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# Impact of Multi-Axle Vehicles and Road Overloads on the Durability of Asphalt Pavements

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## Abstract

The multiplication of heavy vehicle axles and road overloads are phenomena that are becoming increasingly important on the road network of the WAEMU community. These phenomena, although framed by standards, have an impact on the durability of pavements. In this manuscript it is a question of evaluating the life of the road under the effect of traffic of these multi-axle vehicles and the different tolerances of overloads observed on the road network. To achieve this, a modeling of a bituminous pavement was made with the software ALIZE Lcpc Version 231 based on the principle of the French method of sizing. An inventory of multi-axle heavy goods vehicles was also made on a road with a weighing station. This traffic counting made it possible to classify heavy goods vehicles into three categories, namely: 1) trucks, 2) dual-wheeled semi-trailers and 3) single-wheeled semi-trailers. The results obtained show that in terms of aggressiveness, single-wheeled semi-trailers are the most aggressive, followed by heavy goods vehicles in the category of trucks with more than five axles and semi-trailers with dual wheels with more than seven axles. The durability of the road depends on the aggressiveness of heavy goods vehicles, it was found that the tolerance threshold for overloads of 15% of the total permissible rolling weight (TARW) or the total permissible laden weight (TALW) currently granted in the Community area needs to be reviewed. For durable road surfaces, this tolerance may only be allowed for heavy goods vehicles of type P11, P12 and P13. The 5% tolerance can be applied to all vehicles except heavy goods vehicles with single wheels.

## Keywords

Aggressiveness, Multi-Axle, TARW, TALW, Allowable Deformation, Modeling

## 1. Introduction

The lifetime of a bituminous pavement structure depends on its performance under the action of traffic [1]. Heavy vehicles, which represent the most aggressive factor of the pavement in terms of stresses [2], have seen their configuration evolve rapidly and continuously in Burkina Faso [3]. Also, the phenomenon of overloading constitutes an additional deterioration factor. According to data from the national road safety office, 98% of heavy vehicles weighed in 2019 were overloaded [4]. This phenomenon of overloading combined with the appearance of multi-axles is a real issue for the bituminous pavements' durability.

Indeed, heavy vehicles traffic induces deformations under irreversible loads [5], resulting in more or less prematurely roadway degradation. This is not only dependent on the load cycle but also on the axle overloads [2]. The axle load limit respect and the total authorized laden weight (TALW) or total authorized rolling weight (TARW) is therefore of great importance for an efficient roadway exploitation. In reality, the uncontrolled load has become a major issue due to the non-application of excessive overloads regulation at the weighing stations [6]. According to the West African Economic Monetary Union (WAEMU) regulations, an overload tolerance of 5% per axle is authorized and should be taken into account in the reliability margin of the weighing equipment [7]. The Practical Guide to Pavement Design for Tropical Countries of 2019 recommended a tolerance up to 20% axle load [8]. In addition to these two tolerances abovementioned, a tolerance of 15% of overloads has been granted by the Ministers of Transport of the WAEMU state members [9].

In this article, we report the impact of multi-axle vehicles and road overloads on the durability of bituminous pavements.

The aim is to evaluate the aggressiveness of different types of multi-axle vehicles commonly encountered on the road network and their impact on the asphalt roads lifetime. This manuscript will enable transport stakeholders and road designers to perceive the effect of the multiplication of heavy goods vehicle axles associated with road overload on the operation of a road in order to facilitate the full application of the regulation n˚14.

## 2. Materials and Methods

### 2.1. Materials

For the modeling, we have adopted a bituminous pavement with a multilayer structure shown schematically in **Figure 1**. It is made up of materials with viscoelastic (bituminous layers) and elastic (unbonded layers) behavior with standard parameters (**Table 1**) for design [10]. It was sized with the average aggressiveness coefficient equal to one (1), for an estimated lifespan of 20 years.


**Figure 1.** Pavement structure.

**Table 1.** Characteristics of pavement materials.

| Layer | Thickness (cm) | Module (MPA) | Fish coefficient | Calculated deformation (udef) |
|---|---|---|---|---|
| Bearing: BBSG | 5 | 1300 (30˚C) | 0.35 | 47.2 |
| Base: GB3 | 10 | 2700 (30˚C) | 0.35 | 140.3 |
| Foundation: GLAC | 20 | 700 | 0.35 | 355.3 |
| Layer of form | 30 | 200 | 0.35 | 375.4 |
| Ground support (PF3) | Infini | 120 | 0.35 | 269.5 |

The traffic and axle weighing data are those obtained at the Nagréongo weighing station (**Figure 2**).

**Table 2** and **Table 3** present different types of multi-axles encountered on the road to weighing station and their total allowable loaded and rolling weight for truck categories and semi-trailers. The reference axle was the 13 t axle for dual wheels and 2 × 4.25 *t* for single rear wheels [1]. These different loads are those defined in WAEMU Regulations.

