

Load Vehicle Damage Factor (LVDF) on National Highways in the Colombian Caribbean Region

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Abstract

Objective: To determine damage factors of trucks that most frequently use national roads in the Colombian Caribbean Region. **Methods/Analysis:** Information provided by the National Institute of Colombian Roads was used according to a mobile weighing operation carried out in 2005. Damage factors for each truck type were obtained from the weights of each vehicular axle, by implementing three different methods: The AASHTO general method, AASHTO simplified method and SHELL method. **Findings:** 16,611 heavy trucks were totally analyzed in the operation. Subsequently, results obtained were compared with those observed in other similar studies carried out in the country. **Application:** Damage factors defined in this study for lighter vehicles have lower values than those observed in previous measurements. In contrast, for the case of heavier trucks, the opposite occurs.

Keywords: Cargo, Damage factors, Roads, Vehicles

1. Introduction

Vehicle traffic on roads is one of the most critical input parameters for pavement design, traditionally associated as the element of the greatest uncertainty¹. Therefore, great care must be taken when estimating traffic loads to which a structure will be subject during service life. The greater the existing lags between estimated and actual traffic, the greater the economic damage generated by cost overruns, due to demand overestimation or vehicular traffic underestimation. Both situations would cause pavement premature deterioration and increase operating costs for road users. Adequate determination of traffic loads is vitally important for road design, since it reduces

possible uncertainty this factor causes in determining expected performance in pavement structure.

Some road agencies, such as the American Association of State Highway and Transportation Officials (AASHTO), promote the use of vehicle load spectra as a tool for characterizing traffic for pavement design purposes^{2,3}. Nonetheless, traffic characterization in terms of number of equivalent repetitions in the design lane remains equally valid, as it has traditionally been carried out in many countries.

In the Colombian case, although studies have been carried out at the national level regarding obtaining damage factors from commercial vehicles, at the Caribbean Region level this activity has not been as prolific. For this

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reason, it is important to have private studies of this type to be able to establish design parameters adjusted to traffic conditions of the Regional Road Network.

Determining the number of equivalent simple axles of 8.2 tons in the design lane, is the technique most used by most pavement design methods for traffic characterization⁴, and it is basically based on expressing all the axles diversity that would make use of a track, in a certain number of reference standard axles that would cause a certain effect on the pavement^{5,6}. For conversion of mixed traffic to equivalent axles, basically two paths can be followed: through determination of the characteristic truck factor of the road corridor, or through the damage factors previously carried out and established by global studies, considered representative of the particular traffic conditions of the road under study^{7,8}.

1.1 Damage Factors for Commercial Vehicles

“Damage factor” of a commercial vehicle is a value expressing the number of simple double-rim axles of 8.2 tons equivalent to the pass of that vehicle⁷. Thus, if for a given region the damage factors representative of the distinct types of commercial vehicles are known, it will be possible to “convert” all the mixed traffic, into equivalent standard axles, with data of a sector vehicular capacity properly differentiated in its different components.

To calculate the damage factor of each commercial vehicle, the sum of the equivalences of each of the axles that make up the vehicle⁷ is established, as expressed below:

$$CVDF = \sum_{i=1}^m LEF \quad \text{Eq 1.}$$

Where: M: number of axles of the vehicle configuration

LEF: axle load equivalency factor

CVDF: commercial vehicle damage factor

There are several methods for the calculation of axle Load Equivalency Factors (LEF). However, for this study, the following will be taken into consideration:

- AASHTO General Method
- AASHTO Simplified Method
- SHELL method

1.2 AASHTO General Method

For the case of flexible pavements, the following regression equation based on the results of the AASHTO⁹ road test can be used:

$$\log\left(\frac{W_{tx}}{wt18}\right) = 4.79\log(18+1) - 4.79\log(Lx + L2) + 4.33\log(L2) + \frac{Gt}{\beta_x} - \frac{Gt}{\beta18} \quad \text{Eq 2.}$$

Where:

W_{tx} : number of load applications of x magnitude per axis at time t.

$wt18$: number of load applications of 18-kilopound magnitude in a time t.

Lx : magnitude of load per axle in kilopound.

