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Cost-effectiveness of enforcing axle-load regulations: The Douala-N'Djamena corridor in Sub-Saharan Africa☆,☆☆

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ABSTRACT

Road conditions in Sub-Saharan Africa are typically poor, and only a subset of the newly constructed or rehabilitated roads reach their design life. Truck overloading generally causes this rapid deterioration. In Africa, there are few success stories on the imposition of axle-load limits. This study examines the existing regulations on the Douala-N'Djamena international road, which is the main transport corridor in Central Africa and the backbone for internal transport in Cameroon. It benefits from the detailed existing weighing data recorded since 1998 in the corridor's 10 weighing stations. This vast amount of traffic data, together with available information on road structure and deterioration over time, has been used to conduct an accurate calculation of load equivalency factors. The HDM 4 model has been applied to three scenarios between 2000 and 2015: (1) no axle-load control, (2) the real situation and (3) no overloading tolerance. Results show that axle-load regulations have been reasonably well applied in Cameroon and have contributed to maintaining the corridor in fair condition. In spite of the fact that significant traffic increases are presently counterbalancing the damage avoided by axle-load limits, benefits provided by axle-load control have been substantial: in the period of 2000–2015, every € invested or spent on axle-load control has generated more than €20 of savings in road user costs and in road maintenance and rehabilitation expenditure, which represents, in absolute terms, more than €500 million.

1. Introduction: the persistent problem of truck overloading in Sub-Saharan Africa

In the 1980s, international financial institutions started to raise the alarm regarding the rapid road deterioration in many developing countries, especially in Sub-Saharan Africa. In 1988, the World Bank published a detailed policy study on the causes and scope of this problem and on the possible options to overcome it (Harral and Faiz, 1988). The significant expansion of the road

☆ The results of this paper are presented in euros (€) for accuracy reasons. For the total period covered by the study, the Central African currency, the CFA franc, has had a fixed exchange rate to the € (1 € = 655.957 CFA francs), and most of the road investments analysed were funded in €. In addition, many of the costs considered were in € because the European Union has remained the main supplier of Cameroon. The average annual €/US$ exchange rates used in this paper can be found in Appendix C.

☆☆ The findings, interpretations and conclusions expressed in this paper are entirely those of the authors. They do not engage or represent the views of the European Commission.

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network during the previous two decades had not been accompanied with consistent budgets for road maintenance, and traffic had been much heavier than projected. However, sufficient evidence had already been provided to assume that overloading was the main cause of road deterioration and that neglecting road maintenance had contributed to the poor condition of the network (Lea and Ass., 1969). Moreover, it was already known that overloaded heavy vehicles threatened road safety (especially if trucks are in poor condition) and led to increased vehicle operating costs (higher fuel consumption and premature breakdown) (Keita, 1989). Above all, the 1988 World Bank study concluded, the main reason for road deterioration was institutional failure.

The implementation of axle-load control was an integral part of the reforms promoted by donors in the 1990s. By then, they already warned that axle-weight regulations were "the most important, but the most difficult to enforce" (Heggie, 1995). As a matter of fact, road maintenance policies in Sub-Saharan Africa had been quite timid with regard to pavement protection, and international development agencies did not succeed in making African countries respect the axle-load limitations already approved by most of them (Torres, 2001). Almost 20 years later, African regional economic communities still admitted that vehicle overloading was "one of the greatest threats to the sustainability of road infrastructure improvements in Sub-Saharan Africa" (SSATP, 2007). In an independent evaluation of its assistance to the transport sector, the World Bank highlighted that the lack of capacity to enforce vehicle overloading axle-load regulations was widespread in Africa (World Bank, 2007).