## 2.2. Methods

Our approach is largely based on the principles of the French pavement design method [10]. This method is based on an asymmetric multi-layer Burmister model used in the ALIZE L C P C version 231 software. The pavement behavior analysis considers a multilayer structure of elastic, linear, homogeneous and isotropic behavior with a static loading [11]. The mechanical evaluation consisted in performing the satisfaction of the following mathematical inequalities which state that calculated value ≤ admissible value:

For bituminous materials

$$\varepsilon_t \le \varepsilon_{tadm} \tag{1}$$

For a bituminous layer loaded in extension by bending, the allowable deformation is calculated according to Equation (2) [12].

$$\varepsilon_{tadm} = \varepsilon_6 \times \sqrt{\left(\frac{E(10\text{ Hz};10^\circ\text{C})}{E(10\text{ Hz};30^\circ\text{C})}\right)} \times \left(\frac{NE}{10^6}\right)^b \times k_r \times k_c \times k_s \tag{2}$$

$\varepsilon_t$ : Tensile deformation at the bottom of the bituminous layer;


Figure 2. Nagréongo weighing station (BURKINA FASO).

Table 2. Different types of trucks and their TALW.

| Coding of the main silhouettes | Number of front axles | Number of rear axles | Total number of axles | TALW (t) |
|---|---|---|---|---|
| Trucks P11 | 1 | 1 | 2 | 18 |
| Trucks P12 | 1 | 2 | 3 | 26 |
| Trucks P13 | 1 | 3 | 4 | 31 |
| Trucks P21 | 2 | 1 | 3 | 30 |
| Trucks P22 | 2 | 2 | 4 | 38 |
| Trucks P23 | 2 | 3 | 5 | 43 |
| Trucks P24 | 2 | 4 | 6 | 52 |
| Trucks P25 | 2 | 5 | 7 | 60 |
| Trucks P26 | 2 | 6 | 8 | 68 |
| Trucks P35 | 3 | 5 | 8 | 72 |

Table 3. Different types of semi-trailers and their TARW.

| Coding of the main silhouettes | Number of front axles (tractor) | Number of intermediate axles | Number of rear axles | Total number of axles | TARW (t) |
|---|---|---|---|---|---|
| Semi-trailer T11S1 | 1 | 1 | 1 | 3 | 30 |
| Semi-trailer T11S2 | 1 | 1 | 2 | 4 | 38 |
| Semi-trailer T11S3 | 1 | 1 | 3 | 5 | 43 |
| Semi-trailer T11S4 | 1 | 1 | 4 | 6 | 51 |
| Semi-trailer T12S1 | 1 | 2 | 1 | 4 | 38 |
| Semi-trailer T12S2 | 1 | 2 | 2 | 5 | 46 |
| Semi-trailer T12S3 | 1 | 2 | 3 | 6 | 51 |

**Continued**

| | | | | | |
|---|---|---|---|---|---|
| Semi-trailer T12S4 | 1 | 2 | 4 | 7 | 59 |
| Semi-trailer T12S5 | 1 | 2 | 5 | 8 | 68 |
| Semi-trailer T12S6 | 1 | 2 | 6 | 9 | 76 |

$\varepsilon_{tadm}$ : Tensile strain at bottom of asphalt layer;

$\varepsilon_6$ : Strain at 1 million loading cycles;

$E(f, T^\circ\mathrm{C})$ : Stiffness modulus of the asphalt layers at a temperature;

$NE$ : Number of axles equivalent to heavy traffic;

$K_r$ : Coefficient of risk of thickness variation and fatigue test dispersion;

$K_C$ : Coefficient of thickness variation and dispersion of fatigue tests: Wedging coefficient;

$K_S$ : Coefficient depending on the type of the supporting platform.

For untreated materials and supporting soil

$$\varepsilon_z \leq \varepsilon_{zadm} \tag{3}$$

For an untreated material layer and for the soil, the allowable stress is the vertical deformation at the surface of the layer, calculated according to Equation (4)

$$\varepsilon_{zadm} = A \times (NE)^B \tag{4}$$

$\varepsilon_Z$ : Horizontal deformation at the top of the untreated layers or the platform;

$\varepsilon_{Zadm}$ : Permissible horizontal deformation at top of untreated layers or platform;

$A$ : Permanent deformation;

$B$ : Slope of the material fatigue law.

These allowable deformation values are based on the performance data of the pavement materials [13]. They are also influenced by the type of traffic that flows on the pavement during its lifetime. The cumulative traffic is determined according to Equations (5), (6) and (7) [13]. Moreover, the traffic assessment, only involved the heavy vehicle traffic, expressed as the cumulative number of heavy vehicles expected during the pavement lifetime [12]. The heavy vehicles which represent the most aggressive elements in road traffic in Burkina Faso, have seen their configuration evolve rapidly, while multi-axle vehicles configuration was not taken into account in WAEMU Regulation 14.

$$N_{PL} = 365 \times TMJA \times C \tag{5}$$

$$C = \frac{(1+\tau)^n - 1}{\tau} \tag{6}$$

$$NE = N_{PL} \times CAM \tag{7}$$

$NE$: Number of heavy goods vehicles calculated for the lifetime;

$TMJA$: Average Annual Daily Traffic;

$n$: Lifetime of the road;

$\tau$ : Traffic growth rate;

*CAM*: Average Aggression Coefficient.

