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Effect of Overloaded Traffic on Road Pavements Service Life, Structure and Maintenance Costs

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Abstract

Traffic overloads are a real challenge for transportation infrastructures and offices. It contributes to road pavement damage and to vehicle accidents. This has a significant impact on pavement design and maintenance. The objective of this paper is to dress a statistical description of vehicle overloads on some sections of Burkina Faso's Road network and to measure and sensitise people on the effect of overloads on pavement structures, their durability and their maintenance costs and/or take them into account for pavement design. So heavy goods traffic data were collected on six weight stations. The analysis of their data show that around 74.79% of heavy goods traffic are overloaded with maximum average axle loads of 16.92 tons and a record axle load of 24.94 tons. The analysis of the impact of these freight truck overloads on pavements shows that they significantly reduce the pavement service life and increase their maintenance costs following power function model respectively. Dealing with these overloads requires an important increase of pavement structure and consequently the investment costs.

Keywords

Traffic Overloads, Damage, Service Life, Structure, Maintenance Costs

1. Introduction

Demographic and economic growth has led to a significant increase in the need for transportation, driving high mobility in the transport sector. Over the past ten years, road traffic in Burkina Faso has nearly doubled, rising from 71.2 thousand motor vehicles and 83.5 thousand two-wheelers in 1999 to 263 thousand motor vehicles and 1.283 million two-wheelers in 2013 [1]. This growing demand for transportation requires both quantitative and qualitative improvements in transport infrastructure, achieved by developing extensive, high-performance road networks.

However, in Burkina Faso and many countries in the subregion, it has been observed that road networks are severely deteriorated [2] [3]. For example, according to Burkina Faso's Ministry of Infrastructure in 2012, the road degradation rate stood at 60% [4]. A similar situation can be seen across several UEMOA countries [5], where the proportion of roads in poor condition increased from 21% to 25% between 1998 and 2008, despite an improvement in roads in good condition, which rose from 20% to 54%, largely due to the improvement of roads in fair condition, which decreased from 59% to 21%. This situation remains almost unchanged to this day.

Several factors contribute to this degradation, including climatic conditions characterized by alternating periods of severe drought and heavy rainfall, the types of materials used especially lateritic materials specific to tropical regions—and, to a lesser extent, the design methods, construction techniques, and maintenance strategies, which do not ensure long-term durability of the road infrastructure. Among these factors, the most significant is the overloading of heavy trucks [6]. Roads are designed to handle maximum loads of 13 tons, but overloaded trucks exert excessive stress on the road surface, subjecting it to tensile and shear stresses that lead to fatigue and eventual failure [7] [8].

The main objective of this study is to analyze the issue of truck overloading in Burkina Faso and demonstrate its impact on road performance, particularly regarding the durability, structural integrity, and maintenance costs of the roads. The study will begin with a statistical analysis of the overloading, followed by an assessment of its impact on road surfaces. It will conclude by offering recommendations for road network managers, civil engineers, transporters, and other road users to help preserve road infrastructure performance and extend its service life.

2. Literature Review

2.1. Overview of Burkina Faso's and Some Africa Countries Road Network

Burkina Faso's road network has around 61,400 km of inventoried roads, including 15,304 km of roads, classified according to administrative and technical criteria and on which the country's road administration intervenes regularly [1] [2]. According to administrative criteria there are national (RN), Regional (RR) and departmental roads (RD). According to technical criteria, it is possible to distinguish paved roads (bituminous roads), unpaved roads and tracks. The unpaved roads include modern and ordinary unpaved roads while tracks include type A, type B and ordinary tracks (**Figure 1**). The typologies of these different roads are described in [1]. The classified roads represent 25% and the rural tracks 75% of the inventoried road network. The paved bituminous road represents 5% of inventoried roads and 25% of classified roads.

The roads network ensures the movement of the people and their goods. The transport system uses a relatively varied range of mean of transport including motorized vehicles as moped, cars, buses, trucks, trailers, as well as no-motorized vehicles such as bicycles and carts in rural areas, with a predominance of two wheels vehicles which has always represented more than 62% in overall and 87.86% in 2022 [9] [10]. The motor vehicle park includes trailers, buses, trucks, tractors, vans, special and personal light cars which represent around 60% of vehicles park in 2013. But the pavement engineering process distinguishes the light vehicles and the heavy vehicles generally characterized by goods transport vehicles which have permissible gross weight more than 35 kN ou 3.5 tons and considered for pavement design due to their damaging loads. This category of vehicles registered per year, has represented on average 26.4%, or between 22 to 32.5% of motor vehicles park of Burkina Faso from 2015 to 2019 [10]. The most important observation in this section is mainly the mismatch between the high demand of transport and the low quality of the supply of transport characterized by an old vehicle park and an overloaded and damaged road network.

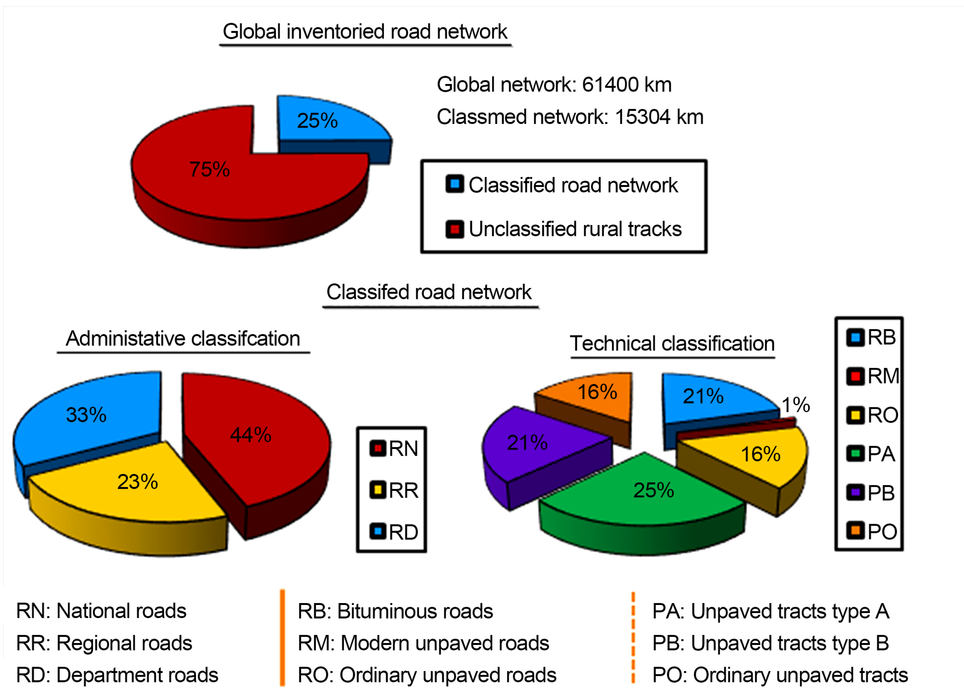


Figure 1. Distribution of road network of Burkina Faso.

Based on several reports (EG/BTP, 2012 ; MID 2012 ; BOAD, 2015), it appears that the road network of Burkina Faso and neighboring countries has many shortcomings. Indeed, according to the African Infrastructure country diagnostic (AICD) cited by Gwilliam [11], the density of the total road network and that of the classified road network are respectively 81.5 km/1000 km^2 and 55.6 km/1000 km^2, while they are respectively 132 km/1000 km^2 and 88.2 km/1000 km^2 for all low-income countries and 318.4 km/1000 km^2 and 278.4 km/1000 km^2 for middle-income countries. The accessibility indices for rural populations within a 2 km radius of a road that is passable in all seasons are 25% compared to 34.1% for low-income countries and 62.7% for middle-income countries. In addition to these quantitative shortcomings, the road network is qualitatively degraded, because according to statistics from the Department of Infrastructure, for a network of 61,400 km of roads, more than 25% of classified roads and 70% of unclassified roads are in poor condition with a degradation rate of 60% (MID, 2012) (**Figure 2**). Focusing on the classified network, it also emerges (BOAD, 2015) that the proportion of roads in poor condition increased from 21 to 25% between 1998 and 2008. Over the same period, the quantity of roads in good condition increased from 20% to 54%, simply by improving the quality of those in average condition which went from 59 to 21%.