Since 2000, various programmes supported by the Official Development Aid (ODA) have focussed on reducing overloading and promoting axle-weight control activities with the primary objective of protecting existing road infrastructure. The evaluation of these programmes financed in Africa by the European Commission highlighted that control of overloaded vehicles has improved but continues to be inadequate due to a lack of political commitment (European Commission, 2016a). Regulations are not enforced, and weighing stations do not operate properly. Overloading continues to be a dominant and seriously damaging setback for the sustainability of the road network in many countries. According to a special report from the European Court of Auditors, most of the African countries audited failed to demonstrate sufficient commitment in implementing effective measures to reduce the incidence of vehicle overloading (European Court of Auditors, 2012). The Court noted that regional and national legislation on axle loads is not enforced effectively and that too little attention is given to the fundamental causes of vehicle overloading. The "offloading" policy of taking excess load out of a vehicle is not applied, and fines imposed are too low to have a deterrent effect. In addition, the licences of hauliers that have repeatedly infringed overloading regulations are rarely withdrawn.

The reasons behind the inadequate implementation of effective axle-load control can be characterized into two categories. The first group relates to the lack of will of many African states to tackle the overloading problem, which is closely linked to the inefficiency and corruption of the public administration responsible for road freight traffic control. Security forces and weighing agents are often bribed to overlook non-compliant loads, which occurs in the context of very low salaries in the public sector (Pinard, 2010). The second group regards the transport freight operators. Where high transport prices prevail due to overregulated transport services markets, overloading is a strategy to maximize loads and revenues from limited trips and low vehicle utilization while keeping capital costs low (purchasing second-hand trucks) and minimizing vehicle maintenance costs. Because the marginal cost of overloading is low, this practice makes sense. In addition, most stakeholders have a vested interest in operating with overloads, such as drivers, who are paid cash for extra tons loaded but not declared; intermediaries, who receive a commission based on the real truck load; and shippers, who pay lower tariff duties. Transport freight companies are poorly organized and managed and are not in a position to break the vicious cycle of transport prices and costs in which overloading is a valuable mitigation strategy (Teravaninthorn and Raballand, 2009).

Globally, few academic studies on the economic benefits of enforcing axle-load regulations exist (Moreno-Quintero et al., 2013). In Sub-Saharan Africa, research in this domain is hindered by the lack of reliable data on overloading practices (Pinard, 2010; UEMOA, 2015). The Douala-N'Djamena corridor constitutes an exception as a result of the close monitoring of overloading practices that has been carried out in parallel to new investments in load control systems. Unlike the corridors in West Africa, most of the Douala-N'Djamena corridor runs in a single country, and there are virtually no alternative routes. Thus, Cameroonian authorities have had easier conditions to enforce and keep track of load regulations (Arvis, 2011).

The lack of progress by African countries in the fight against overloading is one of the reasons why ODA's donors are reducing road investments in the form of grants. In this manner, the 11th European Development Fund, the main aid instrument providing grants to the transport sector in African, Caribbean and Pacific countries, has seen the allocation to roads drastically reduced (Herrero et al., 2015). In a global context of economic uncertainties and financial constraints, it is of paramount importance to increase the effectiveness of ODA for the transport sector (Runji, 2015). In the next few years, aid will favour African partner countries that implement appropriate sector policies to achieve sustainable road transport with relevant and credible measures for addressing vehicle overloading (European Court of Auditors, 2012; African Development Bank, 2014). At the same time, there will be a strengthening of conditions attached to projects and programmes in relation to road maintenance and protection.

The purpose of this paper is to provide a methodology to assess the economic benefits of enforcing axle-load regulations by applying it to the specific case of the Douala-N'Djamena corridor in Cameroon. After this scene-setting introduction, the paper is structured as follows: Section 2 briefly describes the weighing control system in Cameroon. Section 3 starts reviewing the origins and fundamentals of the Highway Development and Management (HDM) model and the load equivalency concept on which this study is based. It is followed by a summary of the hypothesis and data used, the research methodology proposed and a calibration of the model. Section 4 shows the results of the application of this methodology to the Douala-N'Djamena Corridor. Section 5 presents the conclusions of this paper.