Different aggressivity are calculated using the following equations:

- The aggressiveness of an axle is given by Equation (8);

$$A_i = k \times \left(\frac{P_i}{P_0}\right)^{\alpha} \tag{8}$$

- The aggressiveness of a heavy vehicle is calculated using Equation (9);

$$A_{PL} = \sum_i k \times \left(\frac{P_i}{P_0}\right)^{\alpha} \tag{9}$$

- The aggressiveness of heavy traffic is determined by Equation (10)

$$CAM = \frac{1}{N_{PL}}\left[\sum_i \sum_{j=1}^{3} K_j n_{ij} \times \left(\frac{P_i}{P_0}\right)^{\alpha}\right] \tag{10}$$

$K_j$ : constant dependent on axle geometry and pavement structure;

$\alpha$ : axle load: constant depending on the nature of the pavement structure;

$P_i$ : axle load of the considered axle *i*;

$P_o$ : Load of the reference axle which is 13 t;

$n_{ij}$ : Number of axles of type *j* and load $P_i$.

The pavement life for each type of heavy vehicle identified is determined using Equation (11), [12] [14].

$$S = \alpha - \beta \log N \tag{11}$$

$S$ : imposed stress;

$N$ : Pavement life;

$\alpha, \beta$ : Wöhler curve dependent constants.

The values of the calculation parameters for these different equations are those defined in the NF-P-98-086 standard [12]. These are conventional values of calculation, usually taken for the dimensioning.

It should be noted that the work consists in adding for each identified heavy goods vehicles an overload from 0% to 50% of their total authorized weight or total authorized rolling weight for the impact evaluation.

## 3. Results

### 3.1. Effect of Overloads on the Aggressiveness of an Axle or Axle Group

Figure 3 panels "a" and "b" show the evolution of the aggressiveness of twin wheels and single wheels axle, respectively. It can clearly be seen that single wheel axles are more aggressive than the twin wheel axles. However the aggressiveness ratio of these two types of axles increases with the overload. The tandem axle with twin wheels (panel "a") is the less aggressive of all axles while the most aggressive is the 6-axle with single wheels as shown in panel "b".

Referring to WAEMU Regulation 14, an overload tolerance of 5% is equivalent to an increase in aggressiveness of 22%, while an overload tolerance of 15%,