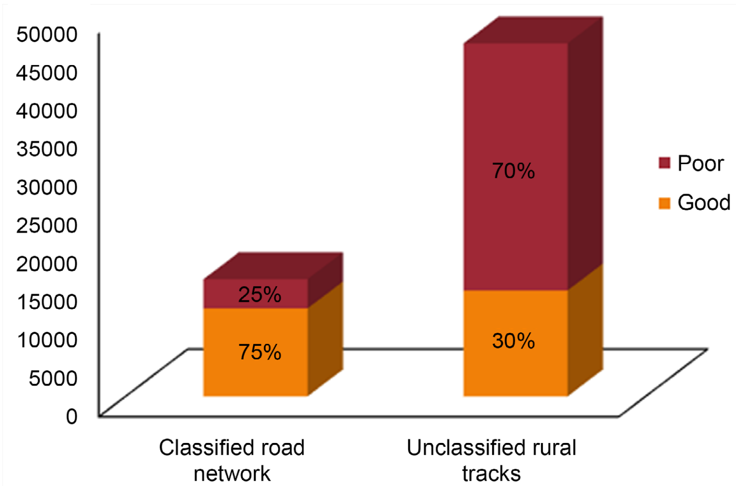


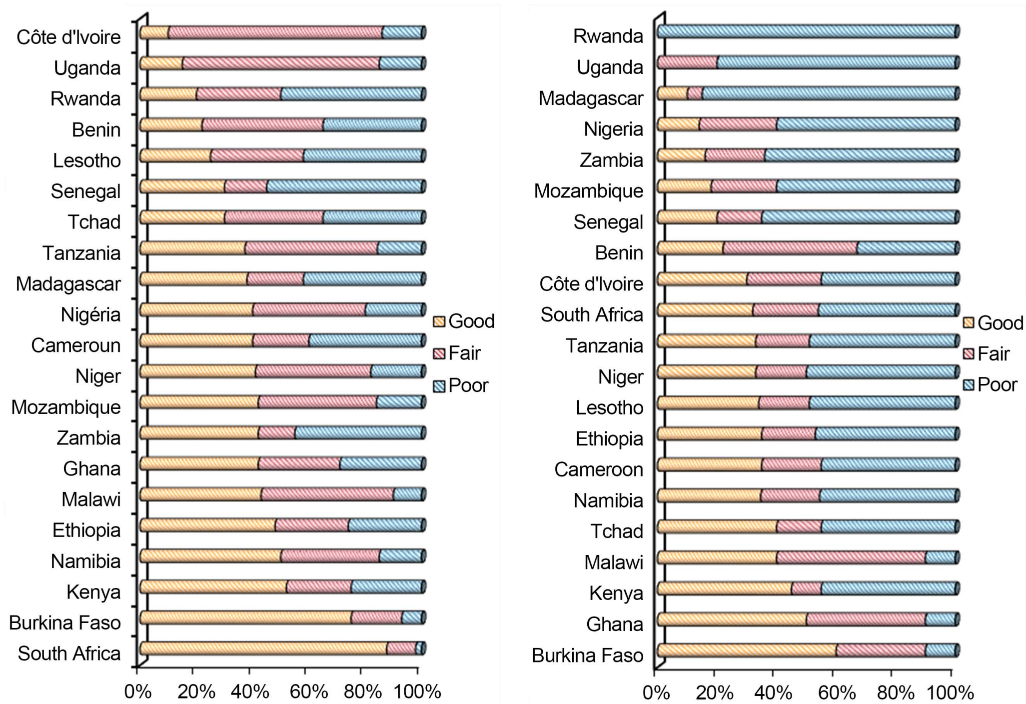
Figure 2. Status of Burkina Faso road network.

These degradations may extend to West African countries, or even to African and other countries in the world with middle or low income, or with rather similar socio-economic conditions. The work of the AICD (African infrastructure country diagnostic) has made it possible to assess the state of the road corridor of Burkina Faso and some neighboring ECOWAS countries [12]. In general, it appears that the part of the sections of the regional corridor crossing Burkina Faso is fully paved and nearly two-thirds are in good condition, well above the average in ECOWAS, and significantly more than in coastal countries (**Table 1**). This allows this part of the country's network to provide basic national, regional and international connectivity, by linking Ouagadougou to international border posts and provincial capitals in the interior until 2006. A trend that has certainly remained unchanged with the country's context of insecurity since 2015.

According to World Bank data [13], more than two-thirds of the main network is in good condition and another third in fair conditions. However, only a little over half of the rural network is in good condition and a quarter in fair conditions **Figure 3**.

Table 1. Status of road network of some ECOWAS countries.

Percentage	Network status				Road type		
	Good	Acceptable	Poor	Unknown	Paved	Unpaved	Unknown
Burkina Faso	58.2	33.6	8.2	0	100.0	0.0	0.0
Ivory Coast	16.1	47.1	35.4	1	90.3	9.7	0.0
Ghana	70.3	23.6	6.1	0	100.0	0.0	0.0
Mali	66.6	21.7	0.0	11.7	99.6	0.4	0.0
Senegal	39.8	15.1	45.1	0.0	99.8	0.2	0.0
CEDEAO	45.1	28.4	22.5	4.0	92.5	7.4	0.1



(a) Principal road network (b) Rural road network

Figure 3. Status of road network of some Africa countries.

The specific pathologies of road degradation in Burkina Faso and many of these countries are mainly patholes, ruths, cracks for paved roads and ravines, etc. for unpaved roads. These pathologies are characteristics of many tropical and income countries and linked to some factors as the climate, road building materials and special traffic overloads.

2.2. Truck Traffic Overloads

The operation of road neworks in sub-Saharan African countries is characterized by overloading practices, particularly on major roads or corridor connecting these countries to coastal regions [2]. While economic growth is the cause of increased transport needs, overloading results from an illegal practice aimed at maximizing freight loads in order to reduce the number of trips or vehicles and naturally reduce transport and road costs. Indeed, the economic operators in place, in their objectives of optimizing transport, use all the provisions that allow them to move the maximum amount of goods [14] [15] at the lowest cost without worrying about the damage caused to roads. However, roads are designed to support limited axle loads of eight (08) tons per axle in some countries [16] [17] and thirteen (13) tons per axle in many Africa subtropical countries [18]. Overloading refers to loads that exceed these legal or reference limits [14]. Such excessive loads place extreme stress on pavements through tensile and shear stresses, leading to fatigue and eventual structural failure, which explains the frequent degradations sometimes observed on many roads.

Overloading is a global issue and, in developing countries, with the lack of regulatory control, the percentage of overloads can reach 60% to 80% of vehicles [15], even if in developed countries, the percentage is relatively lower. Overloading is responsible for reducing the service life of pavements and sometimes for accidents and exorbitant maintenance costs of roads [19] [20]. According to Mehari [14], overloaded heavy trucks account for more than 60% of pavement damage [21]. For Worsak (2005) as well as other researchers, 81% of highway damage is caused by just 33% of overloaded trucks [22].

Several other studies conducted in many countries in Europe, Africa, in United States of America, in Australia, China, India, and other countries reveal that pavement deterioration increases exponentially with overloading, following what is known as the "fourth or fifth power law". This law states that the damage to pavement rises with the load raised to the power of 4 or 5 [2] [23] as illustrated in **Figure 4**.