$L2$: load code per axle, as this:

$L2 = 1$, for simple axle

$L2 = 2$, for tandem axle

$L2 = 3$, for tridem axle

$$Gt = \log\left[\frac{4.2 - Pt}{4.2 - 1.5}\right] \quad \text{Eq 3.}$$

$$\beta_x = 0.40 + \frac{0.081(Lx + L2)^{3.23}}{(SN + 1)^{5.19} L2^{3.23}} \quad \text{Eq 4.}$$

$\beta18$: value of β_x when Lx is equal to 18 kilopounds and $L2$ is equal to 1

Pt : final serviceability index

SN : structural number as a function of thicknesses (in inches), modules of each layer and drainage conditions of the base and subbase, determined as follows:

$$SN = a1 \times h1 + a2 \times h2 \times m2 + a3 \times h3 \times m3 \quad \text{Eq 5.}$$

$a1$: structural coefficient of the tread layer

$a2$: structural coefficient of the base layer

a3: structural coefficient of the subbase layer
 m2: drainage coefficient of the base layer
 m3: drainage coefficient of the subbase layer

$$LEF = \frac{W_{t18}}{W_{tx}} \quad \text{Eq (6).}$$

LEF: axle load equivalency factor
 LEF = W_{t18}

The practical difficulty of this method consists in the determination of the exact value of the structural number of each road where the weighing operations are carried out. For this study, a SN value of four was assumed, characteristic of pavement structures with typical thicknesses found in the country¹⁰.

1.3 Simplified AASHTO Method

From the AASHTO road test it could be established that the impact of each load per individual axle in flexible pavements can be approximately estimated according to “the law of the fourth power”⁹⁻¹¹. This “law” implies that the damage caused to the pavement due to vehicular traffic increases exponentially with the increase in load per axle. This relationship is denoted by load equivalence factor⁹⁻¹².

$$LEF = \left(\frac{W_1}{W_0} \right)^4 \quad \text{Eq 7.}$$

Where:

LEF: axle Load Equivalency Factor for flexible pavements

W1: load which equivalence with the standard is to be determined

W0: standard load

Depending on type of axle, the standard reference loads take the following values¹⁰:

WO = 6.6, for single axle simple wheel
 WO = 8.2, for single axle double wheel
 WO = 15, for tandem axle
 WO = 23, for tridem axle

1.4 SHELL Method

SHELL recommends in its 1978 design method to use the following expression to calculate equivalent traffic for each type of axis¹⁰:

$$Ne = 2.4 \times 10^{-8} \times L^4 \quad \text{Eq 8.}$$

Where:

Ne: Equivalence factor to simple double wheel axle of 8.2 tons

L = P, for double wheel single axle

L = P / 2, for tandem axle

L = P / 3, for tridem axle

W: load per axle in kilonewton

2. Materials and Methods

In this study, results obtained from damage factors coming from a weighing operation carried out in June 2005 on the Río Ariguaní - Ye de Ciénaga¹ highway were analyzed. The Technical Support Sub-direction of the National Institute of Colombian Roads provided database of these operations.

2.1 Types of Analyzed Vehicles

The types of commercial vehicles listed in Table 1 were considered, corresponding to the most representative trucks using the national road network.

Sample Size

16,611 heavy trucks were totally analyzed in the operation, as detailed in Table 2.

3. Results and Discussion

The following are the most notable results achieved in the present study

3.1 List of Unloaded and Loaded Vehicles

The list of commercial vehicles analyzed under loading and unloaded conditions is presented In Table 3.

As Table 3 shows, most of the samples show loaded conditions. Out of the 16,611 vehicles analyzed, 15,786

Table 1. Analyzed vehicles in the Study

Vehicle Type	Code	DESCRIPTION
Small two-axles truck	08	C2-P
Large two-axle truck	09	C2-G
Rigid three axle truck	10	C3
Truck with semi-trailer	11	C2-S1
Rigid 4 axle truck	12	C4
C3 truck with 1 axle in the semi-trailer	13	C3-S1
C2 truck with 2 axles in the semi-trailer	14	C2-S2
5 axle trucks	15	C3-S2
6-axle truck	16	C3-S3

Table 2. Size of the analyzed sample

TYPE OF VEHICLE		NUMBER	PERCENTAGE
CODE	DESCRIPTION		
08	C2-P	638	3.8
09	C2-G	3,202	19.3
10	C3	582	3.5
11	C2-S1	80	0.5
12	C4	12	0.1
13	C3-S1	21	0.1
14	C2-S2	160	1.0
15	C3-S2	2,166	13.0
16	C3-S3	9,750	58.7
	TOTAL	16,611	100.0

correspond to loaded trucks and 825 to unloaded trucks, representing 95.03% and 4.97% of the total sample respectively.