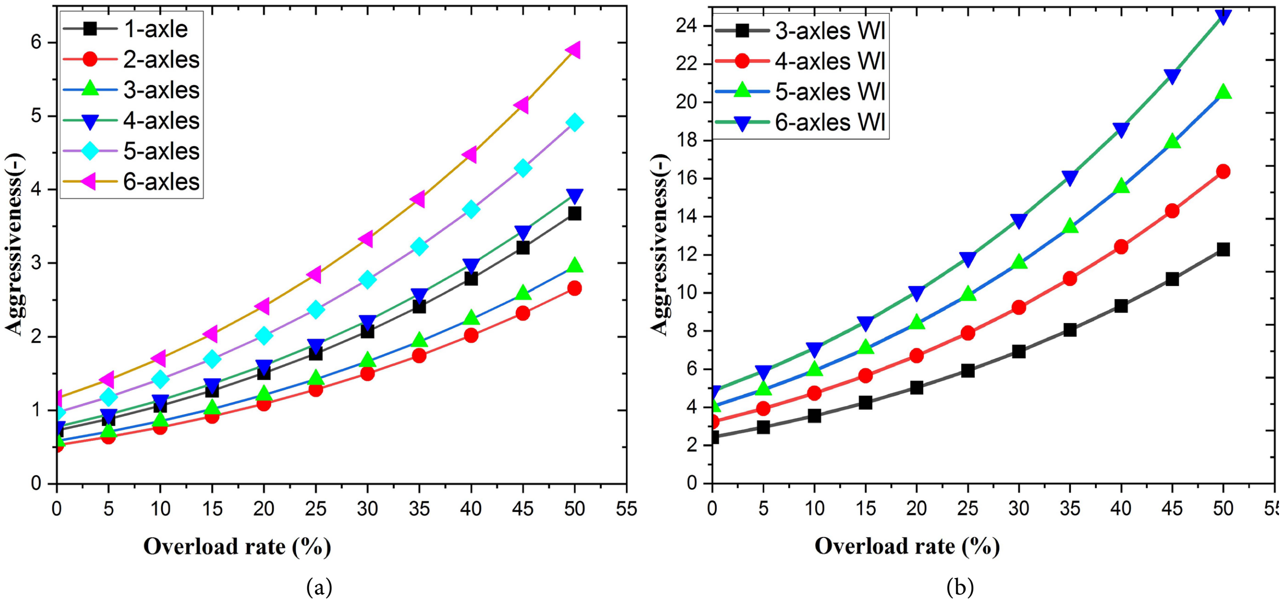



**Figure 3.** Aggressiveness of axles (a) twin axles and (b) single axles b.

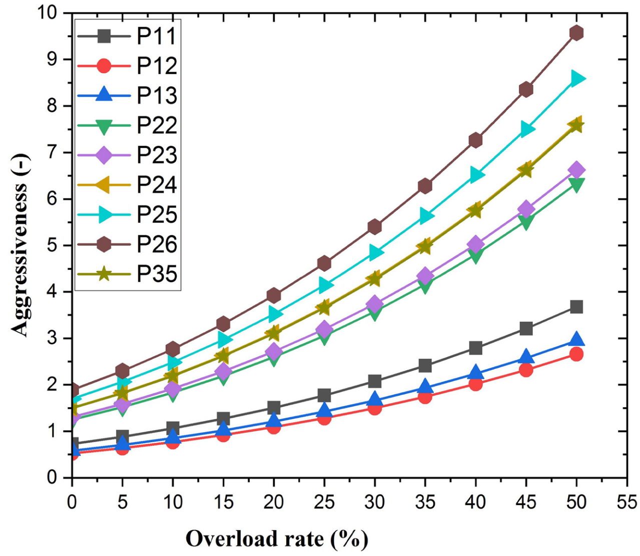
as recommended in the WAEMU transport ministers' meeting in October 21, 2022, would lead to an increase in aggressiveness of 75%. Thus a 20% tolerance would lead to an increase of more than 100%.

### 3.2. Effect of Overloads on the Aggressiveness of Heavy Vehicles

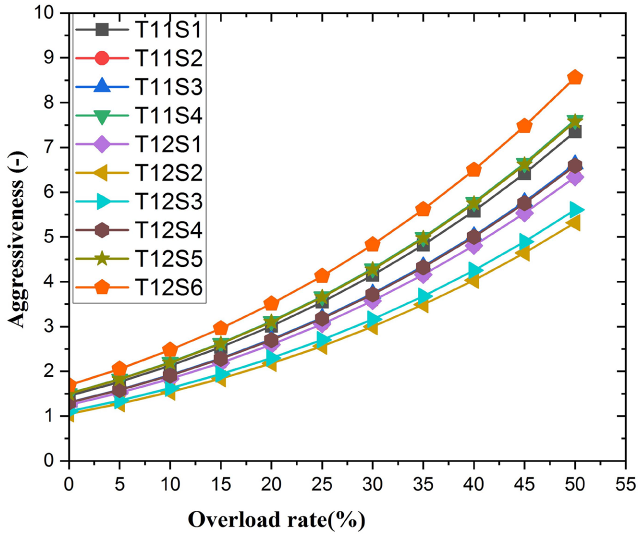
Figure 4 panel "a" and show the evolution of the aggressiveness of trucks and semi-trailers with dual wheels, respectively. The aggressiveness of semi-trailers with single rear wheels is presented in panel "c".

Due to the limited number of weighing stations and the non-existence of mobile weighing systems in some countries of the WAEMU community area, most of the roads are dimensioned with an average aggressiveness coefficient of 1. For the road degradation prevention, the WAEMU regulation 14 before revision recommended a 5% tolerance for the overload rate on the total laden weight of heavy goods vehicles [7].

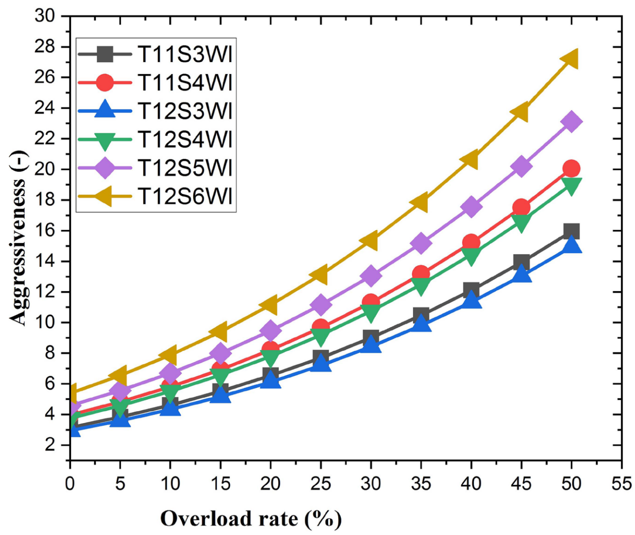
Figure 4 panel "a" shows the average aggressiveness coefficient of type P trucks. In this category of vehicles, we noticed that only those of type P11, P12 and P13 can support an overload of 5% without exceeding aggressiveness value of 1. On the other hand, all the semi-trailer vehicles shown in panel "b" present an aggressiveness coefficient higher than the value of 1 at the normal load. Therefore, a tolerance of 5% of overload rate could be damaging to the road. As it can be observed in Figure 4(c), a single rear wheel trucks presents a higher aggressiveness coefficient compared to that of P type trucks and semi-trailer vehicles from panels "a" and "b". The results indicate that single rear wheel trucks aggressiveness coefficients range from 2 to over 26 while increasing the overload rate from 0% to 50%.




(a)




(b)




(c)

**Figure 4.** Aggressiveness of heavy vehicles (a) P trucks, (b) RJ semi-trailer and (c) RS semi-trailer.

### 3.3. Effect of Overloads on Allowable Loads

The designing method distinguishes three damage mechanisms associated to three valuable expressions [12].

The damage caused by fatigued bituminous materials, taken in to consideration through their acceptable maximum reversible horizontal extension deformation. The second expression is the damage by fatigue of hydraulically bound materials and cement concrete, taken in to consideration through their maximum allowable horizontal traction constraints. The third expression refers to the cumulative permanent deformation damage in untreated materials, taken in to consideration through their maximum allowable reversible vertical deformation [12] [15] [16].