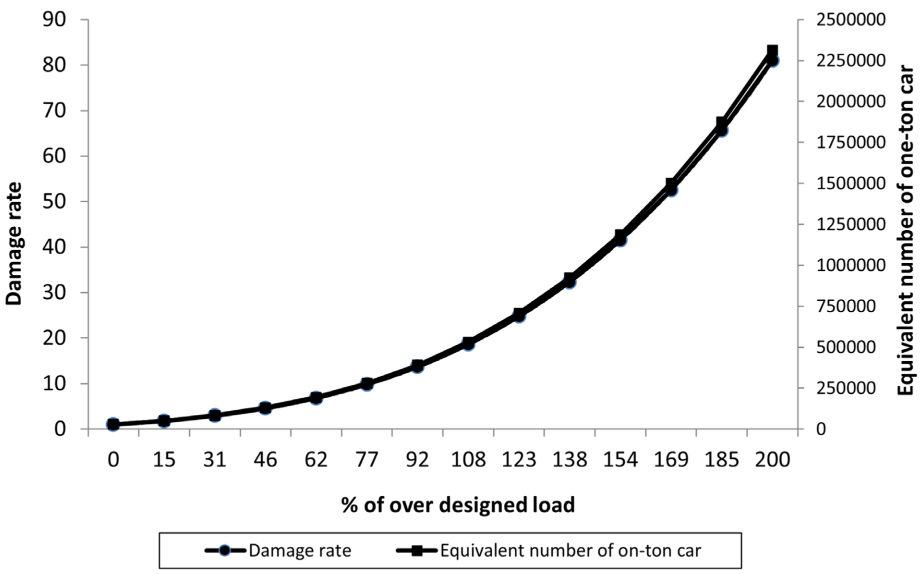


Figure 4. Damage rate and equivalent number of one-ton car [2].

However, scientific or engineering studies have rarely been conducted in West Africa and even less so in Burkina Faso to understand or quantify the impact of these overloads on the lifespan, structural integrity, and maintenance costs of road pavements. The present study will address these issues, with a specific focus on overloads and their impacts on the main roads in Burkina Faso.

Many types of vehicles are used in transport operation to ensure the mobility of people and goods, to face the economic growth and the increase in the needs of transport. But the vehicles of transport of goods, characterize mainly by trucks and tailors are mainly concerned by overloads. So, many methods of pavement design [16] [18] [24], rationals or mechanistics are focused on heavy vehicles defined as vehicles with more than 3.5 gross weight. These vehicles have several axles with regulated weights and contribute more to the deterioration of pavement of roads. The vehicles type or profile is shown in **Table 2** and **Figure 5**.

Table 2. Summary of authorized axle loads and gross vehicle weights [3].

Vehicles type	Vehicle silhouette							Axle load (tons)	Max Authorized Weight (Tons)	Studied vehicle categories
Axle motor vehicle	O	O						6 + 12	18	P11
Axle motor vehicle (with tandem)	O	O	O					6 + 20	26	P12
Axle motor vehicle and above	O	O	O	O				6 + 25	31	P13
Axle trailer		O		O				6 + 12	18	R11
Axle trailer (with 1 tandem)		O		O	O			6 + 18	24	R12
Axle articulated vehicle (three axles)	O	O		O				6 + 12 + 12	30	T11S1
Axle articulated vehicle (four axles)	O	O	O		O			6 + 12 + 20	38	T11S2
Axle articulated vehicle (with tridem)	O	O		O	O	O		6 + 12 + 25	43	T11S3
Axle articulated vehicle (with 2 tandems)	O	O	O		O	O		6 + 20 + 20	46	T12S2
Axle and higher articulated vehicle	O	O	O		O	O	O	6 + 20 + 25	51	T12S3
Axle road train (four axles)	O	O		O		O			36	P11R11
Axles road train (with 1 tandem)	O	O	O		O				38	P12R1
Axle road train (five axles)	O	O	O		O		O		44	P11R12/ P12R11

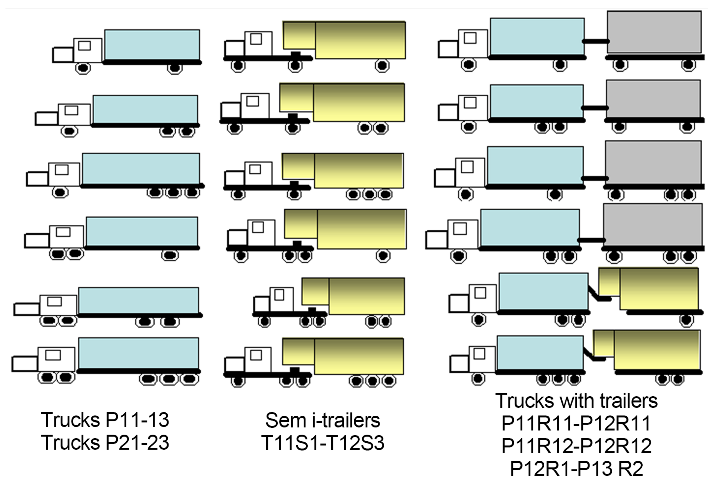


Figure 5. Freight vehicle's profile.

There are articulated vehicles with six axles (T11S4, T11S2S2, T22S2), seven axles (T12S4, T22S3) and eight axles (T22S4), as well as road trains with six axles (P13R2, P112R2), seven axles (T12S2S2), eight axles (T12S3S2) and nine axles (T12S3S3) in the latest updated data. The distribution of total and axle weights of their vehicles or trains is more or less known.

3. Methodology

The study was conducted collecting truck or freight traffic data get in or out Burkina Faso to perform first statistical analysis and finally truck traffic impact on pavement design and maintenance.

➢ The sampling and study area

The study covers the major transportation roads across the country from west to east (latitude 12˚30'00.00" north and longitude 1˚48'00.00"), focusing on key corridors that channel substantial traffic either toward the capital, Ouagadougou, or from the capital toward neighboring countries (**Figure 6**). It primarily investigates the weigh stations strategically located on these main roads where traffic flow is significant (**Figure 6**). Although eight or more weighing stations were initially identified, this study ultimately focused on six of them. Below are the stations of:

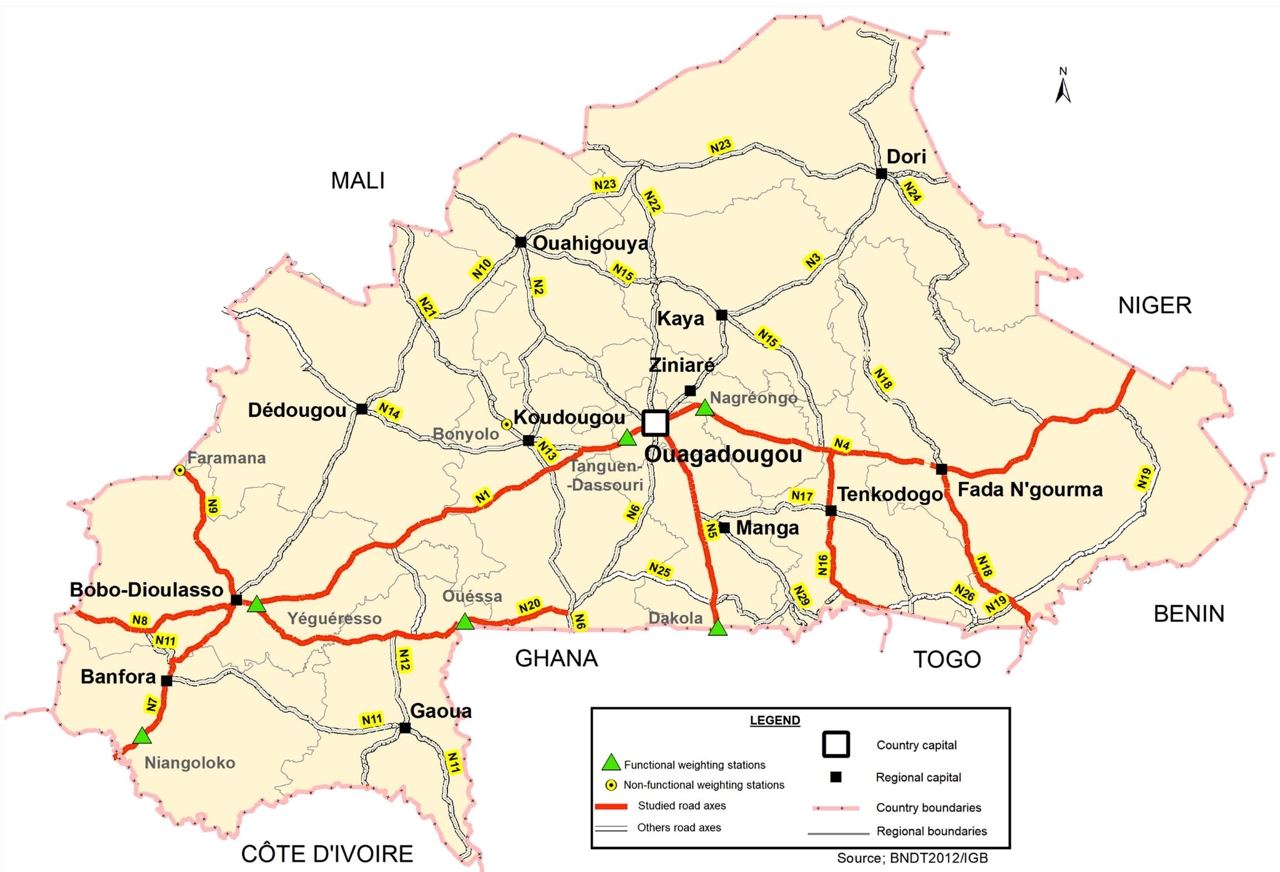


Figure 6. Map of weighing stations and some road sections.

- **Faramana** (*RN9*: *Bobo-Dioulasso-Mali border*)**:** trucks traveling between Burkina Faso and Mali via RN9;
- **Niangoloko** (*RN7*: *Bobo-Dioulasso-Côte d'Ivoire border*): trucks connecting Burkina Faso to Côte d'Ivoire through the RN7 corridor, a key trade axis toward the port of Abidjan;
- **Bobo-Dioulasso** (*RN1*: *Bobo-Dioulasso-Ouagadougou*): trucks headed to or coming from Ouagadougou, including those transiting from other major roads (RN8, RN9, RN7, etc.);
- **Tanghin-Dassouri** (*RN1*: *Ouagadougou-Bobo-Dioulasso*): vehicles moving between Bobo-Dioulasso and Ouagadougou, as well as between Koudougou (via RN14) and other towns along the RN1 corridor;
- **Dakola** (*RN5*: *Ouagadougou-Ghana border*) : trucks linking Burkina Faso and Ghana through RN5, which connects Ouagadougou to Paga, a major border crossing point;
- **Nagréongo** (*RN4*: *Ouagadougou-Niger border*): trucks traveling from Ouagadougou to Niger via Fada N'Gourma (RN4).

➢ Data collection

Truck weight data were collected at each station. These data relate to the type of truck, the nature of the goods transported, the origin and destination, the weight of each axle, and the total weight. The weighing system consists of a weighing platform (Figure 7) load cells with sensors, access ramps, and a control cabin housing the equipment for data management and processing and possibly, beacons, digital displays, and parking areas. The same weighing system and procedure were used for all six stations, except for those not included in this study.

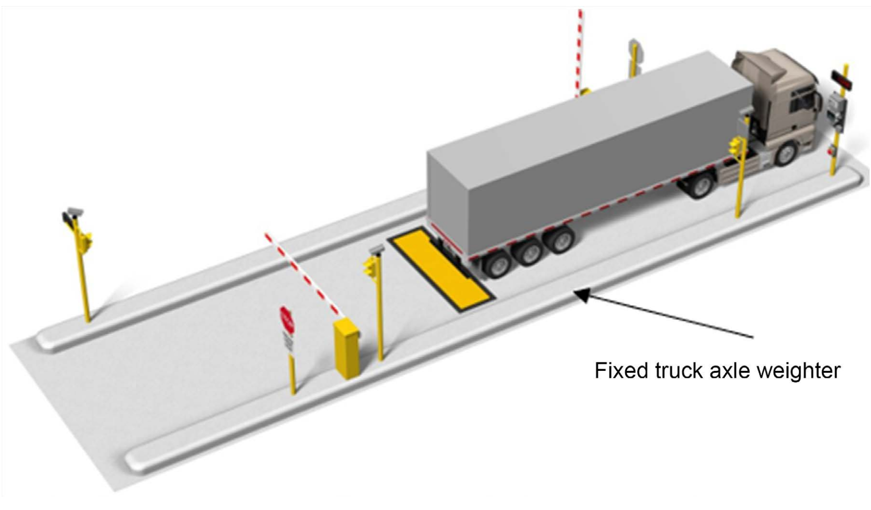


Figure 7. Weighing station device.

Once the truck is weighed using the axle weigher, the data is transmitted to computers in the control cabin. These computers, equipped with specialized software, record, process, display, and print the results, which are provided to the transporter.

The results of the weighing ticket contain information about the truck type, the weight of each axle, the total weight (calculated as the sum of all axle weights), and the fine amount to be paid in case of overloading. It is important to note that a 20% tolerance is applied to excess loads.

➢ Data analysis

The data analysis mainly includes two steps. The first step devoted to a statistical analysis of the weighing data, in particular, a descriptive statistical and a second step which will focus on the impact of overloads on the pavements, in particular the impact on the structure thickness, durability and maintenance costs. For this, the methods of design of pavement in force in the country will be used with the actual or maximum loads recorded, the service lives calculated from the knowledge of the admissible limits of the loading cycles and resistance of the materials to the phenomenon of fatigue, then finally the maintenance costs from the experience lived and drawn from the different road maintenance programs, the budgets allocated in relation to the mileages actually maintained.

4. Results and Discussions

4.1. Statistical Analysis

Data of freight vehicles control from 2017 to 2023 and, on the six stations of 2023 were collected and analyzed. The considered parameters are mainly the number of controlled vehicles, the number of overloaded vehicles, the percentage of overloaded vehicles and their axle load. The results of the analysis of vehicles controlled or inspected per year from 2017 to 2023 are provided respectively in Figure 8. The number of controlled vehicles and overloaded vehicles are in histogram and the percentage of overloaded vehicles.

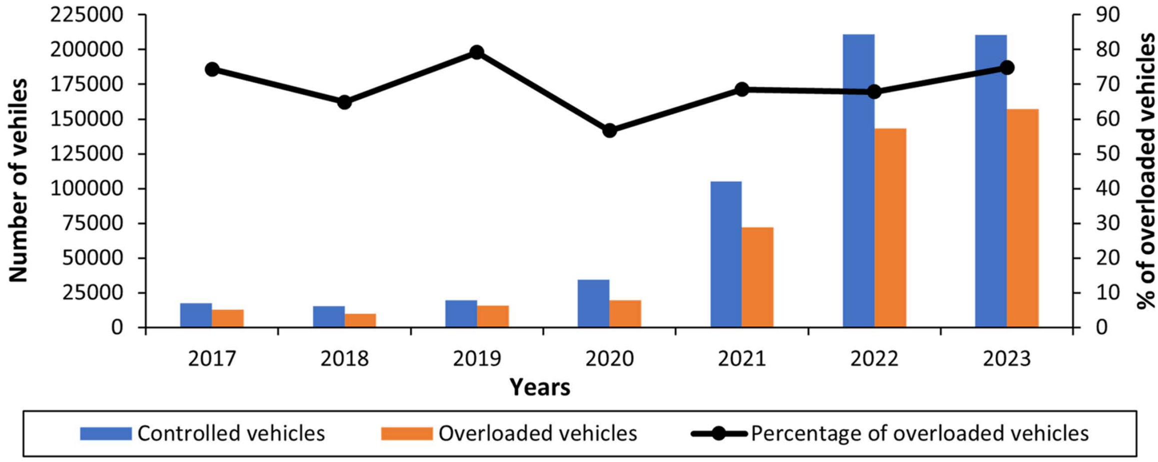


Figure 8. Status of freight traffic per year, from 2017 to 2023.

