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REVIEW ARTICLE

COMPARATIVE STUDY BETWEEN THE “NOMBRE D’ESSIEUX ÉQUIVALENTS” (NE) AND THE NUMBER OF “EQUIVALENT SINGLE AXLE LOAD” (ESAL)

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ABSTRACT

The generalized evolution of the level of road traffic in number and characteristics, associated with overloads, today leads to an underestimate of the loads due to traffic when designing road structures. Consequently, this under-evaluation of the aggressiveness of traffic is accompanied by early appearances of damage to the roads and at the same time causing enormous budgetary expenditure on maintenance and rehabilitation. The objective of this work is to establish the methods for analyzing loadings due to traffic in two design methods (the French rational method and the Mechanistic-Empirical method) and then to establish a relationship between the “Nombred’ Essieuxéquivalents” (NE) and the number of “Equivalent Single Axle Load” (ESAL). The distribution of heavy goods vehicles (HGVs) on different weighing stations in Senegal shows that heavy goods vehicles are generally overloaded with an overload percentage of up to 87%, largely exceeding the tolerance of 20% applied to the Total Authorized Weight. Charge (PTAC) by the West African Economic and Monetary Union (UEMOA). By plotting the ESAL graphs as a function of NE, we notice that the point clouds are arranged in the same way. An exponential type relationship between NE and ESAL is found with a coefficient of determination (R^2) varying between 0.92 to 0.95. The resemblance of the graphs clearly indicates that the effect of the terminal serviceability index (p_t) and the Structural Number (SN) on the number of ESALs has almost no influence on the relationships that may exist between ESALs. and not. The choice of the reference axle and the expression of the load equivalence coefficient, however, constitutes one of the important elements in taking traffic into account in the design of pavement.

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INTRODUCTION

The primary role of roads is to support vehicles and their loads with an adequate level of comfort and safety. The mechanical stresses taken into account for the design of pavement generally come from heavy vehicle traffic loads. From this point of view, the performance of a road goes hand in hand with its capacity to receive, without obvious damage, the various loads brought by cars according to the conditions imposed by environment. Thus, and as with any structure, a good knowledge of operating loads proves to be a major asset in the design of pavement. And this can only be achieved with a good traffic study. Following this logic, it is not surprising that we consider the traffic as a fundamental element which intervenes upstream of any reflection relating to the development of transport infrastructures. Overall, only heavy goods vehicle traffic is considered since the latter constitute the most aggressive elements in terms of loading. Pavement degradation is generally the result of the superposition of effects due to loads and those due to climatic variations. Heavy vehicle traffic, by its volume and loads and depending on the type of pavement, causes innumerable damage and subsequently its destruction through the various mechanical stresses induced on the pavement. Therefore, it is important to control this parameter to be able to determine the most appropriate structure for a given traffic. By definition, the Number of Equivalent Axles (NE) and the number of “Equivalent Single Axle Load” (“ESAL”) all represent the traffic equivalent to a number of repetitions of a reference axle, cumulative over the entire duration life of the pavement to be designed (SETRA-LCPC, 1994; AASHTO, 1993). The evaluation of the aggressiveness of the loading on road structures is done in most design methods based on the concept of simple axle load equivalence. The latter, based on the Average Aggression Coefficient (CAM in the french method) or the “Equivalent Axle Load Factor” (EALF in the AASHTO semi-empirical method) contributes to converting all of the complex loads (i.e. different from the reference axle) into a number of repetitions of the simple reference load, which is easy to use as input data in the structure design procedure (O. M. Sy, 2012). Equivalent traffic therefore makes it possible to express the effect of a multitude of different loads based on a reference load. The equivalent traffic associated with the characteristics of the reference axle which are among others its load, the contact pressure of its tires, the center distance, will allow, from mechanical and/or empirical models, to calculate the admissible stresses at the level of the different layers of the roadway or to predict the performance of the constructed structure. In the method of calculating the equivalent traffic in number of repetitions of the reference axle of 130 kN, “NE” is estimated from the following relationship (SETRA LCPC, 1994):

$$\boldsymbol{NE = N \times CAM} \qquad \text{................(Eq. 1)}$$

where N is the cumulative number of heavy vehicles for the calculation period of p years; CAM is the Average Aggression

Coefficient of the trucks compared to the reference axle (single axle with dual wheels of 130 kN).