2. Axle-load control in Cameroon: A gradual but determined implementation

2.1. The enforcement of the load control system in Cameroon: origins, vicissitudes and specific regulations

As in the rest of Sub-Saharan Africa, truck overloading in Cameroon is not a recent problem. Already in 1959, at the end of the colonial period, the Road Code introduced regulations on vehicle weight and dimensions that allowed single-axle load and gross vehicle weight up to a maximum of 13 and 35 tons, respectively. However, authorities had difficulties enforcing these regulations and, in the early 1970s, requested support from international donors to finance weighing stations and technical assistance (World Bank, 2007). In 1978, the maximum single-axle load of newly imported trucks was reduced to 10 tons. For more than a decade, actions to strictly enforce these regulations remained very inefficient. The Government barely managed to construct new weighing stations and thus extend their coverage.

In 1996, the National Assembly of Cameroon approved the first legislation on road protection and road maintenance.[1] This new law introduced two fundamental principles: the creation of a Road Fund (intended to raise additional resources for road maintenance) and the enforcement of truck weight limitations (per-axle load and gross vehicle weight).

Truck weight regulations enacted in Cameroon are more permissive than those implemented in other African and European countries. In many of them, the limit for a single-axle load is 10 tons and that for gross vehicle weight is 40 tons, whereas in Cameroon they are 13 tons[2] and 50 tons, respectively. A tolerance of one ton is allowed. These apparently generous restrictions raised scepticism from many observers, and they did not prevent the existence of strong opposition from many industries relying on road transport (timber, fuel, etc.).

The current significant coverage of axle-load control in Cameroon should be understood as a result of the convergence of the political will and interests of social actors and the private sector. A common view is that the conditions of the official development aid catalysed axle-load control. According to Gauthier (in press), the long-term donor support of road protection policies has been crucial to legislation enforcement. The European Union has provided continuous institutional support since the early 1990s, accompanied by grants for road construction on the condition of progress regarding weight control. As a matter of fact, in 2012, the European Court of Auditors welcomed the appropriateness of these aid policies (ECA, 2012).

Once the 1996 law entered into enforcement, Cameroon started load control by means of weighbridges, a measure that failed because of its technical limitations and inability to calculate axle load. After this unsuccessful trial, the Government requested support from donors to introduce mobile dynamic axle weighing systems, better adapted to comply with the law. In 1998, the Ministry of Transports and Public Works conducted a baseline study to improve knowledge of traffic's impact on the Yaoundé-Douala road's deterioration (*see* Section 4). The results were enlightening: 850 out of 1000 weighed trucks at the Nomayos station were overloaded, of which 325 were very strongly overloaded (an excess load between 20 and 40%) and 340 were extremely overloaded (an excess load greater than 40%).

After this study, Cameroonian authorities started to apply repressive measures at Nomayos' mobile weighing station, which produced positive and remarkable results only seven months later. Conflict also flared up with some transporters who opposed these measures in several ways (for instance, by refusing to pay the fines or stop at the station). However, the government progressively succeeded in enforcing the regulations and building new weighing stations all along the corridor. Transporters learnt how trucks have to be loaded to avoid excess weight on the axles, and many of them adapted and/or renewed their fleets. Because the vast majority of transporters respected the rules, they understood the advantages of road protection for themselves in terms of operating costs and lifespans of their vehicles.

Following the positive experience of the Nomayos station, more weighing stations were constructed on the Douala-N'Djamena corridor. The available data showed that, during the initial years of enforcement of the law, the proportion of overloaded trucks decreased significantly. Government's credibility in implementing road protection policies contributed to new donor-funded road projects on the same corridor.[3] However, a certain number of drawbacks remained and still today hamper the attainment of Cameroonian roads' service life. The most critical one is that fuel tankers are not controlled (Ministère des Travaux Publics du Cameroun, 2006a). The power of fuel suppliers to evade weight control lies in the needs of the neighbouring countries. Attempts to enforce load regulations on tankers have caused fuel shortages in Chad and the Central African Republic, and controls have had to be lifted.

