in Shanghai, China. The vehicles were

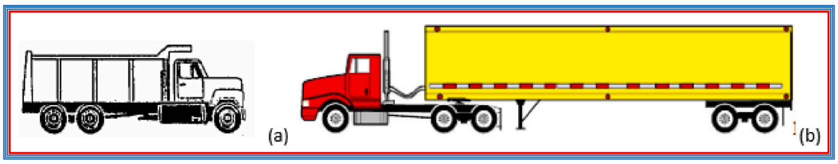

Fig. 2. (a): 3-axle truck; (b): 6-axle truck [2].

[1] Service d'étude technique des routes et autoroutes (SETRA)/Laboratoire Central des Ponts et Chaussées (LCPC).

[2] Centre Expérimental de Recherche et d'Etudes du Bâtiment et des Travaux Publics.

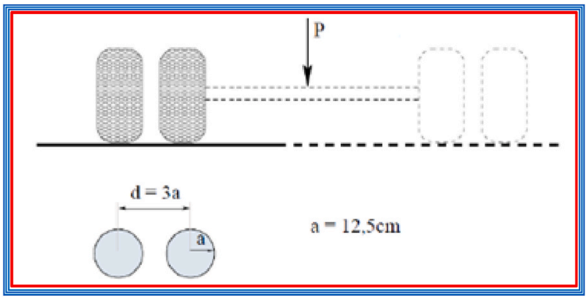

Fig. 3. A scope of an axle load [3].

classified into 10 categories according to their axle features and usage features. Heavy vehicles (multi-axle trucks and trailers, Class 4; 10) are classified based on the axle configurations (number of axles and axle spacing). For the vehicles that possess similar axle features (vans, two-axle buses, and two-axle truck, class 1–3), a multi-parameter classifier is designed to identify those types of vehicles: 2: Two-axle bus; 3: Two-axle truck; 4: Three-axle truck; 5: Three-axle truck; 6: Four-axle truck; 7: Four-axle trailer; 8: Five-axle trailer; 9: Five-axle trailer; 10: Six-axle trailer [13].

In Cameroon, trucks classification is as follows: Buses, 2-axle trucks having a single unit-single tires and a single unit-twin tires, 3-axle trucks having a single unit-single tires and a tandem unit-twin tires, 4-axle trucks, 5-axle trucks, 6-axle trucks and timbers [14].

2.2. Traffic and axle load management systems

2.2.1. Weighing regulations

In Cameroon, the limit for a single-axle load is 13 tons and that for gross vehicle weight is 50 tons. A tolerance of one ton is allowed. Weighing stations are constructed on tared roads and equipped with single/dual fixed dynamic axle scales [Fixed static weigh (FSW)] placed on one or both sides of the road [15].

The Gross Combination Mass in South Africa is currently set at 56 tons with the maximum standard axle load of 9 tons [16].

FHWA's Traffic Monitoring Guide (TMG) (FHWA 2001) recommends Truck Weight Road Group (TWRG) as a way for highway agencies to collect, summarize, and report summary statistics for groups of roads [17].

2.2.2. Counting and weighing materials and methods

Traffic counts for pavement design purposes can be performed by Manual traffic count (MTC), Automatic traffic count (ATC) or semi-automatic traffic count (SATC) methods. Manual traffic counts are carried out by observers at carefully selected observation points or counting stations along a road section. The traffic count survey is usually a classified count where each vehicle passing an observation point is recorded on a prepared sheet/form according to the vehicle type, and each travel direction is recorded separately. The manual traffic count is usually done over a short period of time (typically seven days). The equipment used are: a table, a chair, an umbrella, pens, flashlights, oil lamps and watches. Fig. 4 that follows presents a manual traffic count personnel at work.

Fig. 4. A counting post in Limbè/Cameroon.

ATC and SATC involve either static weighing equipments or weigh-in-motion (automatic traffic count) materials. Concerning static weighing, there are portable static weigh pads (PSW) and fixed static weigh pads (beams). Weigh-in-motion systems measure static and dynamic components of the load. The commonly used automatic traffic count systems can be grouped into three broad types, namely Pneumatic traffic tubes (PTT), Magnetic wire loops (MWL), and piezo systems (PS) [10]. The portable WIM unit automatically converts the data collected from the single wheel path (or half lane width) to the total axle weight and gross vehicle weight (GVW) data by applying a built-in multiplication factor of two, i.e., the measured wheel load is multiplied by two to obtain the axle load [11].

Each site is fitted with field devices: (1) the high speed WIM system (HS-WIM), composed of road sensors, a road side unit (RSU), cameras and communication tools; (2) the module of mean speed measurement (MSM), linked to a WIM system located 5–10 km upstream, provides the average vehicle velocity using its license plate number; (3) the static weighing receiving module (SWRM) receives from the WIM system pictures and characteristics of presumed infringing vehicles to be controlled. It is installed nearby endorsed static or low-speed scales on a parking lot, a toll area, etc.

An Internet central server managing these equipment provides authentication and communications security, collects and temporarily stores data and information required for a well functioning WIM system [18]. The data are collected discreetly while the vehicles move on the road (except portable weigh-in-motion) at normal speed. Concerning Weigh-In-Motion (WIM) systems, WIM static weigh pads and WIM bending plates are some of the most widely used as shown in Fig. 5 (a,b).