In the French method (SETRA LCPC, 1994), the aggressiveness A of an axle is calculated from the following fourth power rule (Eq. 2):

$$\boldsymbol{A = K \times \left(\frac{P}{P_0}\right)^{\alpha}} \quad \text{…………….(Eq. 2)}$$

where P is the load of any axle; P_0 is the reference axle load; K and α depend on the nature of the material and the pavement structure.

The aggressiveness of a trucks is calculated as the sum of the aggressiveness of its axles. On the other hand, the CAM is defined as the sum of the aggressiveness of all the axles divided by the number of heavy goods vehicles. Generally speaking, NE is written in the form (Eq. 3):

$$NE = \frac{(1+\tau)^p - 1}{\tau} \times MJA \times \frac{1}{NPL}\left[\sum_i \sum_{j=1}^{3} K_j \times n_{ij} \times \left(\frac{p_i}{p_0}\right)^{\alpha}\right] \times 365 \quad \text{…(Eq. 3)}$$

where K is a coefficient allowing the type of axle to be taken into account; N_{PL}: number of trucks during the counting period; MJA: average annual daily truck traffic; K_j: coefficient corresponding to the type of axle; n_{ij}: number of elementary axles of type j and load class P_i. In the AASHTO pavement design method, the reference axle chosen to determine traffic is the single axial load of 18 kips (80 kN). The ESAL assessment consists of a summation of the equivalent effects of all axle loads over the design duration and is calculated by the relationship below: (Y. Huang, 1993; NCHRP 1-37A, 2004; A. Hadi, 2009):

$$\boldsymbol{ESAL = \sum_{i=1}^{m} F_i \times n_i} \quad \text{……………(Eq. 4)}$$

where m represents the number of axle groups; F_i *is* the equivalence factor of load class *i*.

The empirical equation developed from AASHO road test to calculate the load equivalence factor F_i ("Equivalent Axle Load Factor") is a function of several variables and is given by Equation 5.

$$\boldsymbol{EALF(flexible) = \left(\frac{L_x+L_2}{18+1}\right)^{4,79} \times (L_2)^{-4,33} \times \left(\frac{10^{\left(\frac{G_t}{\beta_{18}}\right)}}{10^{\left(\frac{G_t}{\beta_x}\right)}}\right)} \quad \text{…….(Eq. 5)}$$

where $\beta_x = 0{,}40 + \frac{0{,}081(L_x+L_2)^{3,23}}{(SN+1)^{5,19}L_2^{3,23}}$ and $G_t = log\left(\frac{4{,}2-pt}{4{,}2-1{,}5}\right)$

L_x is the load on a single axle or on a tandem or tridem axle assembly; L_2 is the axle configuration code; SN is the Structural Number; p_t is the final serviceability index; G_t is a function of P_t; β_{18} is the value of β_x when L_x is equal to 18 Kips and L_2 equal to 1. It is possible to theoretically calculate this factor from stresses, strains and failure criteria, generally using a fourth power law to be applied to the ratio of two different loads to obtain the ratio between the two numbers of application which leads to the same damage. We have:

$$EALF = \left(\frac{\varepsilon_x}{\varepsilon_{18}}\right)^4 = \left(\frac{L_x}{L_s}\right)^4 \quad \text{…………….(Eq. 6)}$$

where $\varepsilon_x$is the tensile deformation due to the load axle x at the base of the bituminous layer; ε_{18} is the tensile deformation due to the 18 kips (80 kN) axle load at the bottom of the bituminous layer.

The general equation for calculating ESAL is obtained by summing all the load groups:

$$\boldsymbol{ESAL = \sum_{i=1}^{m}(p_iF_i)(ADT)_0(T)(A) \times G \times D \times L \times 365 \times Y} \quad \text{(Eq. 7)}$$

where *(ADT)*$_0$ is the annual Average Daily Traffic (vehicle/day) at the start of the design period, Y is the design period in years; L is the lane distribution factorwhich varies with the volume of traffic and the number of lanes (%); D is the directional distribution factor, which is usually assumed to be 0.5 unless the traffic in two directions is different (%); G is the growth factor; A is the average number of axles per vehicle; T is the percentage of trucks in the *ADT*; $p_i$is the percentage of total repetitions for the i_{th} load group. As in some cases the choice of the type of structure and materials is based on the value of the equivalent traffic, then it is essential to have a reliable estimate of "NE" or ESAL. The objective of this study is the comparison between "NE" and ESAL and to assess the effect of overloads on the aggressiveness of road traffic in order to facilitate the transition between rational and mechanistic-empirical design methods.