2.2. Strengths and weaknesses of the Cameroonian weight control system

The network of operational weighing stations in Cameroon has increased from 2 stations in 1998 to 17 in 2015. Out of the current 17 stations, 10 are located on the Douala-Yaoundé-Central African Republic-N'Djamena international corridor. The number of registered weightings drastically fluctuates depending on the road, ranging from less than 10,000 trucks a year in some peripheral stations to more than 250,000 on the Yaoundé-Douala road. In parallel, the government deploys annual campaigns of axle weight control with mobile scales.

Until 2015, all weighing stations were equipped with single fixed dynamic axle scales placed on one side of the road (trucks

[1] Loi n°96/07 du 08 avril 1996 portant protection du Patrimoine Routier National.

[2] 13 tons for a single axle, 21 tons for a tandem axle and 27 tonnes for a triple axle.

[3] In particular, the African Development Bank and the World Bank joined the EU in providing support to the road sector in Cameroon.

coming in the other direction had to turn back to be weighed and then turn around again to return to their initial heading). The average construction and equipment cost of a weighing station varies from €150,000 to €750,000 depending on the dimensions of the surrounding infrastructure (access roads, parking areas, drainages, etc.). Grants of the European Development Fund (EDF) have financed the construction of 11 stations, and the others have practically all been constructed with national resources.

Since 2001, operations and maintenance of the equipment, facilities and premises of the weighing stations have been entrusted to the private sector. The enterprises are recruited under three-year contracts awarded through national competitive bidding. As soon as they were privatized, stations offered high performances and were operational more than 90% of the days per year (Ministère des Travaux Publics du Cameroun, 2008). Currently, according to the annual weighing reports published by the Ministry of Public Works, the average availability rate of equipment is systematically over 95% and sometimes reaches 98% (Ministère des Travaux Publics du Cameroun, 2010 to 2015). Operations are supervised by the Ministry of Public Works, which deploys interdepartmental teams at each station (Roads, Finances, Transport, Gendarmerie). In total, the annual average operation and maintenance costs of one station, including the private firm contract in charge of maintenance and the salaries and bonuses of public staff, are approximately €160,000. Appendix A summarizes the capital and recurrent costs for all the weighing stations on the Douala-N'Djamena corridor between 2000 and 2015.

Any vehicle that exceeds the tolerance limits is fined 25,000 CFA francs/ton (38 €/ton) when the overload is less than five tonnes. Fines increase to 75,000 CFA francs/ton (115 €/ton) when the registered overload exceeds 10 tonnes. Overloaded vehicles remain immobilized at the weighing station until full payment of the corresponding fine and unloading of the excess weight are complete. This is accompanied by a warning letter. Additional expenses due to offloading are borne by the carrier. The issuance of two warning letters leads to the withdrawal of the Public Transport Card.[4] The CEMAC Community Code requires recidivist carriers to be exposed to the withdrawal of their transport license by the transport competency authority.

In 2014, according to the official annual report from the Ministry of Public Works, 1,848,332 trucks other than tankers were controlled in the 17 operational weighing stations. 109,479 were found overloaded, i.e., a national average rate of 5.92%. Lightly overloaded trucks, of less than five tonnes, represent the largest share of the amended vehicles, 98.57% or 107,913 vehicles. Gross vehicle weight overloading was 13.88% of the total amended vehicles, while axle-load overloading reached 86.12%. The biggest problem remains the fuel tankers: the percentage of overloaded tankers was 75%.