The equipment used at the weighing station (static weighing) comprise: weighing devices (weighing beam, data transmission cable, remote control cupboard, displayed board, working station (desktop, printer, weighing management software), constructions (a bituminous access way, a main building, a storing building, parking), water and energy supply (energy supply, water supply (bore hole)). Weighing devices provide: Gross vehicle weight and axle load. Initial calibration is done by the supplier and periodic calibration is performed by the Ministry in charge of mretrology.

Heavy vehicles take the deviation to the weighing beam. Once they get there, they hand the transportation documents of the car to the weighing operator. The ferryman directs the truck to the weighing beam. The truck passes slowly on the beam while axle load values are being transmitted in the working station and appear on the displayed board for the driver. The data are recorded at the same time. Once the last axle has passed, the operator delivers the listing. In case there is overload, the car parks and pays the corresponding amount. If it is not paid, the vehicle is kept at the parking of the weighing station until the overload is removed before getting back on the road. Measurement errors so exist. Most of those equipments are shown in Fig. 6 (a-c).

2.3. *Calculation methods of traffic inputs*

2.3.1. *USA approach of calculation: AASHTO*

The design of multi-layered linear systems involves the cumulative traffic loading over the design period. The concept of axle load equivalency factors (ALEFs) was developed in line with the Mechanistic – Empirical approach (AASHTO traffic design guide). This theory assumes dependence on pavement-related variables (stress, strain), pavement responses (roughness, deflection) and axle configurations (single, tandem, tridem). The values are obtained from field experiments, based on AASHTO Road Test data in the early 1960s. It is related to a standard axle load (81.65 kN, 18 000 lb, 8.165 tons in USA) carried by a single axle with dual tires. The cumulative value is called the equivalent single-axle load (ESAL). Besides that, axle factors (AF), indicates the response effect of different types of axles (single, twin, tandem, quad) based on the standard axle [19,20]. Truck factors (TF) or Truck equivalency factors (TEF) helped to compare and to aggregate truck weights and terrestrial freights. Axle factors depend on: axle spacing, pavement type, pavement response model, axle load, type of truck, single/twin tires, liftable/not liftable axles, pavement thickness, truck suspension type (air, leaf spring), reference speed, tire pressure, traffic class, AASHTO ESAL equation for flexible pavement is given by **Eq. (1)** that follows [21,22]:

$$AF_{ik}(ALEF_i) = \frac{W_{i18}}{W_{ix}} = \left[\left(\frac{L_{18} + L_s}{L_{ix} + L_2} \right)^{4.79} \left(\frac{10^{\frac{G}{\beta_{ix}}}}{10^{\frac{G}{\beta_{18}}}} \right) (L_2)^{4.33} \right]^{-1} \quad (1)$$

Where.

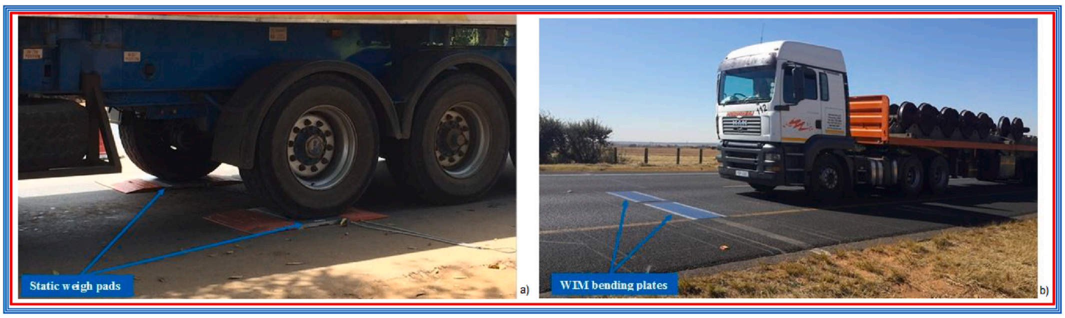

Fig. 5. Weighing materials. a) Portable static weigh pads; b) Weigh-in-motion bending plates [10].

Fig. 6. Meyos Fixed static weigh (FSW) on national road n°1 Yaounde – Obala. a) Weigh pad; b) displayed board; c) working station.

L_{18} , 18 (standard axle load in kips);
L2, code for axle configuration.

1 single axle;
2 tandem axle;
3 triple (tridem) axle (added in the 1986 AASHTO Guide); LS, code for standard axle = 1 (single axle); G, a function of the ratio of loss in serviceability at time, t, to the potential loss taken at a Point, given for flexible pavements by **Eq. (2)** that follows;

$$G = \log\left(\frac{4.2 - P_t}{2.7}\right) \tag{2}$$

P_t is the serviceability;
β_{ix} is given by Eq. (3) that follows;

$$\beta_{ix} = 0.4 + \frac{0.081(L_{ix} + L_2)^{3.23}}{(SN + 1)(L_{ix})^{3.23}} \tag{3}$$

SN: Structural number.

Since the standard axle load is 8165 kg (18, 000 lb; 81.65 kN), to move to a standard axle load weighing 13, 000 kg (30, 000 lb; 13 kg), W_{30} is given as follows in Eq. (4):

$$W_{i30} = \left(\frac{L_{ix} + L_2}{L_{30} + L_2}\right)^{4.79}\left(\frac{10^{\frac{G}{\beta_{30}}}}{10^{\frac{G}{\beta_{ix}}}}\right) \tag{4}$$

Where, W30, number of 30 000 lb. (130 kN) single axle loads.