Method for Collecting road Weighing Data: The West African Economic and Monetary Union (WAEMU) Council of Ministers, in an effort to better preserve the road heritage of states, adopted in 2005 regulations relating to the harmonization of standards and procedures for controlling the size, weight and load of the axle of heavy vehicles (UEMOA, 2005). The maximum authorized axle load of vehicles and combinations of vehicles authorized to circulate on the road networks of WAEMU member states must not exceed the limits given in Table 1 (UEMOA, 2005).

Table 1. Axle load limits of a motor vehicle or trailer and semi-trailer (UEMOA, 2005)

Axle designation	Load limit (tons)
- Front single axle	6
- Intermediate or rear single axle with single wheel	11.5
- Single intermediate or rear axle with dual wheels	12
- Intermediate or rear tandem axle ▪ Type 1 tandem ▪ Type 2 tandem ▪ Type 3 tandem ▪ Type 4 tandem	 11.5 16 18 20
- Tridemaxle ▪ Tridem, type 1 ▪ Tridem, type 2	 21 25
- Trailer, front single axle	6

The State of Senegal, through the Ministry of Infrastructure and Transport and the Roads Department, began raising awareness on July 26, 2012 regarding transporters of heavy vehicles weighing more than 3.5 tons. To control axle loads, the company AFRIQUE PESAGE SA, through its management method, uses a vehicle weighing system using mobile axle weighers. This version uses weighing platforms associated with industrial IT on which weighing and invoicing software is installed. This system provides in real time a set of information including the weight of the axle, the weight of the axle groups, the total weight, the vehicle overload and invoicing in the event of an infraction. In addition, a series of questions is asked to the driver of the vehicles allowing other information to be obtained, including the origin and destination of the vehicle, the product transported, etc. For this study, only the number of trucks and the number of total axle applications in each load interval for a given axle type (single, tandem, tridem and quad) counted over a period are used.

RESULTS AND DISCUSSIONS

Distribution of axle types and truck loads: Data from axleweighings are obtained at the Diamniadio and Kaffrine sites, in Senegal (M. A. Seck and A. Fall, 2014). Trucks are checked for each site in both directions, i.e. entry and exit. The weighing stook place at each site as indicated in table 2. Table 3 indicates that of all the trucks recorded, single axles are by far the most common. Figure 1 shows the distribution of types of trucks recorded.

Table 2. Data table (direction, period, number of trucks, TMJ)

Direction	Number of trucks	Number of weighingdays	MJA
Diamniadio-Bargny1	629	9	70
Diamniadio-Bargny2	689	10	69
Bargny-Diamniadio	969	9	108
Koalack-Kaffrine	1079	9	120
Kaffrine -Kaolack	179	9	20

Table 3. Distribution of axle types recorded (for all trucks)

	Single axles	Tandem axles	Tridemaxles	Quad axles	Total
Number	6298	1807	1947	57	10107
Percentage	62.32	17.84	19.27	0.6	100

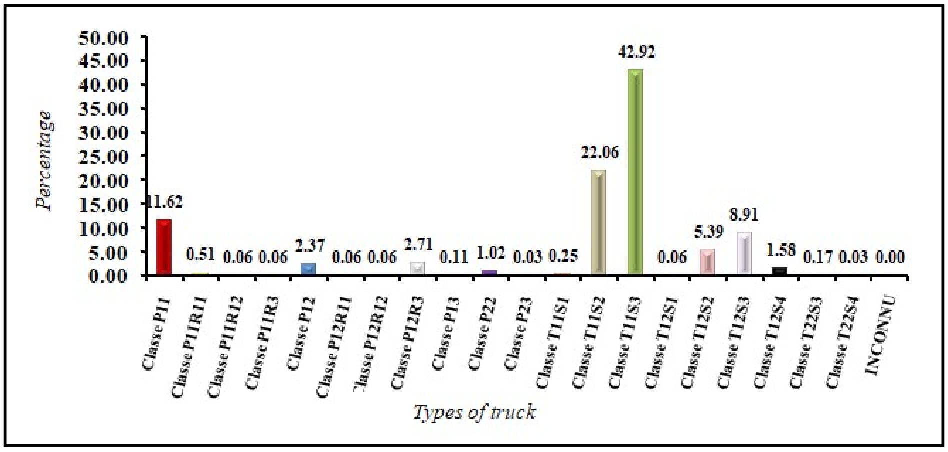

Figure 1. Distributions of types of trucks recorded across all campaign points (Seck and Fall, 2014)