3. Research methodology

3.1. The HDM model and the load equivalency concept

The HDM model simulates the behaviour of roads throughout their lifecycle by considering the effect of traffic, their pavement structure, maintenance operations and the impact of the environment over time. At the same time, the model has the ability to estimate savings in road user costs and predict potential benefits of appropriate road management (lower travel times, reduction of accidents, less environmental effects, etc.). Firstly developed at the initiative of the World Bank, it has significantly evolved since its first version in 1968, thanks notably to empirical evidence collected in developing countries (Kerali et al., 2006). Its last release, HDM-4, is principally conceived as an economic decision-making tool for programming and planning road investments. The model is used by a number of road agencies in developing countries to evaluate and prioritize individual projects, multiannual work programmes and/or long-term network interventions. Furthermore, among other applications, HDM-4 developers claim it has utility in conducting research and, in particular, studying the economic benefits of axle-load control policies (Morosiuk et al., 2006).

HDM-4 performs analysis based on multiple data provided by the user. Required inputs include pavement structure, road geometry specifications, traffic levels and characteristics (types and loads), vehicle fleet unit costs, road conditions, maintenance operations, climate conditions, etc. In most African countries, only a small subset of the relevant data required as input for the HDM-4 model is available. Using average regional data is a current practice for analysts, but such data may significantly differ from the actual national values, and this heavily affects the output quality of HDM-4. Consequently, it is of paramount importance to collect high-quality data specific to the country of the analysis and to apply these data to carefully calibrate HDM-4. Moreover, certain authors have highlighted limitations of the HDM-4 model when studying the African context (Teravaninthorn and Raballand, 2009). On the one hand, actual vehicle fixed costs are reported to be higher than those estimated by HDM-4 due to underestimation of overheads, administrative costs, bribes, etc. However, a substantial part of these costs is financial and not economic, and this paper focuses exclusively on economic benefits of enforcing axle-load regulations. On the other hand, maintenance, fuel and lubricant costs are reported to be higher because HDM-4 uses data for new trucks as an input. In most African countries, transport companies usually purchase second-hand trucks at prices substantially below those of brand new ones. These prices can be estimated by means of local surveys. Regarding variable costs, HDM-4 allows calibration of detailed vehicle parameters to simulate real vehicle maintenance costs and the higher consumption of fuel and lubricants.

For the completion of this study, it is essential to run the model using an efficient estimation of traffic load conditions. To this end, the Equivalent Single Axle-Load (ESAL) concept generated in the 1950s in the United States in the context of the so-called AASHO Road Test has been adopted. Indeed, despite early criticisms, particularly with regard to the geographical specificity of the initial empirical tests (Rolt, 1981), ESAL is, more than fifty years later, the most-used pavement design method linking axle-load and road

[4] The Public Transport Card or "Blue Card" is a vehicle document obligatory in the CEMAC area. It is only required for public transport vehicles. It specifies the transport category of the license obtained by the vehicle operator and the transport lines that the vehicle is authorized to take.

deterioration worldwide (Hudson et al., 2007).

It is worth mentioning that, to calculate the load equivalency factors (LEFs), a simplified fourth-power ESAL formula is frequently used. This is the case of the annual weighing reports published by the Cameroonian Ministry of Public Works:

$$LEF = \left(\frac{P_i}{P_{ref}}\right)^{\alpha}$$

where

P_i = axle load recorded
P_{ref} = standard 80-kN single-axle load
α = power factor (generally equal to 4 for flexible pavement)

However, when implementing a comprehensive simulation model as HDM-4, to assess the impact of axle-load limits, LEFs can be estimated by applying the method established in *Appendix MM* of the *AASHTO Guide for Design of Pavement Structures* (AASHTO, 1986). The complete ESAL equation for flexible pavement is:

$$\frac{W_x}{W_{18}} = \left(\frac{L_{18} + L_{2s}}{L_x + L_{2x}}\right)^{4.79}\left(\frac{10^{G/\beta x}}{10^{G/\beta 18}}\right)(L_{2x})^{4.33}$$

where

W_x = axle application inverse of equivalency factors (where W_{18} = the number of 18,000-lb (80-kN) single-axle loads)
L_x = axle load being evaluated (kips)
L_{18} = 18 (standard axle load in kips)
L_{2x} (code for axle configurations)
= 1 (single axle)
= 2 (tandem axle)
= 3 (triple axle)
L_{2s} (code for standard axle) = 1 (single axle)