Truck factor (TF) is given by **Eq. (5)** that follows:

$$TF_k = \sum\nolimits_{i=1}^{k} W_{i30} \tag{5}$$

Where:

TF_k; Truck factor of truck type k;

The Equivalent single axle load (ESAL) is given by Eq. (6) that follows:

$$ESAL = \sum\nolimits_{k=1}^{p} TF_k \; x \; AADTT_k \; x \; Ld \tag{6}$$

Where:

ESAL, daily equivalent single axle load; $AADTT_k$, annual average daily truck traffic of truck type k;
Ld: Lane distribution factor in %; p, number of truck classes.

The cumulative Equivalent single axle load over the design period is given by **Eq. (7)** that follows:

$$W_{18} = 365 \; x \; ESAL \; x \frac{[(1+q)^n - 1]}{q} \tag{7}$$

Where:

W_{18}, cumulative equivalent single axle load over the design period [23]; n, design period; q, growth rate.

2.3.2. French approach of calculation: SETRA - LCPC

In the French pavement design guide (Mechanistic – Empirical), the road traffic is accounted for by the number of equivalent reference axle loads NE (W_{18}), defined as twin wheel axles, loaded at 130 kN. This number is calculated from the number of heavy vehicles N_{PL} passing on the pavement during the design period, used for each critical quantity (extension for bituminous concrete, tension for hydraulic materials and cement concrete, vertical contraction for granular materials and subgrade) coefficients of mean aggressiveness CAM (ALEF).

The truck traffic is coputed from axle load data. For a single axle, the aggressiveness coefficient A (AF, ALEF) according to the NF–P098-082 standard is defined by Eq. (8) that follows:

$$A_{jgk} = K\left(\frac{P_{jgk}}{P_0}\right)^{\alpha} \tag{8}$$

Where:

P_{jgk} is the mean load of the jth class of axle type g (simple, tandem, tridem), of truck type k; P_0 the reference axle load; α an exponent depending upon the material into consideration (5 for flexible pavements); K a coefficient depending upon the type of axle (single:1; tandem:0,75; tridem:1.1 for flexible pavements).

The aggressiveness coefficient of a given type of axle (g, simple, tandem, tridem) and of a given type of truck (k) was calculated as presented in Eq. (9) that follows:

$$A_{gk} = \frac{\sum_{j=1}^{x} n_{jgk}\ x\ A_{jgk}}{N_{PL-w}} \tag{9}$$

N_{PL-w} is the total number of weighted trucks over the duration of the weighting operation;

n_{jgk} is the number of axles of the jth class of axles type g and of truck type k; A_{gk}, agressiveness coefficient of axle type g from truck type k.

Truck factors (TF) were by Eq. (10) that follows:

$$TF_k = \sum_{g=1}^{k} A_{gk} \tag{10}$$

The Equivalent single axle load (ESAL) is given by Eq. (11) that follows:

$$ESAL = \sum_{k=1}^{p} TF_k\ x\ AADTT_k\ x\ Ld \tag{11}$$

Where:

ESAL, daily equivalent single axle load; $AADTT_k$, annual average daily truck traffic of truck type k;

Ld: Lane distribution factor in %; p, number of truck classes.

The number of heavy vehicles over the design period is calculated as indicated in Eq. (12) that follows [19]:

$$N_E = 365\ x\ ESAL\ x\ \frac{[(1+q)^n - 1]}{q} \tag{12}$$

2.3.3. Sub-Sahara African countries' method of calculation: CEBTP

Sub-Sahara Africa countries empirical design guide was drafted by CEBTP in the early 1970th. This work will come as a great contribution. In the guide, five traffic classes were defined and called « Ti », i takes its values from 1 to 5. These classes go from the lower to the higher: T_1, T_2, T_3, T4, and T5. The unit is ESAL of 13 tons for 15 years of design period. Table 1 that follows gives these classes.

There is neither any axle factor, nor link with the weighing system and nor any possibility to increase the design life.

2.4. Data collection and analysis

2.4.1. Regression and projection of traffic on the reference road

The study was performed on the regional road n°33 Obout – Endom – Akonolinga in Cameroon. The Ministry of Public Works of Cameroon intends to built this road. The contract was awarded to a local supervising company for technical studies. Since the axis is not tared and doesn't have weighing stations, cluster analysis was performed. The reference axis chosen is the national road n°1 Yaounde – Obala which has a fixed static pad (weighing station) at the place called Meyos as presented in Fig. 7(a and b).

Table 1
Traffic classes defined by CEBTP in Sub-Sahara Africa countries [24].

ESAL 13 tons (15 years)	Traffic classes	*AADTT veh/day (N)*
< 5 .10^5	T1	<300
From 5 x10^5 to 1.5 x10^6	T2	From 300 to 1000
From 1.5 x10^6 to 4 x10^6	T3	From 1000 to 3000
From 4 x10^6 to 10^7	T4	From 3000 to 6000
From 10^7 to 2 x10^7	T5	From 6000 to 12000

Meyos weighting station; Roads under studies.

2.4.2. 1.4.1 Regression and projection of traffic on the reference road

The Ministry of Public Works of Cameroon performs manual traffic counts every year on its national road network. These data were provided for the period 2004 to 2009. In order to complete these data, we performed weighting operations on the national road n°1 Yaounde – Obala, during the month of December 2020 giving 31 consecutive days. At the same time, the researchers measured axle spacing for different axle types. The data collected in the Ministry of Public Works are presented in Table 2 that follows.

