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RESEARCHARTICLE

PAVEMENT DESIGN PARAMETERS UNDER THE INFLUENCE OF ECONOMIC DEVELOPMENT: ANALYSIS OF SEASONAL VARIABILITY AND EVALUATION OF THE AVERAGE RATE OF INCREASE IN HEAVY VEHICLE TRAFFIC IN TOGO

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ABSTRACT

The characterization of traffic for the dimensioning of road pavements in Togo comes up against a problem of traffic evaluation and its projection over time. In order to contribute to the credibility of the estimated traffic values, this work has set itself the objective of evaluating the proportion of induced traffic on the total volume of heavy vehicle traffic for new road improvements. In order to overcome the lack of statistical data on road traffic in Togo, the analyzes were based on economic growth over the period 2009 to 2018. Limiting the period to 2018 avoids possible biases due to the effect of the corona virus health crisis which began in 2019.An analysis based on data from field surveys, for eight sections of dirt roads to be developed, made it possible to assess normal traffic. Induced traffic is estimated on the basis of economic benefits through improved vehicle operating costs. The different results of the two sources of traffic (normal traffic and induced traffic) on the different road sections studied are very similar in terms of volume in the composition of the total traffic for the design of the pavements. Heavy vehicle traffic caused by the developments represents between 38% and 50% of total traffic. Assessing traffic growth on the basis of GDP growth gives average growth rates of 4.5%; 6.0% and 7.5% respectively in pessimistic, realistic and optimistic hypothesis.

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INTRODUCTION

The control of heavy vehicle traffic flows for the dimensioning of road pavements requires a good knowledge of the current traffic on the section of road to be developed as well as a realistic estimate of the traffic that would be generated by the positive effects of the amenagement(Carillo, 2015)(Jean Barillot-Hervé, 2020)(SETRA, 2007). In addition, should the total traffic to be supported by the pavement during its lifetime be projected based on a controllable growth rate over a relatively long period? In developing countries, developed infrastructure is sorely lacking and new developments can be a vector for a significant amount of traffic(Bave, Hartmann, Stokenberga, Vesin, & Yedan, 2018)(ORWA, 2014)(Ken Gwilliam, 2008).Togo, with an average GDP growth established at 5.7% between 2009 and 2018, has a density of developed interurban roads of 0.04 km/km². During this period, the minimum GDP growth stood at 4.3% and the maximum at 6.5%. The maximum fluctuation from the period average is around 25%. Roads are increasingly in demand with economic growth, but traffic growth is poorly controlled. This poses a concern for the characterization of the total traffic to be supported by the pavements during the operating life(Rémi Pochez, 2016).The objective of this work is therefore to assess the proportion of induced traffic on pavement design traffic and to estimate the growth rate of heavy goods vehicle traffic.

MATERIALS AND METHODS

Collection and processing of traffic data: From the maps obtained from the mapping services and a visit to the road environment in the Central and Kara regions in Togo, we chose six (06) sections of dirt roads awaiting asphalting. It is:

- SE_02 : Kkpaza-Kemeni-Aleheride (20 km)
- SE_03 : Kpaza-Kri-Kri (11 km)
- SE_04 : Passoua-Yelivo-Sada-Essawasina-Lama Tessi (66 km)
- SE_05 : Fre benin – Soudou – Bafilo (18 km)
- SE_06 : Bafilo– Dacko – Tchatchaminade – RN 17 (57 km)
- SE_07 : Guerin Kouka (RN 17) – Kidjaboun – Katchamba (34 km)
- SE_08 : Katchamba– Takpamba – M'bortchika – Helota – Atalote – Kande (RN1) (36 km)

From the maps obtained from the cartography services and a visit to the environment of these road sections, we have defined the surfaces of the destinations whose routes serve, from one of the identified starting points. The areas of influence of the different sections of the roads have been delimited. This analysis made it possible to choose the different counting stations and the Origin/Destination survey stations for the traffic.Truck traffic data is collected by manual counting for seven days from Monday to Sunday. This counting is carried out from pre-established sheets which are filled in by investigators. In order to optimize the counting activities in the field, it was considered for the design of the sheets, based on the configuration of the trucks circulating on the road network, the following composition for the traffic:

- **Trucks:** a motor vehicle intended for road transport of goods. It differs from the light vehicle, mainly by a greater axle load and dimensions. Trucks with two (2) axles and those with three (3) axles will be counted separately;
- **Articulated sets:** commonly called semi-trailer, it is a hitch composed of a road tractor and one or more semi-trailers strictly speaking, used in the field of road transport.