$G = Log_{10}\left(\frac{4.2 - p_t}{4.2 - 1.5}\right)$ a function of the ratio of loss in serviceability at time t to the potential loss taken at a point where $p_t = 1.5$

p_t = "terminal" serviceability index (point at which the pavement is considered to be at the end of its useful life)

$\beta = 0.4 + \left(\frac{0.081(L_x + L_{2x})^{3.23}}{(SN+1)^{5.19}L_{2x}^{3.23}}\right)$ function that determines the relationship between serviceability and axle load applications

SN = structural number

As can be observed, the ESAL equation derived from the AASHO Road Test allows for a much more accurate calculation of LEFs as it takes into account the road structure, its deterioration and the axle type (single, tandem or tridem). Moreover, this is a more coherent approach since the structural number and road conditions are also key variables of HDM-4.

3.2. Hypothesis and data used to evaluate the impact of the axle-load control system along the Douala-N'Djamena corridor since 1998

The road from Douala to N'Djamena, passing through the east of Cameroon and also serving Bangui, is the main international corridor in Central Africa and the backbone of road transport in Cameroon. The HDM-4 model is applied to alternative scenarios to establish whether savings in road user costs and road maintenance and rehabilitation expenditure, thanks to axle-load control on the corridor, compensate the investments and operating costs of running the weighing stations, and whether further savings could have been obtained if load tolerances would not have been authorised. In April and November 1998, two baseline studies were conducted to estimate the real overloading impact on the Douala-Yaoundé section before and after applying repressive measures at Nomayos' mobile weighing station (Gauthier, 1998a,b). Complete data on axle loading per vehicle type from 2003 to 2015 are available via computerized records at Nomayos' fixed station, located in the Edéa-Yaoundé road section, and at nine other fixed weighing stations along the Douala-N'Djamena international corridor (see Fig. 1 and Appendix A). From these records, eight main vehicle types have been identified, which represent more than 99% of the surveyed traffic. Tandem and triple axles have been distinguished for all weighing records. The identified vehicles are rigid (P11: 2 single axles, P12: single-tandem, P13: single-triple) and articulated (S111, S112, S113, S122, S123).

The number of 80-kN Equivalent Single Axle Loads (ESALs) imposed on the road structure by each vehicle class has been calculated directly from weighing station records. An input to this calculation is the structural number (SN), which has been estimated following the method outlined in HDM 4 Model Version 1.3 (ISOHDM, 2001). Road structure data have been obtained from work contracts and supervision and evaluation reports on EDF-funded projects (Dorsch, 2004; Commission Européenne, 2012). The

Fig. 1. The nine consolidated sections in the Douala – N'Djamena corrider used in the study.

Table 1
Average road structure of the Douala-Yaoundé section.

	Pavement	Base course	Sub-base course	Subgrade course
Type	Asphalt concrete	Bituminous	Granular: CBR ≥ 30	Granular: CBR ≥ 15
Thickness	6 cm	15 cm	30 cm	≥ 35 cm

Table 2
Consolidated sections in the Douala-N'Djamena Corridor and related road structural numbers (2000–2015).

Section	Length (km)	SN (2000)	SN (2005)	SN (2010)	SN (2015)
1.Douala-Edéa	68.90	5.3	5.1	4.6	4.2
2.Edéa-Yaoundé	176.05	5.3	5.1	4.7	4.3
3.Yaoundé-Ayos	137.26	3.6	3.2	3.9	3.8
4.Ayos-Bonis	191.55	Unpaved	Unpaved	Unpaved	3.7
5.Bonis-Garoua Boulaï	253.46	3.6	3.6	3.5	3.0
6.Garoua Boulaï-Ngaoundéré	277.50	Unpaved	Unpaved	Unpaved	4.8
7.Ngaoundéré-Garoua	272.80	3.2	3.0	2.9	2.9
8.Garoua-Maroua	204.40	3.2	3.0	2.9	3.9
9.Maroua-Chad Border	262.70	3.3	3.1	3.1	3.1

average structure for the Yaoundé-Douala road is as follows (see Table 1):