Figure 8 shows an increase in the number of freight vehicles or trucks as well as the number of overloaded vehicles. In 2018, there is a decrease in the number of vehicles (−12.95%) and the number of overloaded vehicles (−24.03%) compared to 2017 and, a stabilization or a slight decrease in the number of controlled vehicles in 2023 (−0.32) compared to 2022. In 2021, the number of controlled vehicles and the number of overloaded vehicles increased by more than 200%. The decrease in 2018 can be explained by some transporters bypassing the weighing system, while the increase in 2021 is likely due to the transfer of the vehicle weighing contract to the company "Afrique Pesage". This contract mainly covered the Dakola - Ouagadougou - Bobo-Dioulasso axis up to Niangoloko. But it can be observed an irregular variation from year to year of freight trucks control, with an overall or annual average growth roughly equal, *i.e.* 51.41% and 51.55% over the seven-year period, respectively for the number of controlled vehicles and the number of overloaded vehicles. Aside from the irregularities in the control process, based on the annual growth, the number of freight vehicles could nearly double every two years. This would lead to road congestion and significant waiting times, unless additional logistical resources are planned in the coming years to strengthen the existing infrastructure context, politics or economic opportunities.

Figure 9 shows the distribution of the freight vehicles on the six weighing stations, mainly the stations of Bobo-Dioulasso, Dakola, Nagréongo, Niangoloko, Ouessa and Tanghin Dassouri.

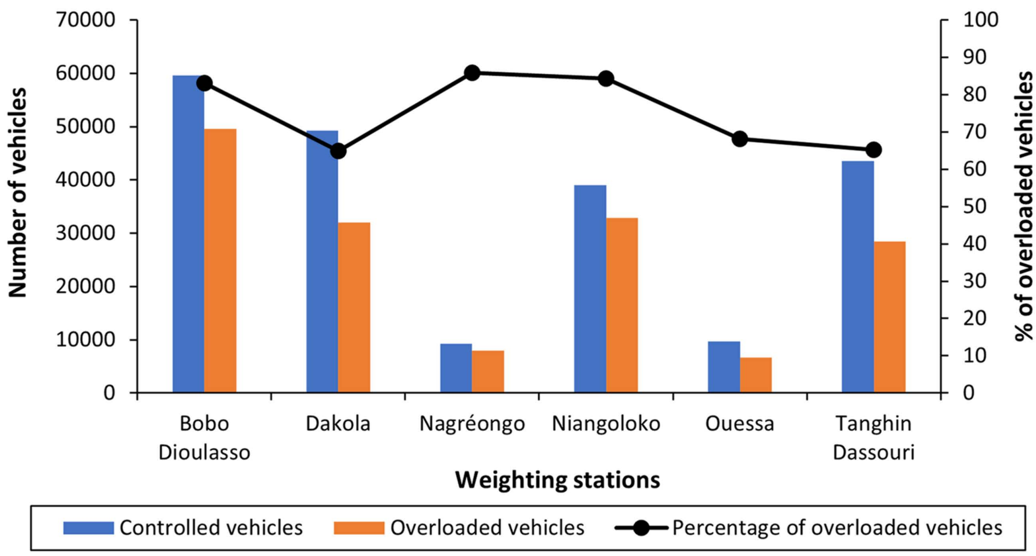


Figure 9. Status of traffic on the six stations.

Apart from the Nagréongo and Ouessa stations, the other four stations handle a significant number of freight trucks, with the Bobo-Dioulasso station holding the record for the highest number of vehicles nearly 60,000 vehicles inspected, compared to almost 50,000 overloaded vehicles, corresponding precisely in overall to 163 vehicles controlled per day. This is due to the fact that these four stations are located along the Dakola—Ouagadougou—Bobo-Dioulasso—Niangoloko corridor, which ensures the highest traffic flow and is subject to stricter controls. The average percentage of overloaded vehicles on the six stations is 75.24% and the weight station of Nagréongo records the highest percentage of overloaded traffic with 85.78%. This high percentage could be due to the relatively low number of vehicles controlled at this station.

In addition to logistical issues, the high number of heavy goods trucks presents technical challenges and are of interest both to road managers and civil engineers, as their weights and overloads significantly contributes to the degradation of road pavements.

Regarding the number and the total loads carried out by each type of vehicles in 2023, it is possible to plot the following graph (**Figure 10**). The analysis of the loads by axle of each vehicle type is provided in histograms in **Figure 11**. It should be noted that only the weights of the first three axles are presented in **Figure 11**, whereas each of the controlled vehicles has between two (02) and ten (10) axles.

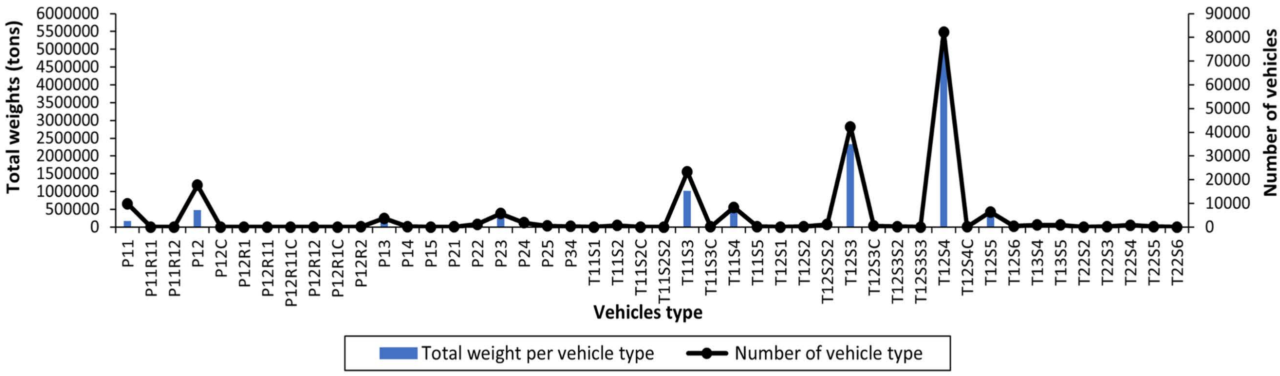


Figure 10. Load supported by vehicles type in 2023.

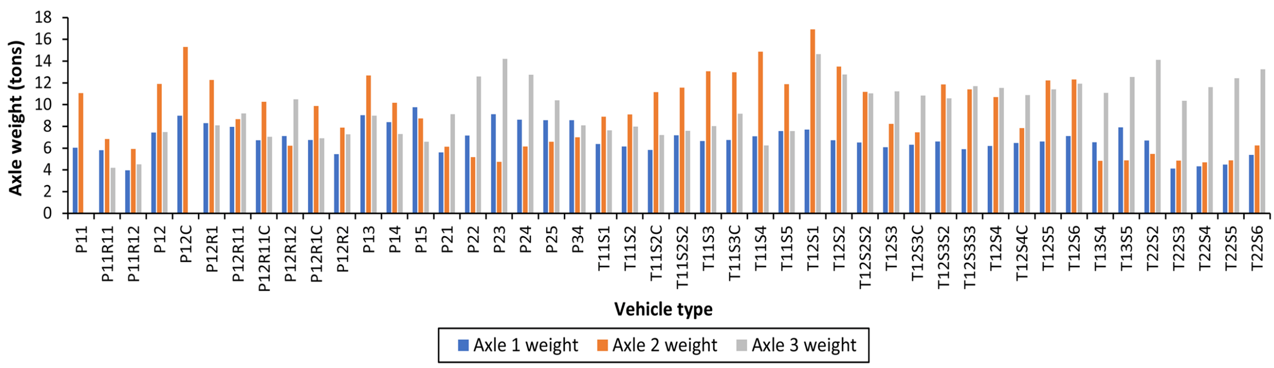


Figure 11. Histograms of three axle loads of vehicles.