Simultaneously with traffic counting operations, origin/destination surveys are carried out on competing routes in order to determine the possibilities of traffic diversion(SETRA, 2012). Each vehicle encountered at these points is politely stopped and quickly submitted to the various questionnaires to complete the origin/destination survey form. The origin/destination survey sheets make it possible to identify the vehicles which, by default of the state of the road section chosen, use lanes (diverted traffic). The normal average daily traffic (TNMJ) is obtained by taking the average of the traffic on the different counting days and by integrating the traffic diverted from the different sections after the origin/destination surveys(SETRA, 1999). This average for heavy goods vehicles is converted into normal annual average daily traffic (TNMJA) from seasonal coefficients evaluated on the basis of traffic history at Défalé road toll booths (PP_01) and Alédjo (PP_02) operating in the study area.The seasonal variation coefficient (C_{vmtpl}) will be based on monthly variations in traffic volume. For the traffic volumes of the i^{th} month of the year (TM_i), the monthly variation coefficient for heavy vehicle traffic is calculated by:

$$C_{vmtpl} = \frac{TM_i}{TM_{moy}}$$

In this equation, $TM_{moy}$is the average monthly traffic during the year and is expressed by:

$$TM_{moy} = \frac{\sum_1^n TM_i}{n}$$

With n the number of months considered.To take into account the effect of developments on traffic, induced traffic is taken into account. This type of traffic is proportional to the gains induced by the costs of road vehicle circulation, and the demand for transport resulting from the developments depends on both the travel time and the generalized cost of transport. The volume of traffic induced by the developments, assumed by approximation, is calculated using the following formula(Anderson, 1990) :

$$\frac{\Delta T}{T} = \left(\frac{\Delta(CEV)}{CEV}\right)^{\alpha}$$

In this equation:

- T is the normal average daily traffic volume in the "without" project situation,
- CEV, the vehicle operating cost calculated in "without" project situations, taking into account the levels of uniformity;
- Δ(CEV), the savings made on the operating costs of the vehicles after fitting out, considering a value of evenness equal to 2,
- (α) is the elasticity of demand,
- ΔT, the volume of induced traffic to be calculated.

The exponent (α), characteristic of the elasticity of transport demand, translates the level of service and varies according to the level of practicability of the road without the project. Depending on whether the road, without the project, undergoes permanent or seasonal impediments or hindrances during the year, its value varies from 0.25 to 1. When this value is close to unity (1), this translates permanent discomfort or even a stoppage or cut.Vehicle operating costs (CEV) are calculated using HDM-4 v3.2 software from unit prices recorded at economic conditions in December 2019. The different values of the parameter (α) used result from observations of the terrain, the estimate of the average level of service over the year for the road sections considered and the level of vehicle accessibility. It is taken equal to 0.5 for trucks of all types(Becker, Delache, Brunel, & Sauvant, 2013).

Estimation of the growth rate of heavy goods vehicle traffic during operation: The growth hypotheses envisaged relate to an operating period of 20 years for the roadway(AGECET/DIWI, 2015). This period is preceded by a 2-year project preparation phase and a 2-year works period. In the absence of long-term statistical data for road traffic, the analysis of traffic growth is essentially based on trends in the main macroeconomic indicators such as population and its growth, gross domestic product (GDP) domestic product, the domestic product per capita and the elasticity of demand for transport. These main indicators will make it possible to calculate the growth in normal passenger and freight traffic over the dead period of 4 years on average (project and works preparation periods) and the consumption period from the date of commissioning**.**GDP and GDP per capita are analyzed over the period 2009-2019, considered relatively long to provide information on the behavior of these main determinants of transport supply and demand and its evolution. In addition, the limitation of this period to 2019 makes it possible to isolate the phase of the Coronavirus health crisis.