Table 4. Distribution of trucks recorded on weighing stations (AFRIQUE PESAGE SA, 2013; M. A. SeckandA. Fall, 2014))

	Main highways				
	Kaolack-Kaffrine	Kaffrine-Kaolack	Diamniadio-Bargny2	Bargny-Diamniadio	Diamniadio-Bargny1
Total number of trucks	1079	179	689	969	629
Numberof trucks overloaded	578	72	65	288	548
Overload percentage	53.57	40.22	9.43	29.72	87.12

These results indicate that the types of trucks which circulate on the RN1 where the weighing sites are located are mainly the following: T11S3 (5 Axle Truck) which represent 42.96% of truck traffic, T11S2 (4 Axle Semi Articulated : 22.06%) and P11 (Light Commercial Vehicle :11.62%). The distribution of heavy goods vehicles on the different weighing stations (table 4) shows that all heavy goods vehicles are overloaded with an overload percentage of up to 87%, far exceeding the tolerance of 20% applied to the Total Authorized Loading Weights (TALW). The calculations of the aggressiveness coefficients and the truck factors allowing respectively the determination of "NE" and ESAL traffics, will be carried out from the numbers of axles by load class and by type of axles in the directions studied.

Calculations of "NE" and ESAL values: The calculation of the values of "NE" and ESAL will only be done for a flexible pavement structure since the law of equivalence of loads for this type of pavement gives more satisfactory results compared to the law of equivalence of loads on rigid pavement which overestimates, for most cases, the aggressiveness of the axles.

"NE" and ESAL calculationassumptions: The equivalent traffic "NE"will be calculated from equation 3 and the ESAL with equation 7.

Diamniadio-Bargny direction: We have a 2 x 2 lanes roadway, so the ADT and TJM will be corrected with a lane distribution factor equal to 0.9 to take into account the distribution between the two lanes in the direction concerned.

- The traffic growth rate is taken equal to 7%
- In the Bargny-Diamniadio direction:$(ADT_0)xT$ = MJA = 108 trucks/day
- In the Diamniadio-Bargny1 direction:$(ADT_0)xT$ = MJA = 70trucks/day
- In the Diamniadio –Bargny2 direction:$(ADT_0)xT$= MJA = 69 trucks/day

Kaolack-Kaffrine direction

On this axis we have a 2 x 1 lane roadway so we will take 100% of the traffic in the lane considered.

- The trafficgrowth rate = 4%
- Kaffrine-Kaolack direction:$(ADT_0)xT$ = MJA = 20trucks/day
- Kaolack-Kaffrine direction:$(ADT_0)xT$ = MJA = 120trucks/day

The design period will be taken equal to 20 years. As the directions are considered separately, the directional distribution factor will be taken equal to 1. Likewise, the percentage of trucks for ESAL calculation is equal to 100 since all the vehicles registered are heavy vehicles (M. A. Seck and A. Fall, 2014).

Effect of overloads on aggressiveness coefficient: The results from the weighing campaign on the Kaolack - Kaffrine axis associated with the calculation hypotheses will be used following three scenarios to show how overloads influence the calculation of equivalent traffic.

Scenario 1: the results of the axle load distribution are used (real data obtained during the weighing campaign). In this case no processing is carried out on the data.
Scenario 2: The weighed axles are overloaded according to WAEMU regulations (tolerance of 20%). If the axle load exceeds tolerance limit, then the weight of the overloaded axle is replaced with the limit load authorized for this type of axle.For example, for a single axle the load limit is 6 tons, but with the tolerance of 20% the limit passes to 7 tons. So, for a single front axle, if the weight exceeds 7 tons, we maintain this last value.
Scenario 3: None of the weighed axles are overloaded.

Table 5 gives the results of the CAM and NE calculations for the three scenarios. In the Kaolack-Kaffrine direction, daily truck traffic is taken equal to 120. According to the (SETRA LCPC, 1994) guide, the class of this traffic is T3; in the case where the calculation of the CAM is not possible, a default value of 0.8 is given by the guide for this traffic class. Among the three scenarios, only scenario 3 gives a value close to the default value, so it is obvious that the overloads noted on roads considerably increase 2 to 3 times the aggressiveness of traffic.