It can be seen that vehicle type T12S4, T12S3, T11S3, P12, T11S4, P23, T12S5, P11 and P13 are more common and representative in freight traffic in 2023, with a record set by T12S4 vehicles, totaling 82,253 units and transporting nearly 5.24 million tons. There is a certain proportionality between the number of vehicles and the weight transported by each vehicle type. However, within each vehicle category, when the total transported weight is divided by the number of vehicles in that category, it becomes evident that many vehicles exceed the maximum authorized gross weight (PTAC, as shown in Table 2). Exceptions include a few vehicle types, such as P11R11, P11R12, P12R2, P21, T11S2C, T12S3S2, T22S3, and T22S4.

Analysis reveals that the maximum average intermediate axle load is 16.92 tonnes, carried by the T12S1 vehicle category, followed by 15.29 tonnes, 14.87 tonnes, and 14.65 tonnes, transported respectively by P12C, T11S4, and again T12S1, this time on its third axle. Additionally, front axles are often overloaded.

By examining the maximum values of total weight and axle load transported at each of the six stations in 2023, the following table (Table 3) was established.

Table 3. Maximum weight in each station in 2023.

	Total weight (tons)	Max weight per axle	Axle type	Vehicle type	Destination
Bobo Dioulasso	132.36	22.64	Axle n˚3	T12S5	Ghana
Dakola	100.04	24.94	Axle n˚4	P35	Ghana
Nagréongo	92.86	17.58	Axle n˚2	T12S6	Ouagadougou
Niangoloko	121.78	23.22	Axle n˚7	T12S6	Abidjan
Ouessa	88.78	13.98	Axle n˚4	T13S5	Ouagadougou
Tanghin Dassouri	104.4	16.94	Axle n˚2	T13S5	Ouagadougou

Following these analyses, it appears that the maximum axle weight in 2023 is 24.94 tons for the P35 type vehicle, registered at the Dakola station and bound for Ghana, followed by axle weights of 23.22 tons and 22.64 tons respectively for the T12S6 and T12S5 type vehicles, registered at the Niangoloko and Bobo-Dioulasso stations and bound for Abidjan and Ghana respectively.

4.2. The Impact of Overloads on Pavements

This section focuses on assessing the impact of overloads on road durability, structural design, and infrastructure maintenance costs. Thus, based on the analysis of overloads in the previous section, three hypotheses corresponding to possible road usage scenarios by freight transport trucks have been selected for the further analysis:

- Case n˚1 corresponds to the situation where vehicle loading complies with the axle load limits defined by the UEMOA R14 regulations and, at worst, with the reference axle load defined in the pavement design guide [18];
- Case n˚2 represents the situation of maximum average overloads. It concerns the most heavily loaded truck type, T12S1, and assumes that within this category, the excess load of overloaded trucks is redistributed to underloaded trucks;
- Case n˚3 corresponds to the situation of maximum vehicle overloads, similar to the loading of the P35 truck recorded at the Dakola station.

Table 4 summarizes the three cases with the axle loads considered.

Table 4. Situation of loads considered for analysis.

	Case n˚1	Case n˚2	Case n˚3
Axle loads (in tons)	12/13	16.92	24.94

4.2.1. Overlaods and Their Impacts on the Damage Rate and the Durability of Roads

The objective of this section is to assess and demonstrate the impact of overloads on pavement service life. To achieve this, it was first necessary to determine the vehicle aggressiveness coefficient or damage rate and, on the other hand, to estimate the cumulative truck traffic as well as the stresses or deformations it may cause.

The traffic data from the Niangoloko station was selected due to its proximity to the average number of vehicles recorded across the six stations, with an annual average daily traffic (AADT) of 107 vehicles per direction per day in 2023, and a growth rate of 6.20%. This rate is considered more realistic [1] [2] compared to the average growth rate obtained from **Figure 8**, given the variability in enforcement over the years and among the control authorities.

The projected design life of the pavements in the reference scenario is 15 years. **Table 5** provides some key parameters considered for truck traffic loads evaluation.

Table 5. Some parameters considered for traffic evaluation.

Parameters	Values
AADT in 2023	107
AADT in 2025	121
AAGR (%)	6.20
Pavement service life (in years)	15

Some parameters considered for traffic evaluation, based on the loads in the three operating scenarios presented in **Table 6** and a few intermediate cases, were used to determine the overload percentages and the corresponding damage rate.

Table 6. Considered loads, overloads and damage rate.

Charges	% of Overloads	Damage rate
12/13 (case n˚1)	−7.7/0.0	0.73/1.00
14.65	12.70	1.61
16.92 (case n˚2)	30.15	2.87
20.02	54	5.62
22.64	74.15	9.20
24.94 (case n˚3)	91.85	13.55

Using the different information, the curve of the pavement expected service life is plotted according to the damage rate and the percentages of overloads as shown in **Figure 12**.

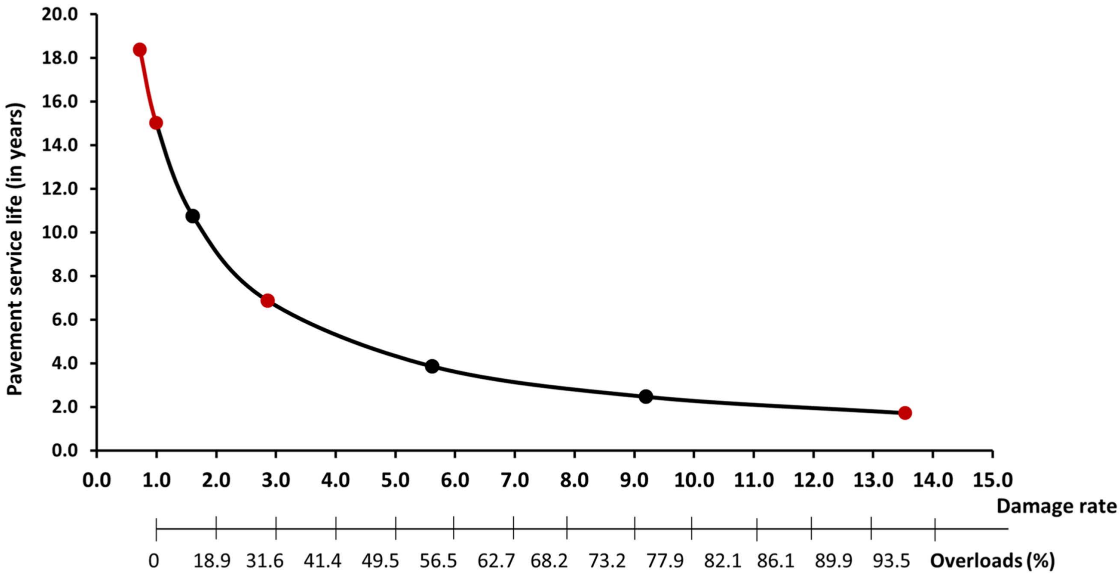


Figure 12. Impact of damage rate on pavement service life.

It can be seen from **Figure 12** that the pavement service life decreases as the damage rate increases. With a damage rate equal to 1, corresponding to the hypothesis that the vehicles on the roads would be loaded at 13 tons per axle, there is zero overload and the road design period remains unchanged and is equal to 15 years. In the case where the vehicles are loaded at 16.92 and 24.94 as observed in the previous analyses, in terms of overloads, this corresponds to 30% and 92% overloads and an aggressiveness coefficient or a damage rate of 2.87 and 13.55 respectively. These situations have a considerable impact on the pavement service life and for these specific cases, the initial design period of 15 years is reduced to 7 years (or about half) and to 2 years (divided by 7.5). On the other hand, if the vehicles are loaded below the reference load of 13 tonnes, more precisely 12 tonnes, this improves the design life of the roads which goes from 15 years to 18 years.