Over this period, Togo's national GDP showed positive growth with an average annual rate of 5.71%; the average annual variation calculated is 14.26%. On the basis of this variation, the average annual rates in high and low assumptions recorded are respectively 6.5% and 4.3%. This results in a maximum fluctuation of around 25% compared to the average.Over the same period, the average annual growth rate calculated for gross domestic product per capita over the period 2009-2018 is 2.89%. According to the results of the latest Population and Housing Censuses of 2010 provided by the General Directorate of Statistics, the average annual growth rate of the population of Togo calculated over the period 1981-2010 is 2.84%(DGSCN, 2011).As for the coefficient of elasticity of demand for road transport (k), it varies from 0.5 to 1.33(Delache, 2013). Considering the level of motorization and the lack of developed infrastructure in the study area, the choice for this study will be brought to the maximum limits. It is taken as equal to 1.1 for the idle period (4 years) and 1.33 for the operating period (20 years). Normal traffic forecasts are drawn up for heavy goods vehicle traffic and evaluated on a pessimistic (-25% on the GDP rate) and optimistic (+25% on the GDP rate) assumptions.

The average annual growth rate of traffic volume is estimated by:

$$t_{pl} = k \times T_{pib}$$

In this equation :

t_{pl} = heavy vehicle traffic growth rate
T_{pib}= Average annual growth rate of GDP which is 5.7% over the study period.
The growth rate for normal traffic (t_n) is estimated by :

$$t_n = \frac{4 \times t_{pl(pm)} + 20 \times t_{pl(pe)}}{24}$$

$t_{pl(pm)}$is the increase in heavy goods vehicles for the dead period corresponding to the project phase and ;
$t_{pl(pe)}$is the increase in heavy vehicle traffic for the period of operation of the road.

In terms of quantifiable benefits generated by road investments to be taken into account in the analysis, it is generally accepted that those resulting from induced traffic contribute only half(Bernet & Coupé, 2012). Thus the rate of increase in induced traffic is evaluated by :

$$t_{ind} = \frac{t_{pl(pe)}}{2}$$

The average arithmetic growth rate for the different types of heavy goods vehicles is evaluated by making a quadratic average of the different growth rates with the traffic volumes according to the equation:

$$t_{moy} = \frac{N_n \times t_n + N_{ind} \times t_{ind}}{N_n + N_{ind}}$$

In this equation, the parameters are defined as follows:

- Nn normal traffic volume and $t_n$its increase;
- Nind the volume of traffic induces and t_{ind} its increase.

RESULTS

Seasonal variation and induction of heavy vehicle traffic: The analysis of monthly HGV traffic data at toll booths PP_01 (in Défalé) and PP_02 (in Alédjo) reveals a variation in the volume of traffic during the year (Figure 1).For a three-year analysis period (2016, 2017 and 2018), the variations do not follow the same paths each year. Item PP_01 shows a maximum in the seventh month in 2017 and 2018 while the maximum is recorded in the sixth month in 2016. The minimum traffic is obtained in the first month of the years 2016 and 2018 while the year 2017 records its minimum in the fourth month . For item PP_02, data for the second, third, fourth and fifth months of 2016 was not recorded. And based on the available data, the minimum truck traffic is recorded in the first month of the years 2016 and 2017. The year 2018 presents a minimum in the tenth month while the maximums are obtained in the eighth, sixth and seventh month respectively for 2016, 2017 and 2018.

The average analysis of the variation in the volume of traffic over the three years according to the month of the month considered made it possible to establish for each of the two stations, the evolution of the monthly variation coefficients (Figure 2).The monthly traffic coefficients of variation for PP_01 vary from a maximum of 1.16 in the first month to a minimum of 0.88 in the seventh month of the year. At PP_02, the maximum, with a value of 1.31, is recorded in the fourth month, while the minimum always remains in the seventh month. Traffic surveys are carried out in October. The monthly variation coefficients obtained for the different study sections are therefore 1.24 for SE_01, SE_02, SE_03, SE_04, SE_05 and SE_06. This coefficient is 1.03 for SE_07 and SE_08.The annual average daily traffic (TMJA) obtained by correcting the average daily traffic (TMJ) from traffic surveys shows variability depending on the study sections. Indeed, the results of the traffic surveys give the normal traffic volume on the different study sections. This normal traffic, made up of traffic directly counted on the track and diverted traffic estimated from the origin/destination surveys, is not identical on the different sections.The condition of the dirt roads in Togo and the level of smoothness of the paved roads in service give the operating costs (CEV) before and after the developments from the HDM4 model (Table 1).But the weight of normal traffic on the total traffic estimated for pavement design varies slightly from one section to another. It presents a fluctuation between 50% and 62% (Table 2).The weight of traffic generated by road improvements therefore constitutes an important part of the design traffic of pavements in Togo. It represents between 38% and 50% of the expected traffic on the upgraded road (Figure 3).