From these data, AADTT stands at 1048 during this period with the following repartition: buses, 7%; trucks two axles, 20%; trucks three axles 58%; trailers, 12%; timbers, 3%. Trailers are mostly composed of T_4, T_5 et T_6 trucks. The traffic regression curve is represented in Fig. 8.

The regression equation is given by Eq. (13).

$$Y = 47,683X - 94616 \tag{13}$$

From this equation, the heavy vehicles traffic growth rate q is 4.5% per year. This regression helped to perform projection of heavy vehicles traffic in 2021, since weighing data were collected in 2020. So, the value of the projected traffic is 1751. In connection with the percents given from the data collected in the Ministry of Public Works, this includes 123 buses, 368 trucks two axles, 998 trucks three axles and 263 trailers.

The results of the weighing operation performed on NR 1 Yaounde – Obala in December 2020 is presented in Table 3 that follows.

2.4.3. Regression and projection of traffic on the specific road

Weighing, axle load data and axle factors collected on the national road n°1 Yaounde – Obala were used.

From road traffic data collected for the period 2004 to 2009 in the Ministry of Public Works of Cameroon, the percent of truck traffic was calculated. The value is 51 heavy vehicles/day/2 lanes. The data collected are presented in Table 4.

From these data, AADTT stands at 61 with the following repartition: buses, 5%; trucks two axles, 57%; trucks three axles 27%; trailers, 4%; timbers, 7%. The traffic regression curve is represented in Fig. 9.

The heavy vehicles traffic is decreasing; we assumed a growth rate q of 4% per year as from 2008. So, the value of the projected traffic in 2021 is 106. The enlarged decomposition of traffic for all heavy vehicle categories, according to the rates obtained on the national road n°1 Yaounde – Obala gave the following results in Table 5.

2.5. Calculation of cumulative ESAL

For this study, 2-axle trucks and buses shall be put together. Trailers and timbers shall be put together and divided into three categories: 4-axle trucks trailers having a single unit-single tires, a single unit-twin tires and a tandem unit-twin tires, 5-axle trucks trailers having a single unit-single tires and two tandem unit-twin tires and 6-axle trucks trailers having a single unit-single tires, a tandem unit-twin tires and a tridem unit-single tires. Trucks of more than 6 axles will not be taken into consideration regarding their number as summarized in Fig. 10 (a-e).

3. Results and discussion

The repartition of heavy vehicles of the national road number one Yaounde – Obala during the month of December 2020 was done. The values are presented in Fig. 11 that follows.

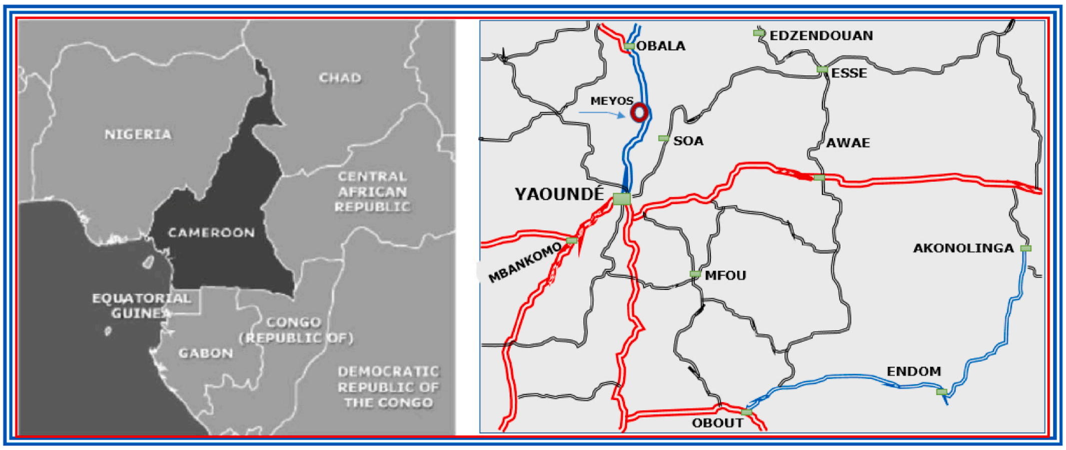

Fig. 7. Study location; a) Map of Cameroon; b)Road sections and weighting stations.

Table 2
Traffic data on national road n°1 Yaounde - Obala from 2004 to 2009 [9].

	2004	2005	2006	2007	2008	2009	Average
Bus	52	55		96		81	71
T2A	225	200		198		221	211
T3A	558	556		737		570	605
Trailers	62	69		156		211	124
Timbers	36	41		50		18	36
AADTT	933	921	0	1237	0	1100	1048