4.2.2. The Impact on the Pavement Thickness.

Taking into account the realities of traffic operation described at the beginning of this section and classified in the **Table 7** on the one hand and, choosing subgrade soils classified S3 according to subtropical countries pavement design guide [18] on the other hand, this part tries to analysis the impact of traffic on pavement structure, in term of thickness of pavement layers in the three road usage scenarios or cases. A pavement structure consists, from top to bottom, of a surface layer, a base layer, a sub-base layer, and possibly a subgrade layer, all resting on a supporting soil. The thicknesses of the layers that make up the pavement structure depends on traffic levels, the subgrade soil classification, and the types of materials used for each layer.

In this study, only the first three layers have been considered. To facilitate comparisons, the BB/GB/GNT structure was selected, which consists of a surface layer made of asphalt concrete, a base layer made of bituminous treated aggregate, and a sub-base layer made of natural or untreated aggregate. The thicknesses of the pavement layers in the three cases are given in Figure 13.

Table 7. Some Inputs data for pavement design.

Parameters	Case 1	Case 2	Case 3
Equivalent single load	7.56E+05/1.04E+06	2.99E+06	1.41E+07
Traffic class	T2	T3	T5

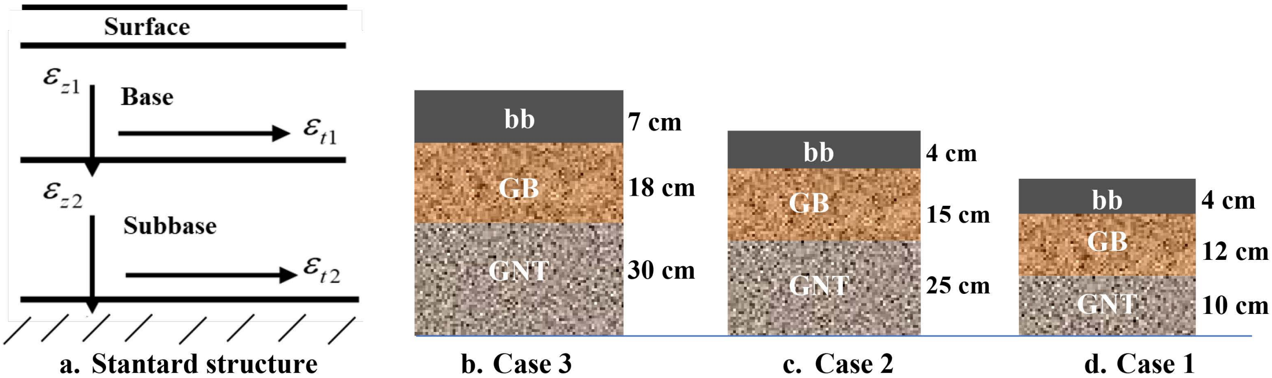


Figure 13. Pavement structure thickness according to the damage rate.

It is possible to see that the pavement structure thickness increases according to the traffic damage rate. From the case n˚1 to n˚2, there is an increase of 18 cm on the total structure thickness, 3 cm and 15 cm for base and subbase layers respectively. This increase from the case n˚1 to n˚3 is 29 cm on the total structure, 3 cm, 6 cm and 20 cm for surface, base and subbase layers respectively.

4.2.3. The Impact on Road Building or Maintenance Cost

Given the impact of traffic damage rate on the durability and structure of roads, it is evident that this has effects on road construction and maintenance costs. If roads are subjected to loads below the reference thresholds, their design life increases, and maintenance costs decrease. Conversely, non-compliance with regulatory load limits accelerates pavement deterioration. To address this, road managers have only two options: either build robust structures to withstand traffic intensity or increase the frequency of maintenance. The first option raises investment costs, while the second increases maintenance costs. In this study, Figure 14 provides an overview of the possible evolution of the maintenance costs over fifteen (15) years.

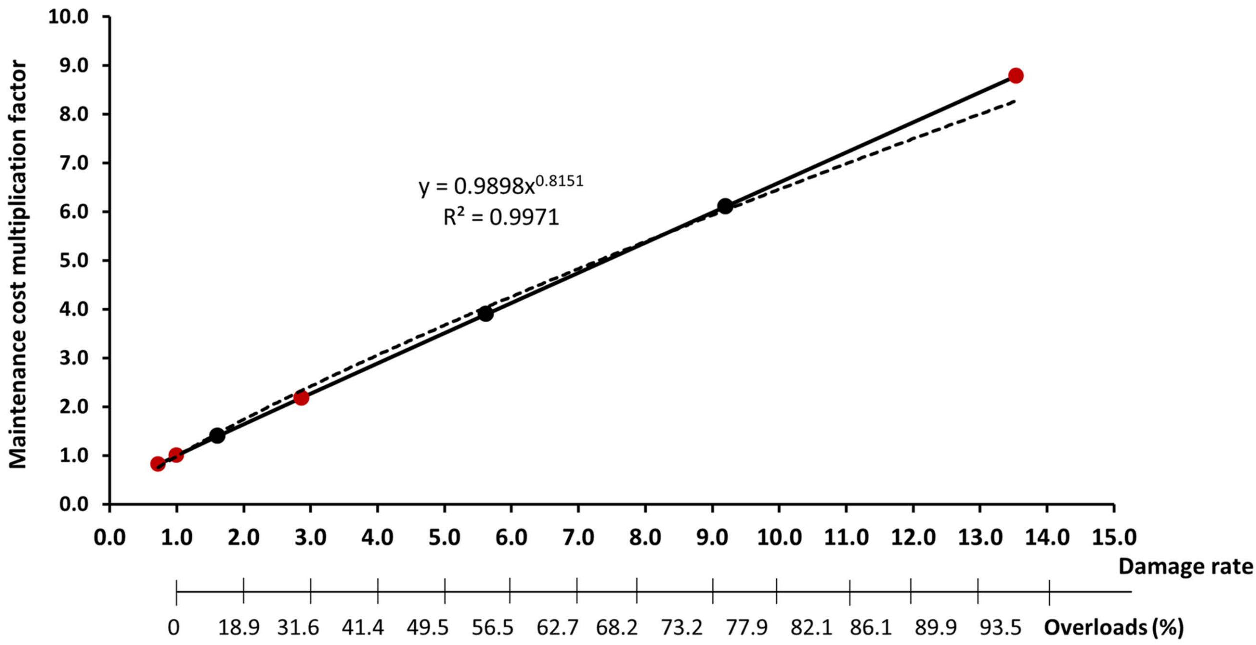


Figure 14. Evolution of the maintenance cost.

The curve provides an idea of the evolution and, more specifically, the multiplication factor of maintenance costs based on overloads or the damage rate. It can be seen that the multiplication factor increases. When the damage rate go from 1 to 2.87, the multiplication factor or the maintenance cost double (from single), and when the damage rate reaches 13.55, the maintenance cost multiplication factor is multiplied by 8.80. However, it is 0.82 over 15 years for damage rate of 0.73 corresponding to the limited axle loads of 12 tons recommanded by UEMOA. Otherwise, it is possible, knowing the maintenance cost in normal situation, to estimate the maintenance costs under overload conditions if the damage rate or the aggressiveness coefficient is known.

It is also possible to invest on a solid pavement. But it is clear that the construction cost and the pavement structure, both increase according to freight load scenarios or the aggressiveness coefficient (see **Figure 15**). In the structure shown above (**Figure 13**), from case n˚1 to n˚2, the surface layer remained intact, while the base and subbase layer increased by 25% and 150% respectively. Moreover, the surface layer, the base and the subbase layer increased by 75%, 50% and 200% from case n˚1 to n˚3. This will result in a proportional increase in construction costs. However, the actual costs could be determined through a pricing study of the materials constituting these pavement structures. It should also be noted that beyond a certain level of aggressiveness or damage rate, natural or untreated soils are no longer suitable. Instead of increasing the thickness of the layers, it becomes necessary to completely change the pavement structure—for example, transitioning from flexible pavement to reinforced, stiffened or even concrete pavements.