3.2 Damage Factors Obtained

Table 4 shows the damage factors obtained for loaded and unloaded trucks. These results have been obtained from

Table 3. List of Loaded and Unloaded Vehicles

TYPE OF VEHICLE		NUMBER OF TRUCKS		
CODE	DESCRIPTION	UNLOADED	LOADED	ALL
08	C2-P	47	591	638
09	C2-G	17	3,185	3,202
10	C3	22	560	582
11	C2-S1	10	70	80
12	C4	0	12	12
13	C3-S1	7	14	21
14	C2-S2	15	145	160
15	C3-S2	216	1,950	2,166
16	C3-S3	491	9,259	9,750
TOTALS	No.	825	15,786	16,611
	%	4.97	95.03	100.00

Table 4. Damage factor for load and empty trucks

TYPES OF VEHICLE	DAMAGE FACTORS					
	LOADED TRUCKS			UNLOADED TRUCKS		
	AASHTO METHOD		SHELL METHOD	AASHTO METHOD		SHELL METHOD
Description	General	Simplified		General	Simplificado	
C2-P	0.12	0.13	0.12	0.009	0.013	0.009
C2-G	2.49	2.77	2.93	0.065	0.082	0.066
C3	2.91	3.49	2.49	0.180	0.206	0.103
C2-S1	5.21	5.69	6.14	0.113	0.131	0.115
C4	5.49	6.63	4.64	----	----	----
C3-S1	2.71	3.11	3.08	0.113	0.154	0.110
C2-S2	2.92	3.18	3.23	0.208	0.250	0.207
C3-S2	4.54	5.14	3.82	0.146	0.245	0.130
C3-S3	5.61	5.93	4.51	0.147	0.256	0.133

the Load Equivalence Factors (LEF) evaluated by the three considered methods. That of loaded vehicles was taken as a representative condition, because they represent 95% of the total sample.

Table 5 shows results of the analysis of variance and Tukey test to establish a comparison among the damage factors obtained for each type of vehicle under loaded condition.

According to the ANOVA results presented in Table 5, it can be established that the damage factor for trucks C2-P, C2-S1, C4, C3-S1 and C2-S2, shows in each case, values significantly similar for the three methods. On the other hand, for the C2-G, C3, C3-S2 and C3-S3 trucks, damage factors obtained by the three methods are significantly different. From the ANOVA results, it can be established that damage factors obtained by the SHELL method, in most cases in which there is a significant difference, tend to present values lower than those from the general and simplified AASHTO methods. Out of the three methods applied, those presenting greater similarity in results, are the two from the AASHTO methods.

Due to the similarity between values obtained by the two AASHTO methods, and, considering that for the general method it is required to know the pavement Structural Number (SN), a parameter not always available, the damage factors obtained from the simplified AASHTO method are recommended to implement.

3.3 Comparison of Damage Factors from Different Studies

For comparative purposes, Table 6 shows damage factors under loaded conditions for the seven truck types of greater frequency established in Table 2, corresponding to this study and two other studies conducted at the national level. Values of column “1984” correspond to results obtained in the first phase of the National Pavement Research in Colombia. Values of column “1996”, to those obtained by the Cauca University in a research carried out the same year and values of the “study” column correspond to those obtained in the present work, with the AASHTO simplified method.

Table 5. Hypothesis test for damage factors of load trucks

TYPES OF VEHICLE	CALCULATION METHODS			HYPOTHESIS TESTS		
	AASHTO		SHELL	STATISTICAL F_0	P VALUE	TUKEY $T_{0.05}$
	GENERAL	SIMPLIFIED				
C2-P	0.12	0.13	0.12	1.567	2.09E ⁻⁰¹	0.02
C2-G	2.49	2.77	2.93	29.669	1.4E ⁻¹³	0.13
C3	2.91	3.49	2.49	51.718	1.6E ⁻²²	0.23
C2-S1	5.21	5.69	6.14	1.284	0.28	1.37
C4	5.49	6.63	4.64	0.745	0.48	4.01
C3-S1	2.71	3.11	3.08	0.131	0.878	2.13
C2-S2	2.92	3.18	3.23	0.548	0.579	0.76
C3-S2	4.54	5.14	3.82	89.867	3.62E ⁻³⁹	0.23
C3-S3	5.61	5.93	4.51	2,197.6	0.0E ⁺⁰⁰	0.05