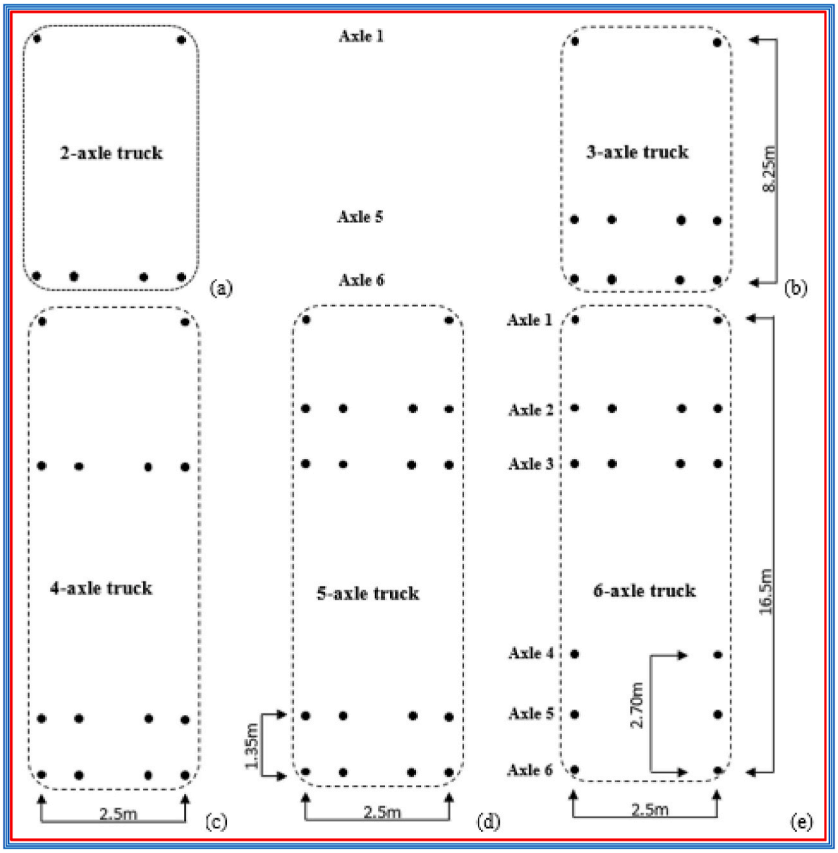

Fig. 8. Regression of heavy vehicles' traffic on the national road n°1 Yaounde – Obala from 2004 to 2009.

The repartition showed that most of the vehicles circulating on the NR1 Yaounde – Obala during the month of December 2020 are composed of 3-axle trucks, representing 69% of the weighted vehicles. These trucks carried 61% of the terrestrial freight on this road, rating 177, 431, 360 kg. Also, axle load spectra was represented. The values are presented in Fig. 12 as follows.

Though the regulations do not provide limits for single units single tires (front tires), the average value rates at 6,8 tons. Then this limit could be fixed at 7 tons. 4-axle trucks present the highest load value (12.5 tons). This type of truck presents too much risk of overload. Then, shippers should pay attention while loading, in order to avoid overloads and road deterioration. AF were calculated according to LCPC – SETRA method; the values are given in Fig. 13 (a-e) that follows.

From these figures, 1% of 2-axle trucks carrying 2% of freight of this category present an overload in average gross vehicle weight (more than 20 tons) and in AF (more than 1). In the same vein, 6% of 3-axle trucks carrying 7% of freight of this category present overload in average gross vehicle weight (more than 28 tons) and in AF (more than 1); Also 7% of 4-axle trucks carrying 9% of freight of this category present overload in average gross vehicle weight (more than 40 tons) and in AF (more than 1); 1% of 5-axle trucks carrying 2% of freight of this category present overload in average gross vehicle weight (more than 49 tons) and in AF (more than 1); 8% of 6-axle trucks carrying 10% of freight of this category present overload in average gross vehicle weight (more than 55 tons) and in AF (more than 1). Cluster or data analyses can also be performed for other road sections in Cameroon since many weighing stations have been constructed and many other road sections are still to be constructed.

ALEF and TEF were obtained. The values are presented in Fig. 14 (a-e) that follows.

Table 3
Gross vehicle weight data collected on NR 1 Yaounde – Obala in December 2020.

Truck class (kg)		T2A		T3A		T4A		T5A		T6A		Total	
lower	upper	Num	T GVW (kg)	Num	TGVW (kg)	Num	TGVW (kg)	Num	TGVW (kg)	Num	TGVW (kg)	Num	TGVW (kg)
0	5000	1	4560	0								1	4560
5000	10000	15	124 480	0								15	124 480
10000	15000	112	1 493 440	6	87 640	1	12 740					119	1 593 820
15000	20000	307	5 384 020	152	2 780 160	4	72 720	7	129 040			470	8 365 940
20000	25000	146	3 170 480	2240	52 669 500	13	293 460	20	466 780	4	94 180	2423	56 694 400
25000	30000	7	186 280	4055	109 420 720	58	1 610 980	85	2 385 740	22	622 980	4227	114 226 700
30000	35000			375	11 732 100	59	1 918 980	86	2 766 820	62	2 024 440	582	18 442 340
35000	40000			21	780 280	105	3 919 440	274	10 467 940	53	2 005 160	453	17 172 820
40000	45000					17	698 320	713	30 296 040	213	9 167 620	943	40 161 980
45000	50000					1	45 740	271	12 684 500	393	18 617 880	665	31 348 120
50000	55000							19	989 660	57	2 945 580	76	3 935 240
55000	60000							1	58 600	9	503 840	10	562 440
60000	65000							2	125 160	3	186 580	5	311 740
		588	10 363 260	6849	177 470 400	258	8 572 380	1478	60 370 280	816	36 168 260	9989	292 944 580
		6%		69%		3%		15%		8%		100%	

The heavy vehicles' traffic volume obtained after regression (1751) is different from the weighted heavy vehicles (9989 for 31 days, 333 trucks per day). It means that all the heavy vehicles are not loaded. The loaded rate of heavy vehicles on the national road n°1 is then 20%.