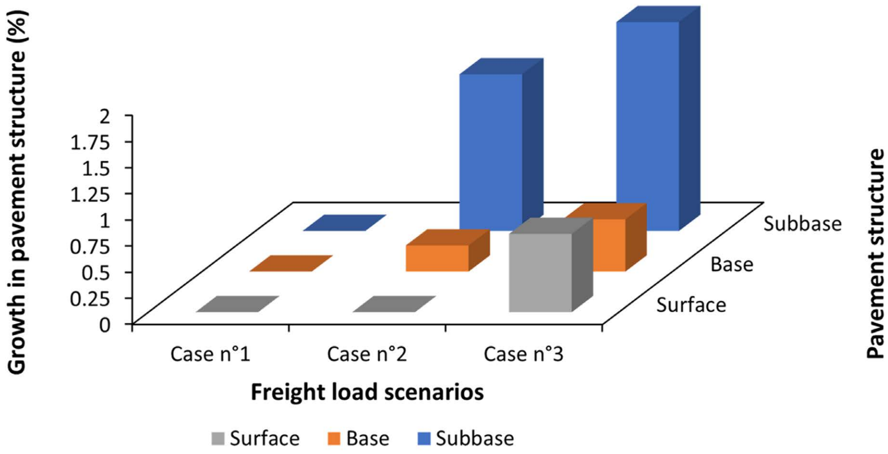


Figure 15. Evolution of the pavement structure and the construction costs.

4.2. Discussions

The results of the study show a strong growth in freight trucks from 2017 to 2023 and their high concentration in 2023 at the station of Bobo-Dioulasso, which recorded the highest number of vehicles, followed by the Dakola, Tanghin Dassouri and Niangoloko stations. This is due to the fact that these stations are located on the most important road axis of the country linking the Ivory Coast to Ouagadougou and Ouagadougou to the Ghana border. However, the strong and irregular growth in truck traffic since 2017 is the result of, on one hand, the measures taken by transporters to bypass weigh stations and, on the other hand, the changes in management that occurred during this period. Each manager has a different level of control, with some being less strict or more lenient than others. Nevertheless, this growth remains far from the levels obtained by Gansonré *et al.* [1] [2] based on surveys of road traffic flows in Burkina Faso. In addition, the studies reveal that trucks are generally overloaded. The average percentage of overloaded vehicles is 74.79%, with a record high of 85.78% at the Nagréongo station, which may be due to the small sample size of vehicles in these stations. The maximum average axle loads are around 16.92 tons, with a record maximum load of 24.94 tons recorded at the Dakola station, carried by the P35-type truck. Although the percentages of overloaded vehicles and record axle loads are high, these values remain lower than those obtained by CONSIA-SITRASS-BESTE in 2008 [3] (30 tons per axle).

Most importantly, the use of statistical analysis results highlights the impact of vehicle overloading on road service life, structures, and maintenance or construction costs. In fact, when overloading increases by 30%, it reduces the projected service life of roads—normally 15 years—by half. For overloads of 92%, corresponding to the record load of 24.94 tons, the service life or the design period of pavement is devided by 7.5. There exists a power function in the following form (Equation (1)) where (a, α) and the correlation coefficient (R^2) are provided in **Table 8**.

$$ax^{\alpha} \quad (1)$$

These overloads also impact road structures by increasing the surface layer, base and subbase layer by 3 cm, 6 cm and 20 cm respectively, for maximum loads (24.94 tons) and by 3 cm and 15 cm on base and subbase layer respectively, for maximum average loads (16.92 tons). It is important to note that these thicknesses are determined solely using the pavement design guide; however, validation through numerical programs may yield different thickness values. All of this affects the cost of road construction and maintenance. Regarding maintenance and investment costs, they increase with overloading. Maintenance costs are inversely proportional to the projected service life of roads, meaning they double when the service life is reduced by half. Investment costs, on the other hand, are proportional to the increase in road structure thickness caused by overloading. The actual values of these costs can only be determined through specific price studies, including materials, labor, etc. However, Adolehoume's work [3] estimated the annual additional maintenance costs due to overloads at around 30 billion CFA francs for eighteen (18) major road corridors totaling 1,450 km of paved roads, equivalent to 21 million CFA francs per kilometer of paved road. This study shows that these costs increase according to the overload damage rate, following also the power function (Equation (1)) with (a, α), and correlation coefficient (R^2) provided in **Table 8** and demonstrating the reliability of these relationships.

Table 8. Coefficients a, α and R2 of the service life and maintenance cost fonction.

Parameters	Coefficients		Correlation coefficients (R^2)
	a	α	
Pavement service life	15.155	−0.815	0.9949
Pavement maintenance costs	0.9898	0.8151	0.9971

Beyond the few limitations highlighted in the previous paragraphs, the study also faces constraints related to the classification of trucks and the relatively small sample of weigh stations. However, the analysis focused on six weigh stations, as there are very few truck control points in the country (approximately eight weighing stations identified). These are the only operational stations equipped with axle load weighing systems, located along the country's main roads. While these roads do not represent the entire national road network, they are where traffic and overloading are most prevalent. This makes them ideal for studying and quantifying the impact of overloading on flexible or lightly reinforced pavements.

Although the study focuses on flexible pavement structures, it is important to note that the impact of overloading would likely be even more severe on semi-rigid and rigid pavement structures.

In practice, it sometimes happens that non-standard trucks arrive at weigh stations. These are usually classified into the closest existing category, which can affect data accuracy and distort the analysis. Nevertheless, such cases are relatively rare. Still, this highlights the need to raise awareness among road authorities and transport operators about the dangers posed by these modified trucks—not only to road safety but also to the drivers themselves, as well as the transported passengers and goods. These vehicles should either be brought into compliance with regulations or be banned from using public roads.

5. Conclusions and Recommendations

The objective of this study was to perform statistical analysis of the overload traffic on some weight stations and to investigate their impact on pavement durability, structure and their maintenance or construction cost. The results of the statistical analysis show that the number of heavy traffic on the six studied weight stations increases every year with an annual average growth rate of 51%, and whatever the station, the percentage of overload vehicles is more than 64%, the average value is 74.79%. The station of Bobo Dioulasso records the highest number of controlled vehicles while the station of Nagréongo records the highest percentage of overload vehicles (85.78%), may be due to the small sample size of vehicles recorded at this station. The study highlights the significant impact of overloaded traffic on the road pavement damage with a medium and a maximum damage rate of 2.87 and 13.55 respectively, corresponding to loads of 16.92 tons and 24.94 tons and, demonstrating that excessive weight and frequent overloading contribute to accelerated wear and tear. This leads to a reduction in pavement service life, increases the pavement structure thickness and increases the frequency and cost of repairs or maintenance. The study shows that 30% of overload (corresponding to 16.92 tons) reduced the service life of pavement to half and increased the maintenance cost to double. When they reach 92% (corresponding to 24.94 ons), the pavement expected service life is divided by 7.5 while the maintenance costs are multiplied by 9. Even better, satisfactory models (R^2 greater than 0.99) were found for predicting both service life and maintenance costs, respectively, in the form of ax^{α}, with a and α were presented in **Table 8**. Regarding the pavement structure, the base and subbase layers increased by 25% and 150% respectively under 30% overloads, while the surface, base, and subbase layers increased by 75%, 50%, and 200% respectively under 92% overloads. This corresponds to a total pavement thickness increase of 69% and 112% respectively in the two cases. Beyond these overload levels or with a higher annual average daily truck traffic volume than considered in this study, the use of concrete pavements becomes essential.

Ultimately, the study provided satisfactory results regarding the statistical analysis of overloads and their impact on pavement service life, structure, and maintenance costs. It offered insights into the evolution of these parameters but did not provide detailed information on the actual investment or maintenance costs required due to overloads, nor the change for other types of roads. These aspects could be explored in future research.

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Conflicts of Interest

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

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