Truck Traffic Growth Rate: The analysis of growth rates backed by the variation in GDP makes it possible to obtain, on a realistic assumption, for normal traffic, a rate of 6.27% for the growth of heavy goods vehicle traffic in the off period corresponding to the project phase.

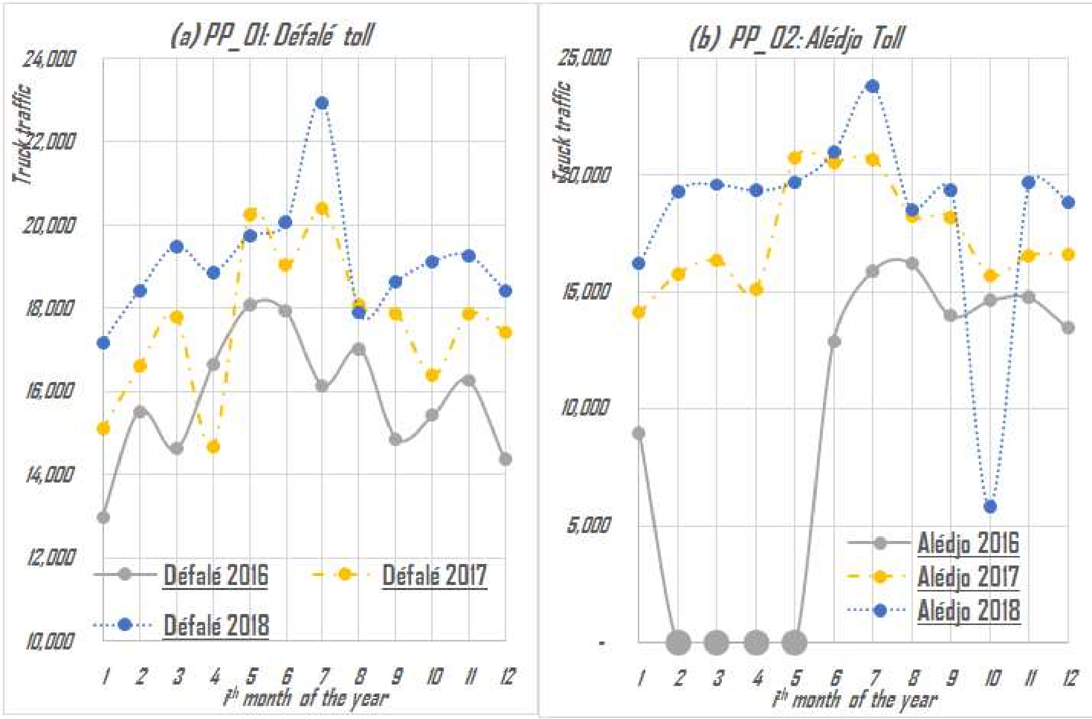

Figure 1. Monthly variation in traffic volume at toll booths (PP) neighboring the study sections