These allowable stresses are the limit values not to be exceeded when pavements undergo deformation.

According to **Figures 5-7**, these acceptable deformations decrease with the road overloads.

#### 3.3.1. Allowable Deformations in Asphalt Concrete (BB)

The pavement modelling gave a value of 47.2 micro deformation (μdef) as the tensile deformation at the bottom of the asphalt concrete layer. This value is found to lower than the admitted values (**Figures 5(a)-(c)**) for all types of heavy traffic, including the surplus up to 50% road overload. This means that the asphalt layer can last for long in fatigue without breaking. The lifetime of the asphalt layer is therefore evaluated by fatigue damage.

#### 3.3.2. Allowable Deformation of Gravel Bitumen (GB3)

**Figure 6** presents the admitted horizontal deformations for three categories of heavy vehicles under study. It can be observed a decrease of deformations as a function of the overload rate. The maximum extension deformations estimated values are lower for certain overload rates than that calculated for the bottom asphalt mixture as shown in **Table 1**.

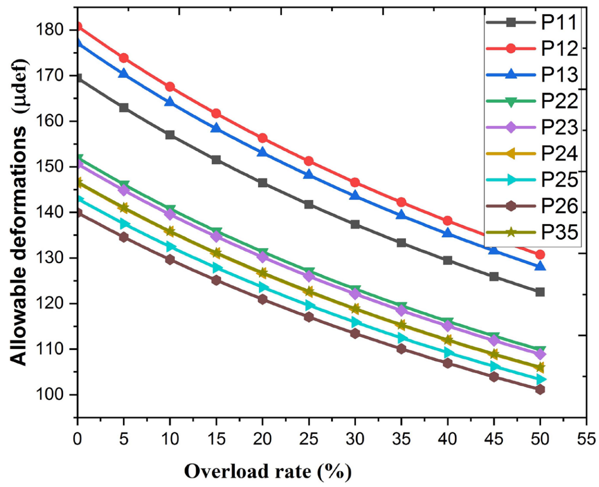
For P24, P25 and P26 trucks type (**Figure 6(a)**), semi-trailers T11S1, T12S5 and T12S6 (**Figure 6(b)**) type, including all those of single wheels (**Figure 6(c)**). The admitted values are lower than the value calculated without an overload tolerance. In the situation where these allowable values are lower than the calculated value, the lifetime of materials or the pavement can no longer be evaluated in terms of fatigue, since this situation is likely to induce cracking from the bottom to the top of the layer [10]. From that a premature degradation of the pavement is expected.

#### 3.3.3. Allowable Deformations on Untreated Materials and Supporting Soil

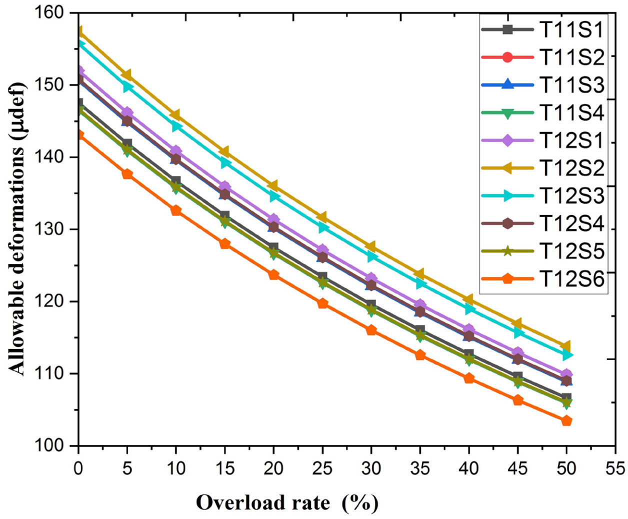
For an untreated material layer and subgrade, the allowable stress is a vertical deformation at the surface of the layer. In the pavement structure modeled for this study, three layers of materials are evaluated based on this stress criterion.

The foundation layer made from improved crushed stone material has an estimated deformation value lower than the permitted values for both heavy vehicles categories as shown in **Figure 7(a)**, and **Figure 7(b)**. The acceptable values for single-wheeled heavy vehicles are found to be lower than the calculated value without overload (**Figure 7(c)**). For an overload tolerance of 15%, it is found that the allowable values (**Figure 7(a)** and **Figure 7(b)**) are lower than the calculated ones for heavy trucks of P24, P25, P26 types (**Figure 7(a)**) and T11S1, T12S5 and T12S6 (**Figure 7(b)**).