Table 6. Comparison of damage factors from different studies

TYPE OF VEHICLE		LOADED TRUCK DAMAGE FACTORS		
CODE	DESCRIPTION	1984	1996	STUDY
08	C2-P	0.10	1.14	0.13
09	C2-G	2.80	3.44	2.77
10	C3	4.60	3.76	3.49
11	C2-S1	1.40	3.37	5.69
14	C2-S2	6.70	3.42	3.18
15	C3-S2	5.30	4.40	5.14
16	C3-S3	5.90	4.72	5.93

In this study, C2-P trucks have a slightly higher damage factor than in 1984, but significantly lower than in 1996. This may be because in recent years use of smaller trucks with lower capacity for cargo transportation has increased, which were taken as commercial vehicles since the rear axle corresponds to a single axle with double rim at the ends.

C2-G trucks in this study had a damage factor as in 1984, but significantly lower than in 1996. This trend may be related to the fact that to transport substantial amounts of cargo products represented by numerous units, it is more profitable to do so by using trucks of greater capacity (articulated type), where the operating costs per ton of cargo tend to be lower, being this more profitable for transporters.

C3 trucks have a decreasing damage factor. This can be explained because operating costs per ton transported to full capacity, tend to be higher than those presented in articulated trucks of greater capacity.

C2-S1 trucks have an increasing damage factor. However, in this case, this gradual increase in damage factor has minor impact on the deterioration generated in the pavements, as its pass frequency is among the lowest observed in the national road network.

C2-S2 trucks, in this study have a damage factor as in 1996, but significantly lower than in 1984. In this case, no meaningful change in damage factor associated with this kind of truck has occurred in recent years.

Trucks C3-S2 and C3-S3 in this study have a damage factor somewhat lower or similar as in 1984, as but significantly higher than in 1996. This can be attributed to the fact that a key component of the truck traffic of this type (about 21.3% for C3-S2 trucks and 56.4% for C3-S3 trucks, respectively) transport coal, with loads very close and even higher to the legal maximum allowed for this type of vehicles.

Table 7 shows the ANOVA results to establish comparison between damage factors determined in the present study and those obtained in 1984 and 1996.

Table 7 shows that in 1984, for vehicles type C2-G and C3-S3, there was no significant difference in damage factors obtained. In contrast, for vehicles C2-P, C3, C2-S1, C2-S2 and C3-S2, there are statistically significant differences in damage factors. In 1996, only in the C2-S2 vehicle the null hypothesis was not rejected, that is, no statistically significant differences were observed in the damage factor obtained. Whereas, for the rest of the vehicles compared, the null hypothesis is rejected, that is,

Table 7. Hypothesis test for comparing damage factors from other studies

TYPES OF VEHICLES	DAMAGE FACTORS FROM 1984			DAMAGE FACTORS FROM 1996		
	t_0	$t_{\alpha/2, n-1}$	DECISION ON H_0	t_0	$t_{\alpha/2, n-1}$	DECISION ON H_0
DESCRIPTION						
C2-P	5.22	1.96	Rejected	169.85	1.96	Rejected
C2-G	0.71	1.96	Not rejected	16.47	1.96	Rejected
C3	13.98	1.96	Rejected	3.43	1.96	Rejected
C2-S1	10.35	2.00	Rejected	5.60	2.00	Rejected
C2-S2	15.24	1.96	Rejected	1.06	1.96	Not rejected
C3-S2	2.08	1.96	Rejected	9.40	1.96	Rejected
C3-S3	1.65	1.96	Not rejected	68.33	1.96	Rejected

there was a significant difference in the damage factors obtained.

4. Conclusion

According to the study results, vehicles with greater load capacity tend to present the highest damage factors. This means that each time a heavy truck passes; it will generate more damage on the pavement than one of smaller capacity. Nonetheless, it must also be considered that larger trucks, having more capacity, can transport more load each time they make a repetition on the pavement. Damage factors of the lighter vehicles (rigid units) found in this study, have lower values than those observed in 1996. However, for heavier trucks (articulated units), the opposite occurs. This can be because transporters are taking full advantage of the capacity of larger trucks to reduce transportation costs per ton.

Because the damage factors for loaded trucks are significantly greater than those observed when not loaded and considering that more than 95% of trucks analyzed in the present study are loaded, it is recommended to con-

sider this condition for the evaluation of traffic, unless there is information available regarding distribution of loaded and unloaded trucks.

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