AND DISCUSSIONS

The use of the method of calculating the equivalence factor with the empirical equation (Eq. 5) gives several values of ESAL (18 values) for a single value of *NE* although this equation depends on the Structural Number (*SN*) and the terminal serviceability (p_t). Table 6 indicates the results obtained after calculation with different values of *SN* and p_t. It emerges from the results of table 6 that when p_t and *SN* increase, the number of ESAL decreases until reaching a limit value for SN=5 whatever the value of p_t and begins to increase. And the ESAL values closest to NE are obtained for SN= 5 and Pt=3. By plotting the ESAL (p_t, *SN*) graphs as a function of NE (Figure 2) we notice that the point clouds were arranged in the same way. An exponential type relationship between NE and ESAL is found with a coefficient of determination (R^2) varying between 0.92 to 0.95 (Eq. 8).

$$\boldsymbol{ESAL = Ae^{B(NE)}} \qquad \text{…………. (Eq. 8)}$$

Table 5. "CAM" and "NE" values found following the three scenarios (Seck and Fall, 2014)

Scenarios	CAM	NE
1	3.3	4.32 E+6
2	1.5	1.93 E+6
3	0.74	9.59 E+5

Table 6. Calculated values of "NE" and ESAL

	KAOLACK-KAFFRINE	KAFFRINE-KAOLACK	BARGNY-DIAMNIADIO	DIAMNIADIO-BARGNY2	DIAMNIADIO-BARGNY1
NE	**4.32E+06**	**7.66E+05**	**4.42E+06**	**1.25E+06**	**2.99E+06**
ESAL (p_t=2 et SN=1)	2.22E+07	5.44E+06	2.67E+07	7.22E+06	1.01E+07
ESAL (p_t=2 et SN=2)	2.14E+07	5.25E+06	2.58E+07	7.01E+06	9.74E+06
ESAL (p_t=2 et SN=3)	1.95E+07	4.75E+06	2.35E+07	6.50E+06	8.98E+06
ESAL (p_t=2 et SN=4)	1.78E+07	4.29E+06	2.14E+07	6.05E+06	8.31E+06
ESAL (p_t=2 et SN=5)	1.74E+07	4.16E+06	2.09E+07	6.00E+06	8.22E+06
ESAL (p_t=2 et SN=6)	1.80E+07	4.30E+06	2.17E+07	6.22E+06	8.52E+06
ESAL (p_t=2.5 et SN=1)	2.20E+07	5.40E+06	2.65E+07	7.18E+06	1.00E+07
ESAL (p_t=2.5 et SN=2)	2.03E+07	4.96E+06	2.45E+07	6.73E+06	9.31E+06
ESAL (p_t=2.5 et SN=3)	1.66E+07	3.98E+06	1.99E+07	5.70E+06	7.77E+06
ESAL (p_t=2.5 et SN=4)	1.35E+07	3.18E+06	1.62E+07	4.89E+06	6.56E+06
ESAL (p_t=2.5 et SN=5)	1.29E+07	2.97E+06	1.54E+07	4.81E+06	6.42E+06
ESAL (p_t=2.5 et SN=6)	1.39E+07	3.20E+06	1.68E+07	5.20E+06	6.95E+06
ESAL (p_t=3 et SN=1)	2.18E+07	5.35E+06	2.63E+07	7.12E+06	9.92E+06
ESAL (p_t=3 et SN=2)	1.90E+07	4.60E+06	2.28E+07	6.38E+06	8.76E+06
ESAL (p_t=3 et SN=3)	1.34E+07	3.15E+06	1.60E+07	4.86E+06	6.46E+06
ESAL (p_t=3 et SN=4)	9.51E+06	2.14E+06	1.13E+07	3.77E+06	4.89E+06
ESAL (p_t=3 et SN=5)	8.77E+06	1.92E+06	1.04E+07	3.67E+06	4.72E+06
ESAL (p_t=3 et SN=6)	1.00E+07	2.18E+06	1.20E+07	4.16E+06	5.40E+06