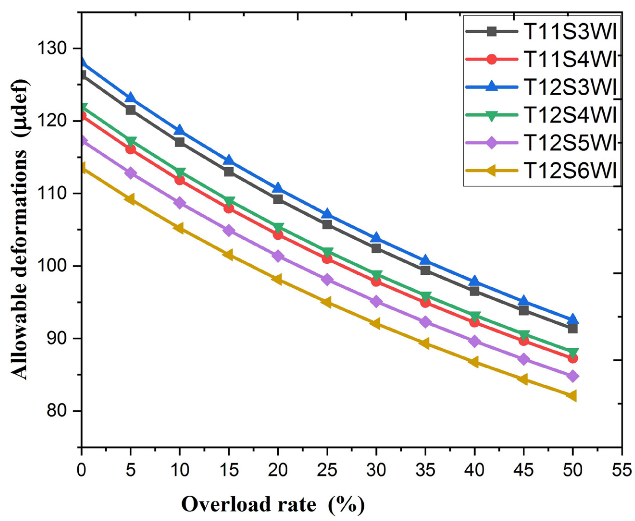
The second layer of untreated material is the subgrade. At this level without even a tolerance of overload, the permitted values are also lower than calculated for all single-wheeled trucks and trucks of types P24, P25, P26, P35 and T12S6. For an overload tolerance ranging from 15% to 20%, only the vehicles P11,




(a)

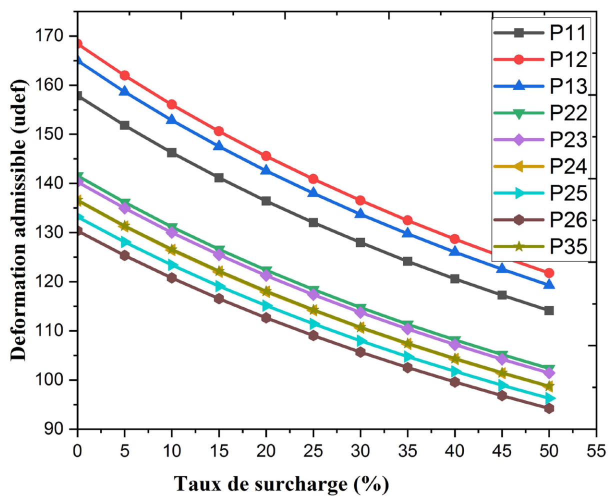



(b)

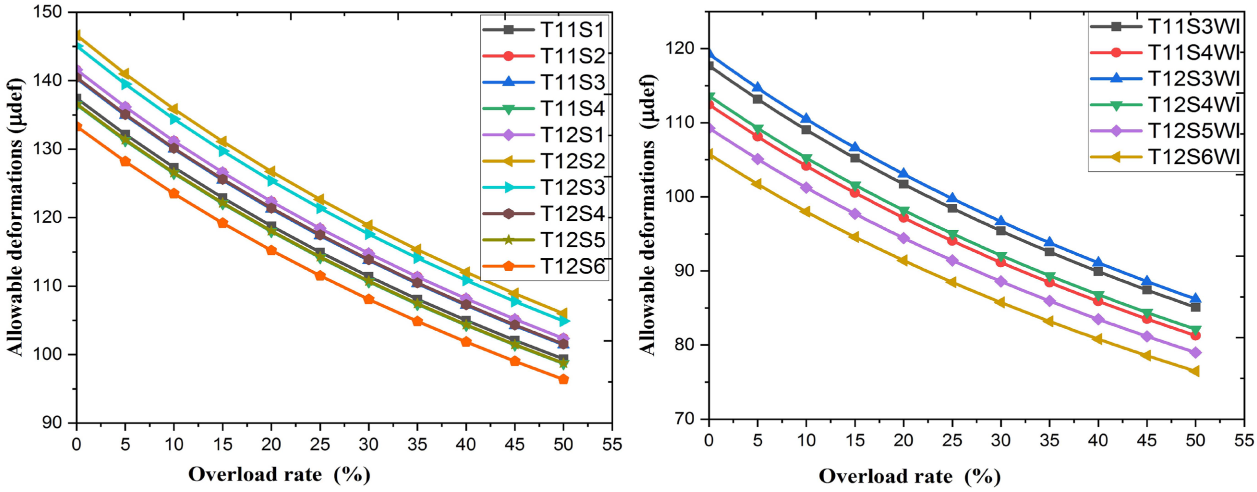



(c)