The SN remained approximately equal to 5.3 from 1998 to 2003, taking into account periodic road maintenance works that took place after road construction in 1980–85 (asphalt concrete overlays of 2.5 cm). After 2003, the SN decreased due to road deterioration, reaching approximately 4.3 in 2015 (see Table 2). Terminal Serviceability is estimated at 2.0.

The Ministry of Public Works has defined 30 road sections on the Douala-Yaoundé-N'Djamena international corridor. Traffic counts have been performed in these sections from 2000 to 2014 per vehicle type (see Appendix B). For the purpose of this study, traffic counts in the two sections adjacent to Yaoundé (Yaoundé-Nomayos: 19.7 km, and Yaoundé-Nkolafamba: 23.8 km) have not been taken into account because of high local traffic. Vehicle operating costs in these two sections have been estimated by applying traffic count results of contiguous sections, where local circulation is not relevant compared to medium- and long-distance traffic. Traffic counts are not available or reliable in some sections for a certain number of years. In such cases, estimates have been obtained by linear interpolation or extrapolation.

ESAL estimations from the ten weighing stations have been applied to the nine consolidated sections shown in Table 2. These sections are the result of aggregating the 30 road sections defined by the Ministry of Public Works, taking into account the main criteria of homogeneity for traffic, road structures and road deterioration (Fig. 1).

Estimated road structural numbers (SN) are shown in Table 2. Upgrade and rehabilitation works that took place from 2000 to 2015 have been taken into account, as well as road deterioration modelling results by applying the HDM-4 road deterioration model (see Section 4.1).

It is assumed that effective overload control for a road section started when the weighing stations became fully operational. Therefore, axle-overload values prior to 1998 are applied to road sections before commissioning of the weighing stations in these sections. This is a pessimistic assumption due to the fact that a certain number of trucks circulating through these sections were previously controlled at the initial corridor's weighing stations, such as Nomayos, and they accordingly reduced axle overloading to all their routes to the north. However, there is no data to precisely estimate this effect.

Fig. 2 shows the research methodology. First, ESALs, LEFs and average weights are estimated per vehicle type, station and year selected for analysis. These intermediary results feed the HDM-4 road deterioration model (RDM) and road user costs model (RUC). These models are run for all the overloading control scenarios, road sections and time periods. The results obtained are vehicle operating costs, travel time costs and estimation of the periodic maintenance and rehabilitation backlog. Finally, cost-effectiveness ratios of axle-load control are estimated for the overloading control scenarios.

3.3. Calibration of the models for estimating the effects of axle overload

HDM 4 software for estimating road deterioration and road user costs has been calibrated and applied. Appendix C displays the main economic data for running the HDM 4 RUC model, which are vehicle fleet economic unit costs in Cameroon from 2000 to 2015. Appendix D shows the basic utilization parameters of vehicles and road section geometry, which have not substantially varied since 2000.

Average vehicle fleet economic costs and basic utilization parameters have been obtained from a World Bank Road User Costs Study (2006) for African countries when they are not available at the national level or when average figures are difficult to estimate (passenger time, cargo delay, labour and overhead costs, kilometres and hours driven per year and vehicle, etc.). Shadow prices for fuel and gasoline have been estimated, taking into account the annual product price structure. Ex-refinery prices, total storage, transport, stabilization and distribution costs are included. All taxes, custom duties and fees have been excluded on the basis of data from IMF country reports (International Monetary Fund, 2014 and 2016). Regarding fleets, 10 vehicle types have been analysed: medium cars, pick-ups, small buses, medium buses, and trucks (P11, P12, S112, S113, S122, and S123). P13 and S111 trucks have been embedded into the P12 and S112 categories, respectively.