Table 4
Road data existing in the Ministry of public works of Cameroon for the regional road n°33 Obout – Endom – Akonolinga from 2000 à 2009.

	2002	2003	2004	2005	2006	2007	2008	2009	Average
Bus	3	5	2	2					3
2-axle truck (T2)	65	46	31	17		15			35
3-axle truck (T3)	21	15	28	3		15			16
Trailers (L)	0	0	0	0	0	0	0	0	2
Timbers									4
AADTT	86	61	59	20		30			61

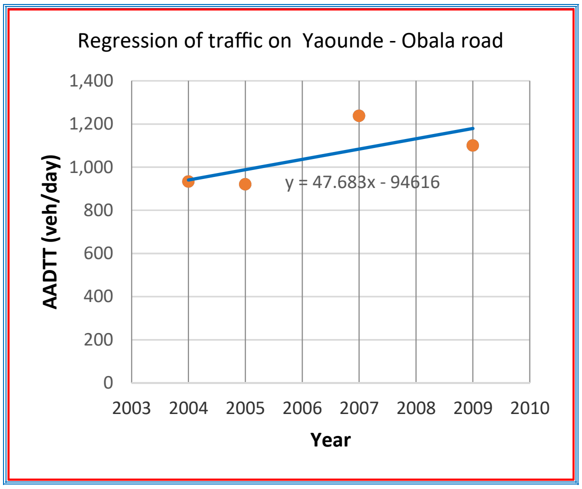

Fig. 9. Regression of heavy vehicles' traffic on the regional road n°33 Obout – Endom – Akonolinga from 2001 to 2008.

Table 5
Enlarged decomposition of heavy vehicles traffic per category on the regional road n°33 Obout – Endom – Akonolinga in 2021

Catégories of heavy vehicles						
	2-axle truck (T_2) 6%	3-axle truck (T_3) 69%	4-axle truck (T_4) 3%	5- axle truck (T_5) 15%	6-axle truck (T_6) 8%	Total
AADTT	6	72	3	16	9	106

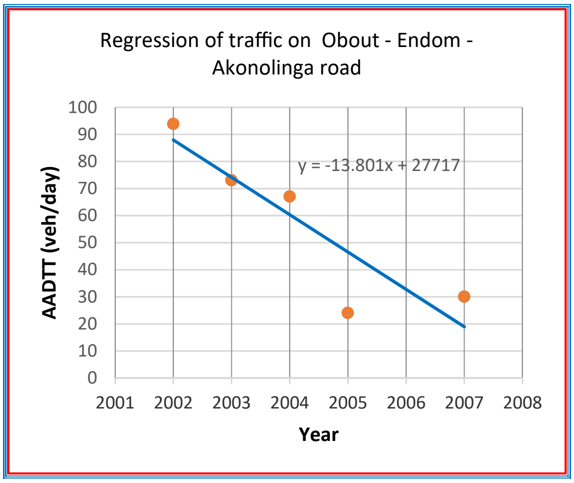

Fig. 10. Truck classification & axle spacing. a) 2-axle trucks; b) 3-axle trucks; c) 4-axle trucks trailers; d) 5-axle trucks; e) 6-axle trucks Calculations were then performed according to the various methods proposed in 1.3.

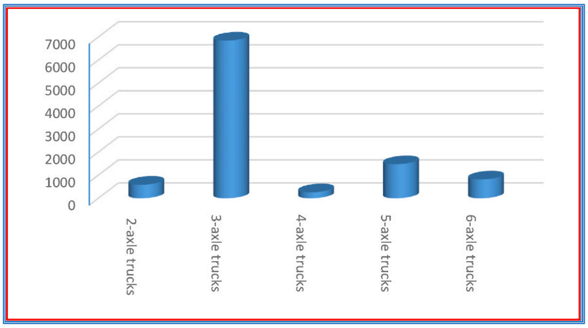

Fig. 11. Frequency distribution of heavy trucks weighted on the national road n°1 Yaounde – Obala in December 2020.

a) 2-axle trucks; b) 3-axle trucks; c) 4-axle trucks trailers; d) 5-axle trucks; e) 6-axle trucks.

According to these values, there is not enough similarity between AASHTO and LCPC – SETRA methods; the highest TEF for AASHTO method was encountered for 6-axle trucks, while this highest value was found for 4-axle trucks. The traffic equivalency factor rated 0.7 for LCPC – SETRA and 0.9 for AASHTO. The results of the calculation of ESAL over the design period (15 years) were summarized in Table 6 that follows.

AASHTO and LCPC – SETRA give nearly the same values; for CEBTP, the value is a bit high. This shows that no method is fit to be used in Sub-sahara African countries to generate traffic data. It is necessary to deepen studies in this way in order to propose a scientific approach. Further more, these values as far from the one obtained by the supervising company in charge of technical studies of this road (317 trucks per day, 3 322 588 ESAL, traffic class T3).

Weighing and axle-load control systems were found to be inaccurate; these operations are performed at the same time by public services. Also, overloaded vehicles continue to circulate on the road despite weighing points. It could be envisaged to have weighing operations being done by shippers at the loading points and administration to undertake controls. This would avoid overloaded vehicles to reach the road. It seems to be an important step to make in order to industrialize transportation and insure economic growth. On the other side, no link was found between manual traffic counts, weighing operations and pavement design.