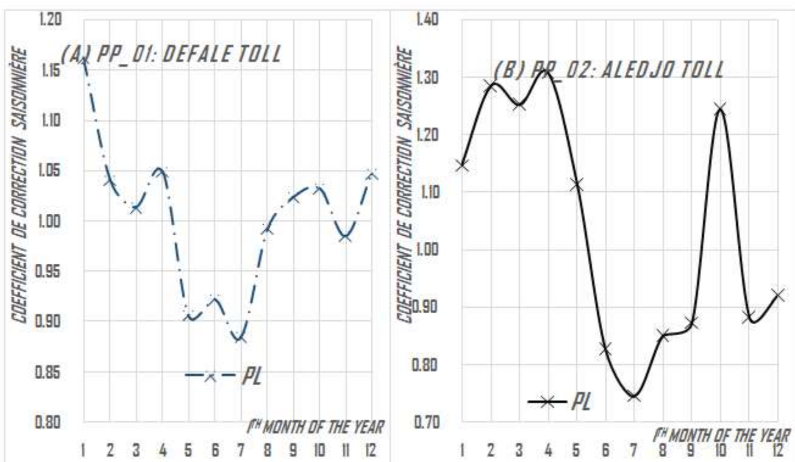

Figure 2. Monthly traffic variation coefficients at toll stations (PP) neighboring the study sections

Table 1. Savings on vehicle operating costs

Type of truck	CEV before amenagement(FCFA/Km)	CEV afteramenagement (FCFA/Km)	Economy ofCEV (FCFA/Km)
2 axle trucks	740	370	370
3 axle trucks	990	500	490
Articulated sets	1630	790	840

Table2. Proportions of normal and induced traffic

Study section	Average daily traffic (TMJ)		Seasonality coefficient	Annual average daily traffic (TMJA)	
	Normal	Induced		Normal	Induced
SE_01	38	25	1,24	47	31
SE_02	390	279	1,24	484	346
SE_03	120	74	1,24	149	92
SE_04	947	645	1,24	1174	800
SE_05	905	888	1,24	1122	1101
SE_06	990	812	1,24	1228	1007
SE_07	433	338	1,03	446	348
SE_08	760	522	1,03	783	538

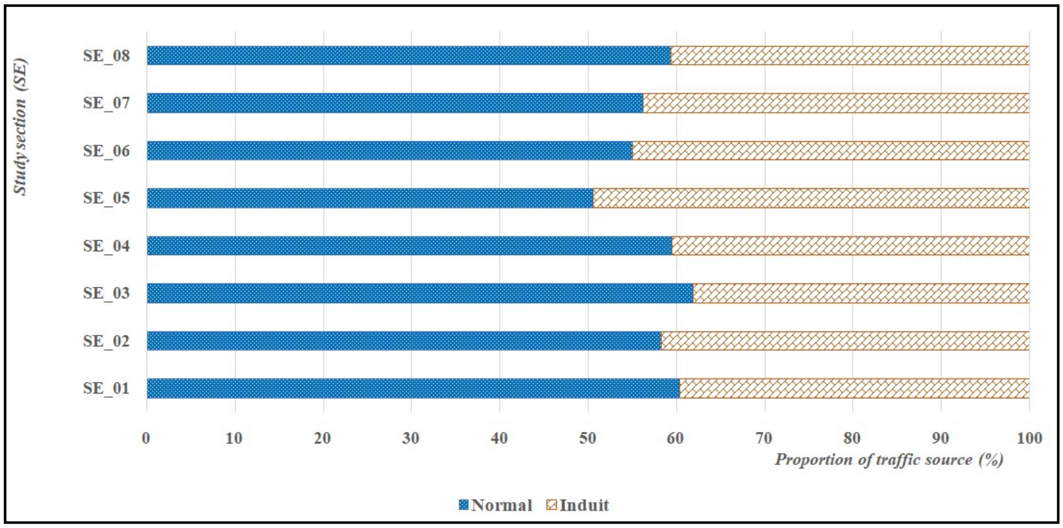

Figure 3. Proportion of traffic sources for development of study sections

During the pavement operation phase, the normal traffic growth rate is estimated at 7.41%. The increase in induced traffic, evaluated on the basis of the normal traffic increase rate in the operating phase, is estimated at 3.71%. These different traffic growth rates lead to an average heavy vehicle traffic growth rate on the different study sections varying between 5.48% and 5.88% (Table 3).