**Figure 5.** Allowable deformations at BB (a) P-trucks, (b) SRJ semi-trailer and (c) SRS semi-trailer.

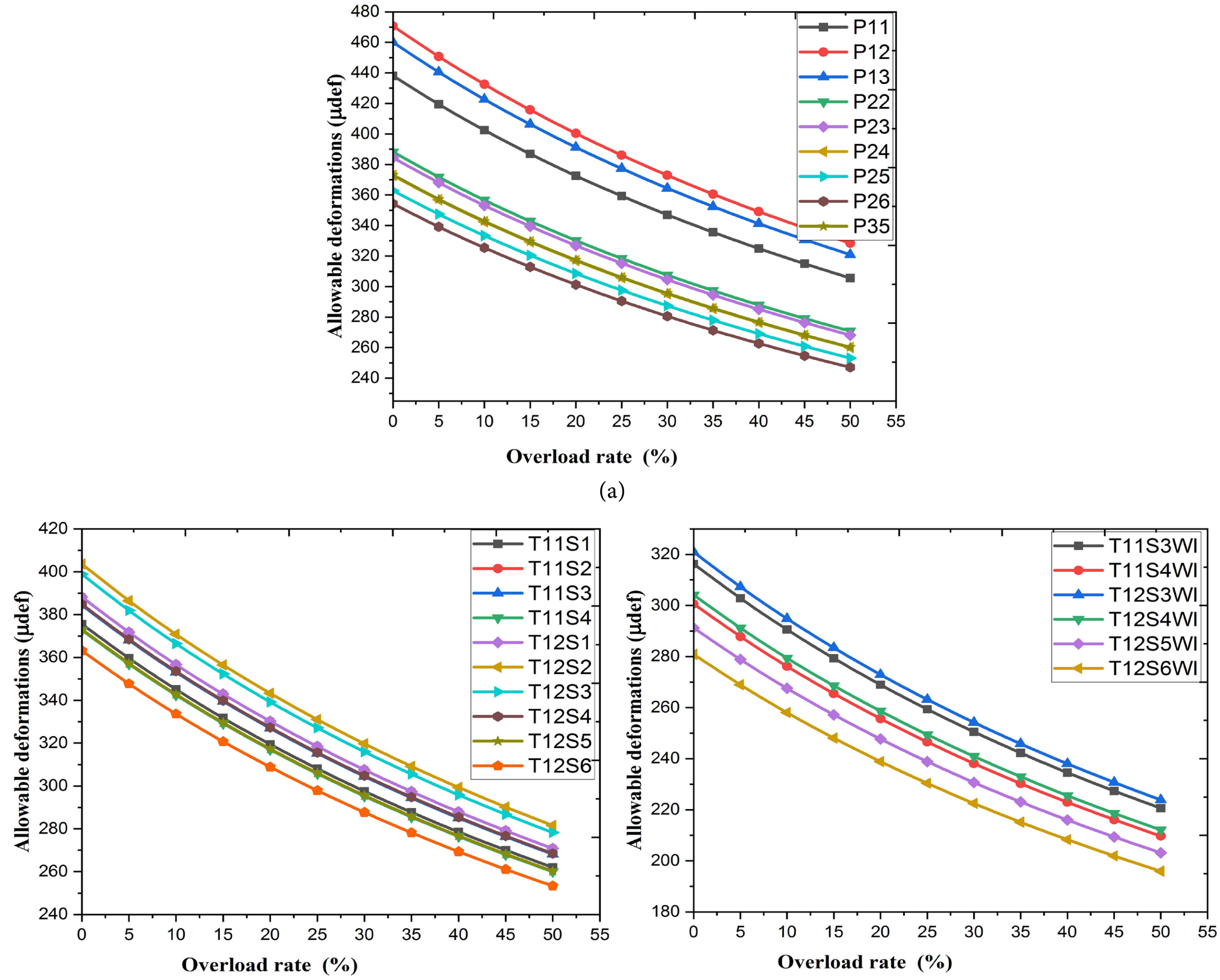



(a)




(b) (c)

**Figure 6.** Allowable deformations at GB3 (a) P trucks, (b) SR semi-trailer and (c) SR semi-trailer.




(a)

(b) (c)

**Figure 7.** Allowed deformations at the untreated material level and the supporting soil (a) P trucks, (b) SR semi-trailer and (c) SRI semi-trailer.

P12 and P13 in **Figure 7(a)** present a permitted values higher than the calculated value.

As for the supporting soil, the allowed values of the trucks, except that of T12S6 and T12S5 with single wheels, remain higher than the calculated values for an overload tolerance of up to 20%. The observations made for untreated materials are similar to those of asphalt gravel. Thus, a breakage of these materials could occur under the traffic of certain heavy vehicles with or without overloads.

### 3.4. Effect of Overloads on Pavement Life

**Figures 8(a)-(c)** show the lifetime of bituminous pavements as a function of the overloading rate. In this paper, the pavement structure is designed for a last for 20-year with a traffic load of average aggressive coefficient of 1.

When the traffic is reduced to a single type of heavy vehicle, namely P type, the results show that the pavement could last for more than 20 years under the traffic of P11, P12 and P13 type trucks with a margin overload from 5% to 10%. On the other hand, the pavement lasts less than 20 years under their traffic of P type vehicles. Thus, it comes out that trucks of P24, P25, P26 and P35 type are very harmful to the pavement and it shows that a pavement could last for less than 15 years, only under their effects without being overloaded. In order to maintain long last roads, it could be necessary to systematically proceed to a relief of all multi-axles' trucks and trailers in case of overloads. Moreover, the established 5% of overload tolerance should not only be applied P11, P12, P13 type trucks, while taking into to take into account the equipment reliability margin. As 15% overload allowance would reduce the pavement lifetime by 35%, it is therefore unacceptable overloading tolerance on the road assets of the WAEMU community area.

## 4. Discussion

The study was carried out only on a flexible bituminous pavement, so the results obtained concern only this type of pavement. The methodology used to calculate the aggressiveness is only valid for roads in running section. ZOA Ambassa [11], in determining the aggressiveness of heavy vehicles on a roundabout, showed that the contribution of centrifugal forces due to the curvature of the section must be taken into account. In this thesis work, ZOA [1] also calculated the aggressiveness of 5 types of axles and several types of heavy vehicles for three pavement structures named VRNS26; VRNS2 and VRS2. The results obtained with the VRNS26 pavement structure are similar to the results presented in **Figure 3(a)**; **Figure 4(a)** and **Figure 4(b)** of this paper. However, for the results of the other two Zoa structures, discrepancies were found. In a collection of SETRA study reports [17], it is shown that the aggressiveness is a function of the nature of the materials making up the pavement. In this same SETRA report, it is mentioned that the aggressiveness is a function of the bearing capacity of the