Fixed weighing stations are high-cost for Low Middle Income Countries (LMIC), and cause too much disturbance for road drivers and transport industries. It is necessary to advice those countries in investing in WIM which are low-cost and more accurate in data

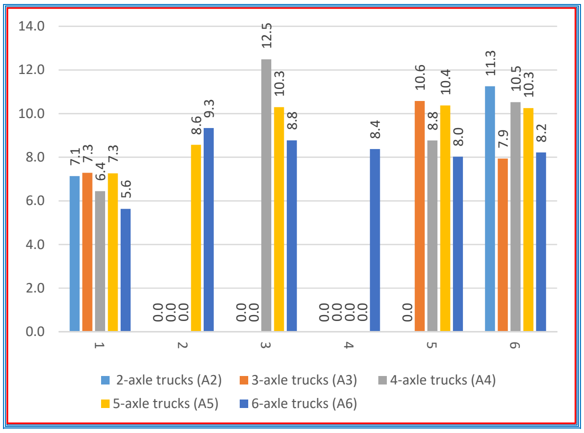

Fig. 12. Axle load spectra distribution on the national road n°1 Yaounde – Obala in December 2020.

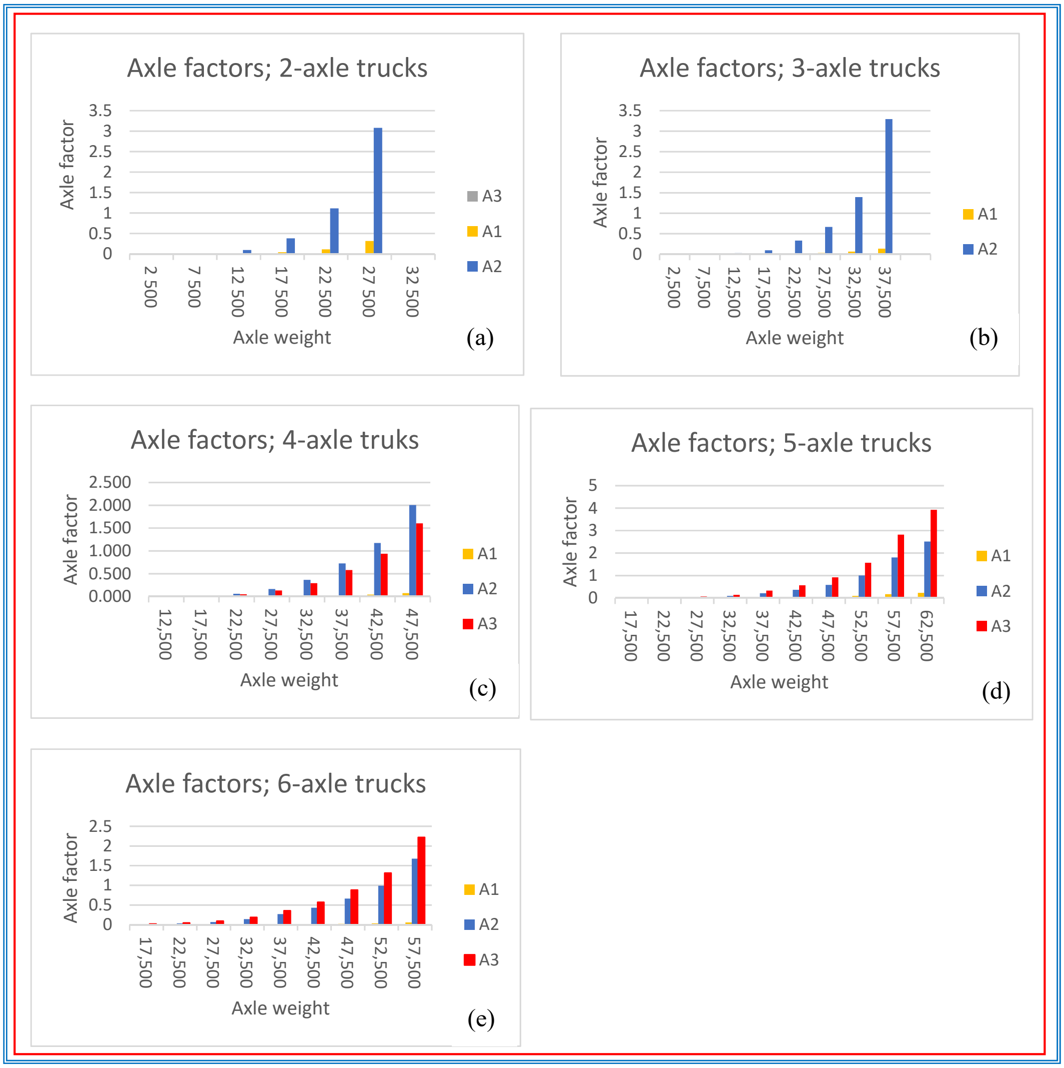

Fig. 13. AF distribution for different trucks. a) 2-axle trucks; b) 3-axle trucks; c) 4-axle trucks trailers; d) 5-axle trucks; e) 6-axle trucks.