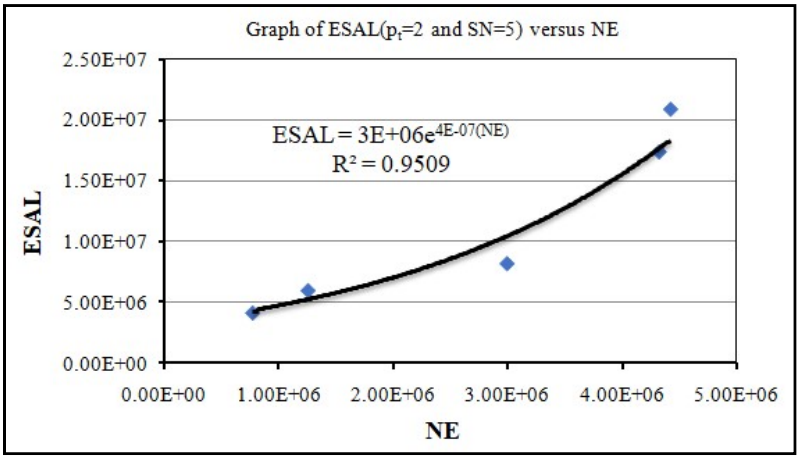

Figure 2. Graph of ESAL(p_t=2 and SN=5) versus NE

where A varies from 2.00E+06 to 4.00E+06, and B=4.00E-7. The resemblance of the graphs clearly indicates that the effect of p_t and *SN* on the calculation of EALF, and consequently on the number of ESALs, has almost no influence on the relationships that may exist between ESAL and NE. Following this we used the fourth power law (Eq. 9) to calculate the load factors for each load class.

Tableau 7. Values of "NE" and ESAL (fourth power law)

	KAOLACK-KAFFRINE	KAFFRINE-KAOLACK	BARGNY-DIAMNIADIO	DIAMNIADIO-BARGNY2	DIAMNIADIO-BARGNY1
NE	4.32E+06	7.66E+05	4.42E+06	1.25E+06	2.99E+06
ESAL (fourth power law)	1.45E+07	3.37E+06	1.75E+07	5.29E+06	7.10E+06

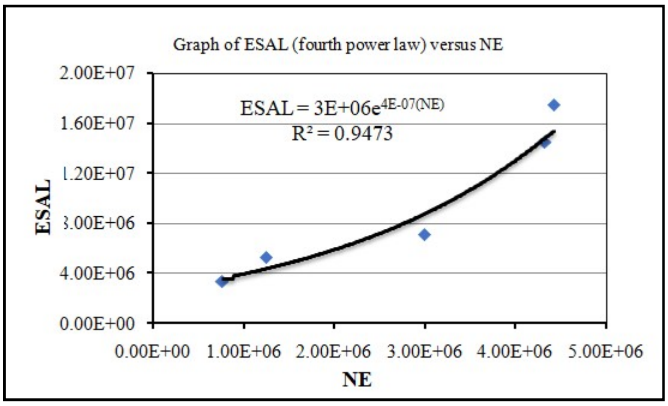

Figure 3. Graph of ESAL (fourth power law) versus NE

The results obtained are reported in table 7 and figure 3. By calculating EALF using the fourth power law, the same trend is obtained.

$$EALF_i = EALF_{ref} \times \left(\frac{L_i}{L_s}\right)^4 \qquad \text{(Eq. 9)}$$

L_i = is the class center load of each axle group
L_S = is the load of a standard axle having the same number of axes.

- For single axles $L_S = 18\ kips = 80\ kN$
- For tandem axles $L_S = 32\ kips = 142\ kN$
- For tridem axles $L_S = 48\ kips = 214\ kN$

$EALF_{ref}$= 1 for a single axle, 0,857 for a tandem axle, and 1,033 fora tridem axle, according to the tables in the AASHTO guide giving the equivalence factors for SN=5 and p_t=2.5 (AASHTO, 1993). By comparing equations 3 and 7 we notice the following differences: the expression of the load equivalence factor used and the value of the reference axle load. These two elements are essentially used to calculate the average aggressiveness coefficient (*CAM*) and the truck factor (T_f), which both represent the average number of reference axles per heavy vehicle. Therefore, the choice of the reference axle and the expression of the load equivalence coefficient constitute one of the important elements in taking traffic into account in the design of pavements.

CONCLUSION

This study is a comparison between "NE" and ESAL traffics, which is used to evaluate the performance of pavements. The results show a relationship in exponential form between "NE" and ESAL with a coefficient of determination (R^2) varying between 0.92 to 0.95. This relationship finds its importance in the case where the effect of loadings due to traffic is estimated with the value of "NE" or ESAL following rational or semi-empirical methods. Therefore, it is convenient to have a relationship which allows to move from one design method to another. Regarding the effects of overloads, the results showed how overloads considerably increase the aggressiveness of traffic. To get closer to the actual loading conditions, it isrecommended that the value of the Average Aggression Coefficient (CAM) is no longer taken by default, or better, use the Equivalent AxleLoad Factor (EALF).

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