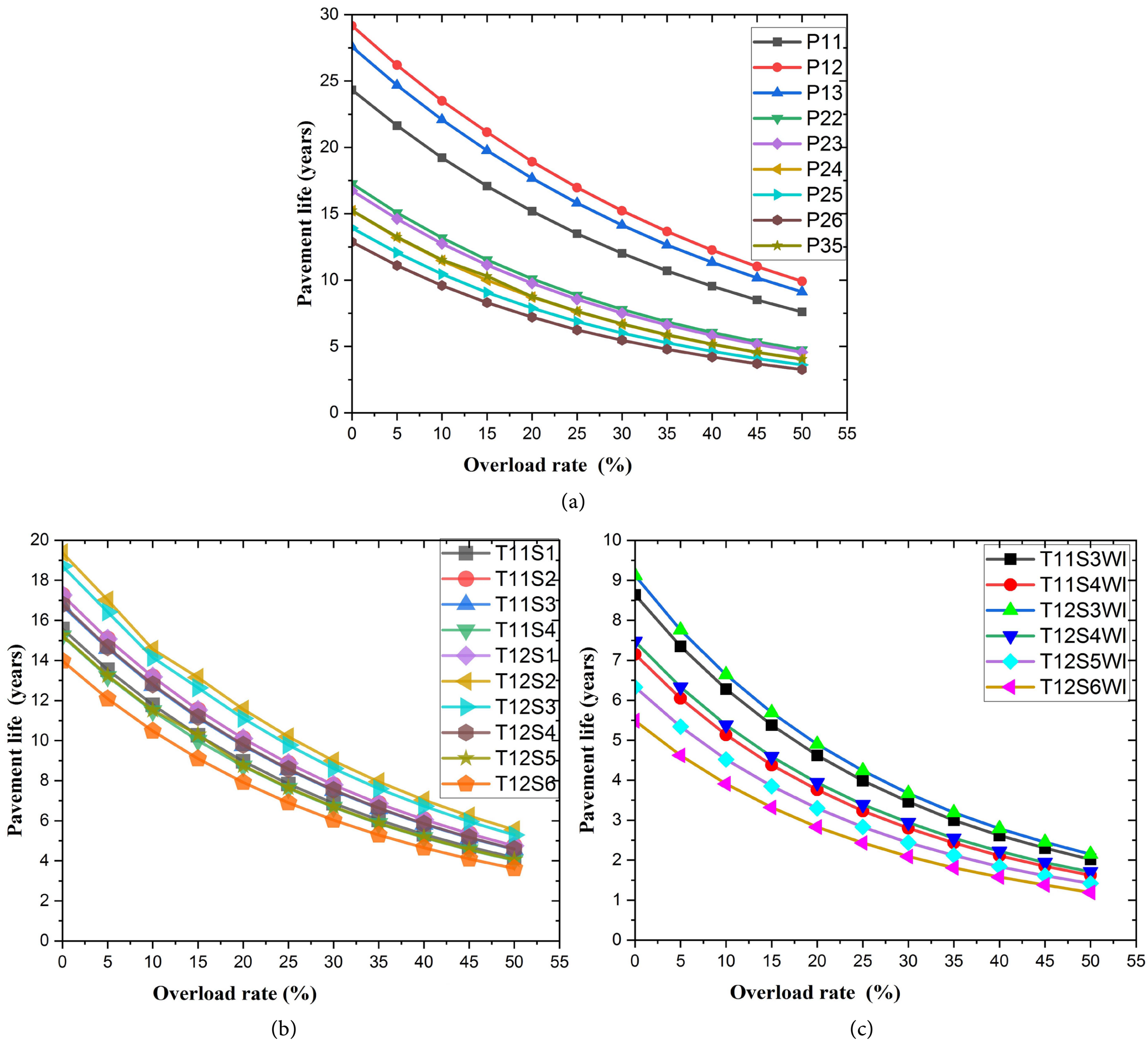



**Figure 8.** Pavement life as a function of heavy trucks (a) P trucks, (b) SR semi-trailer and (c) SRI semi-trailer.

pavement support base. The discrepancies observed with the ZOA work are therefore due to the fact that the two structures VRNS2 and VRS2 have different subgrade classes than the structure under study. Bassem Ali [18] also found in his work that twin tires are less aggressive than super single tires which is in agreement with the results found in this work.

## 5. Conclusion

The results obtained show that multi-axle trucks and different overload tolerances have a significant impact on pavement durability. In this work, it was found that the increase in axles of a heavy vehicle is not necessarily equal to the increase in aggressiveness of this vehicle. It is the overloads that greatly influence the aggressiveness of these multi-axles. Single wheel trucks are more aggressive than dual wheel trucks. Like the aggressiveness, the fatigue life of the pavement is greatly influenced by these overloads. A reduction in fatigue life of 13% and 35% is observed for overload tolerances of 5% and 15% respectively. The pavement life is also strongly influenced by the type of heavy vehicles in the traffic. These results show that for durable pavements, it is important to categorize the overload tolerances according to the type of truck. For this categorization of overloads, it is necessary to complete this work with another study on the influence of the silhouettes of these trucks and the axle wheelbases on the pavement life.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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