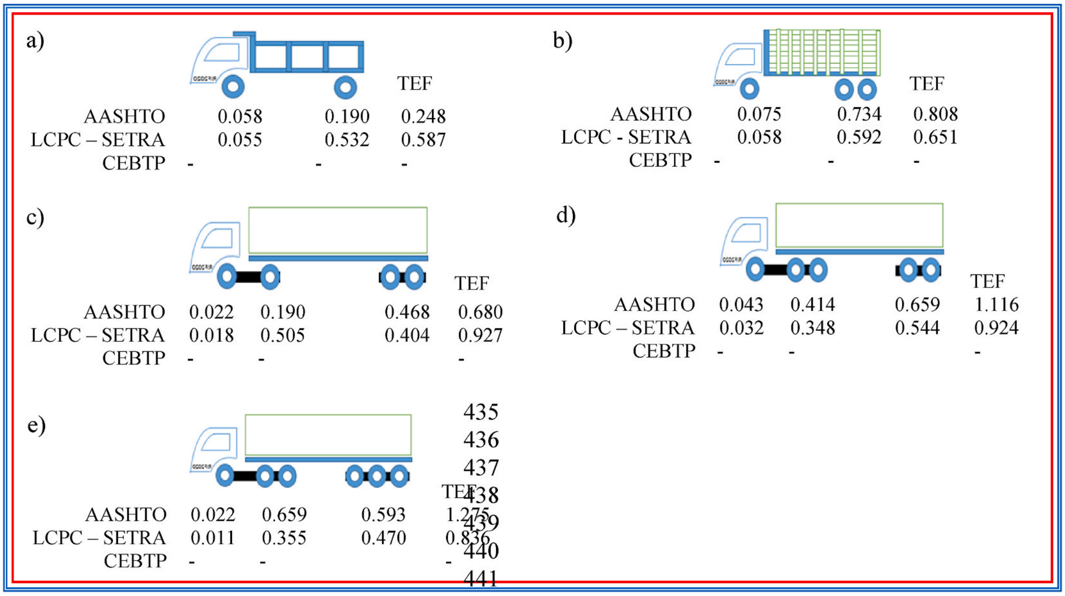

Fig. 14. ALEF and TEF distribution for different truck classes and for different methods.

Table 6
C - ESAL from different methods

Method	AASHTO	LCPC-SETRA	CEBTP
C-ESAL (13 tons)	332 822	275 771	500 000

collection and involve researchers of those countries to get interested in the domain.

Our literature review was based on articles that are free of charge because of our relatively low incomes. In the case that the researchers are subsidized, the domain and other related topics will be explored further.

4. Conclusion

The cumulative truck traffic over the design period in term of equivalent axle load is an important input for pavements. Many methods have been proposed so far to come up with this input. But those methods are relatively different. This is the reason why it has been necessary to get an overview and perform a comparison. So, regular traffic data collection is important in pavement design. Unfortunately, manual traffic count is still performed in Sub-Sahara African countries besides semi-automatic traffic count. Automatic traffic count is mostly found in Higher Income Countries. This study brought out equipment used for these purposes. Nevertheless, vehicle classification is the base of traffic studies as well as truck classification. In many countries, traffic study guides are tools that help to give better results. Though this document was not drafted in Cameroon, we collected traffic data available in the Ministry of Public works of the said country in order to capture annual average daily truck traffic for some passed 10 years.

Axle and gross vehicle loads were recorded on a fixed static weigh (weighting station) pad on the national road n°1 Yaounde – Obala in Cameroon. Weighting operations were performed during the month of December 2020. These date helped us to have traffic load spectra. Cluster analysis followed so as to move from this road to the regional road n°33 Obout – Endom – Akonolinga. Regression of the data gave us a traffic growth rate. Three methods were presented in this study in order to generate traffic data. According to these methods, AFs were calculated. The results showed that 2, 3, and 5-axle trucks presented higher values (nearly 4); 4 and 6-axle trucks presented lower values (less than 2). TEFs rated between 0.248 (2-axle trucks) to 1.275 (6-axle trucks). Those methods gave us nearly the same value of ESAL. But the one used in Sub-Sahara Africa countries seems very poor. This is why studies must be carried out in order to propose adequate traffic surveys in this area, according to mechanistic – empirical approach for pavement design.

The precision of the data obtained were not evaluated and it is recommended to do so during the further studies. Data analyses can also be performed for other road sections in Cameroon and abroad according to this method in order to carry out evaluation works of traffic studies. One month data collection is normally sufficient for this type of study.

As far as the applications are concerned, terrestrial freight management system of Cameroon can be improved in order to give monthly volumes. Having realized that overloaded vehicles continue to circulate on the roads in Cameroon despite weighing points, shipping systems can be improved. In this way, it is recommended to revise regulations so as to industrialize weighing operations by allowing private companies to create and manage weighing activities at shipping points before taking the road. This will reduce expenses of government in constructing and managing weighing stations, avoid corruption of government personnel appointed at weighing stations and sustain economic growth. Also, it will help shippers to avoid overload fees. In the same vein, traffic studies' manual of Cameroon can be drafted according to this study which has helped to link traffic count and weighing systems taking into account M-E pavement method which is more accurate than the empirical method.

Scientific community is therefore equipped with a case study coming from Cameroon and Sub-Sahara African countries. Also, this paper will be an important step to carry out research in pavement design in Cameroon and Sub-Sahara African countries. The use of WIM is not yet part of traffic studies in Cameroon and Sub-Sahara African countries; Research can be undertaken in this way.The calibration of weighing equipment was not done during this study and it is the main weakness. It is recommended to proceed to calibration during further analyses. Also, this research was not subsidized and that was also a weakness.

Author contribution statement

Richard Fogue & Mpele Mamba: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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