Table 3. Average growth rate of heavy goods vehicle traffic on the study sections on a realistic assumption

Study section	Normal Trafic	Induced Trafic	$t_{pl(pm)}$	$t_{pl(pe)}$	t_n	t_{ind}	t_{moy}
SE_01	47	31	6,27	7,41	7,22	3,71	5,83
SE_02	484	346					5,75
SE_03	149	92					5,88
SE_04	1174	800					5,80
SE_05	1122	1101					5,48
SE_06	1228	1007					5,64
SE_07	446	348					5,68
SE_08	783	538					5,79

When the economic growth forecasts drop by 25% (pessimistic hypothesis) the growth rate of normal traffic is established at an average of 4.7% for the growth of heavy goods vehicle traffic in the off period. During the operation phase of the pavements, the rate of increase in normal traffic is estimated at 5.6% for this assumption. The pessimistic increase in induced traffic is 2.8%. This leads to an average increase in heavy vehicle traffic, in a pessimistic hypothesis, on the different study sections varying between 4.1% and 4.4% (Table 4).

Table4. Average growth rate of heavy goods vehicle traffic on the study sections in a pessimistic hypothesis

Study section	Normal Trafic	Induced Trafic	$t_{pl(pm)}$	$t_{pl(pe)}$	t_n	t_{ind}	t_{moy}
SE_01	47	31	4,7025	5,558	5,42	2,779	4,37
SE_02	484	346					4,32
SE_03	149	92					4,41
SE_04	1174	800					4,35
SE_05	1122	1101					4,11
SE_06	1228	1007					4,23
SE_07	446	348					4,26
SE_08	783	538					4,34

On an optimistic assumption (25% increase in economic forecasts), the normal traffic growth rate stands at an average of 7.8% for heavy vehicle traffic growth in off-peak periods. The pavement operation phase presents a normal traffic growth rate of 9.3%. The increase in traffic induced in the optimistic hypothesis is calculated at 4.6%. It follows that the average growth rate of heavy vehicle traffic, on the different study sections, varies between 6.9% and 7.35% (Table 5).

Table5. Average growth rate of heavy goods vehicle traffic on the study sections in an optimistic hypothesis

Study section	Normal Trafic	Induced Trafic	$t_{pl(pm)}$	$t_{pl(pe)}$	t_n	t_{ind}	t_{moy}
SE_01	47	31	7,8375	9,263	9,03	4,631	7,28
SE_02	484	346					7,20
SE_03	149	92					7,35
SE_04	1174	800					7,25
SE_05	1122	1101					6,85
SE_06	1228	1007					7,05
SE_07	446	348					7,10

DISCUSSION

The analysis of monthly variations in traffic at toll booths PP_01 and PP_02 shows fluctuations during the year. The average monthly coefficients of variation have minimum values corresponding to the busiest months and peaks which reflect the lowest traffic levels. The highest traffic volumes are recorded in the fifth, sixth and seventh month for PP_01 and in the sixth, seventh and eighth month for PP_02. These periods coincide with periods of intense agricultural activities in the study areas. Agriculture would therefore be one of the biggest traffic generators in Togo. In addition, the weight of traffic generation by the effect of developments is very high with rates above 38% for the eight study sections. This situation is reflected in the low level of economic development of the various localities and the pressure exerted by agriculture on road infrastructure. The need to reach markets for the supply of inputs and the sale of agricultural harvest products is therefore an important factor in the development of road infrastructure in Togo.In order to fill the lack of information on the rate of increase in heavy goods vehicle traffic, the estimate of the increase backed by GDP gives average growth rates estimated at 4.30%; 5.73% and 7.16% respectively for the pessimistic, realistic and optimistic hypotheses. These rates can be taken approximately equal respectively to 4.5%; 6% and 7.5%.

CONCLUSION

The design of road pavements in Togo faces a number of problems including the characterization of traffic and its projection over time. The source composition of heavy vehicle traffic and the growth rates are some of these traffic characterization parameters. An analysis based on traffic surveys at eight road sections in Togo gives two sources for heavy vehicle traffic. For the first source, it is normal traffic, made up of traffic directly counted on the tracks and diverted traffic estimated from origin/destination surveys. The second source consists of traffic induced by road construction. The two sources of traffic are very similar in terms of volume in the composition of total traffic for pavement design. Heavy vehicle traffic caused by the developments represents between 38% and 50% of total traffic. Assessing traffic growth on the basis of GDP growth gives average growth rates of 4.5%; 6.0% and 7.5% respectively in pessimistic, realistic and optimistic hypothesis.

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