In the Douala-N'Djamena corridor, the rate of empty-truck return trips has recently been estimated at 85% by a World Bank project appraisal document (2014). This average has been applied to estimate the LEFs for each vehicle type and section. Axle load distribution for empty vehicles has been estimated using average observed weights and dimensions per vehicle type. Average operating weights have been obtained from weighing station records by applying the rate of empty-truck return trips. Average loads of heavy buses have been taken into account for ESAL estimation, even though their axle-load is not controlled in Cameroon. An average

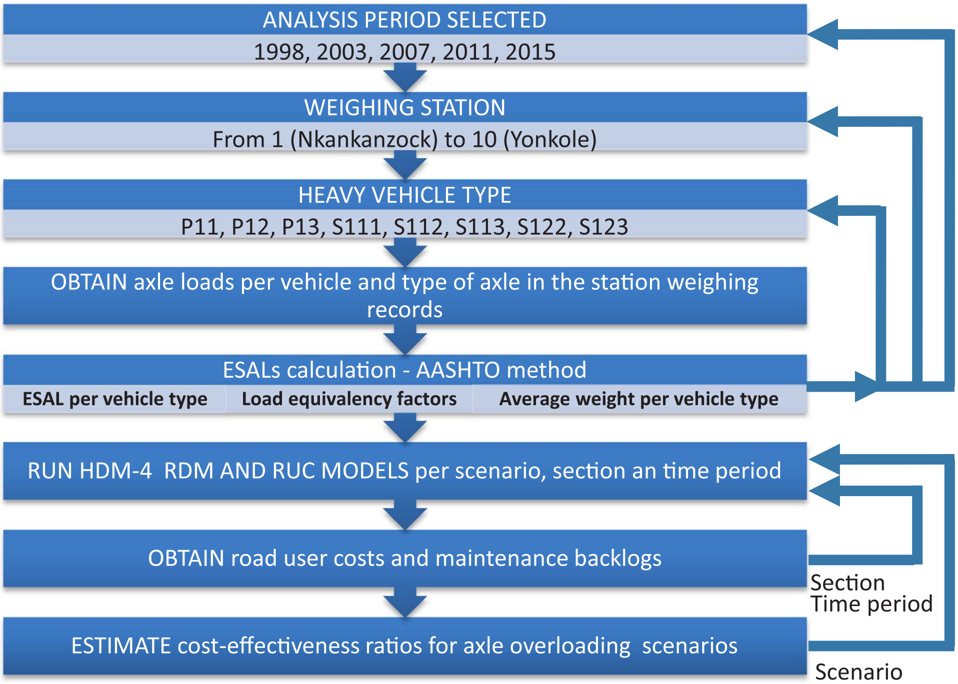

Fig. 2. Research methodology.

gross bus weight of 11.9 tonnes has been applied (4.4 tonnes for the front axle, 7.5 tonnes for the rear single axle) (World Bank, 2006).

The HDM 4 model has been applied to three alternative situations:

0. "Do nothing" scenario: the situation prevailing before April 1998 is maintained (no axle-load control). Consequently, LEFs remain the same as they were in April 1998 at the Nomayos station. It is assumed that LEFs calculated at the Nomayos station can be applied to all sections in the Douala-N'Djamena corridor. In addition, vehicle-operating weights for this scenario have been estimated from April 1998 weighing records at the Nomayos station.
1. Real situation: what has actually happened from 2000 to 2015.
2. Optimal scenario: zero overloading tolerance since 2000. This means that the 1996 legislation on road protection and road maintenance would have been strictly applied. Available data on axle loads from records at the ten weighing stations along the Douala-N'Djamena corridor have been modified to simulate strict application of axle-load legal constraints.

These three scenarios have the same maintenance standards. Differences lie in the enforcement of axle load regulations. It is assumed that traffic recorded at traffic counts from 2000 ("normal traffic") would not have substantially decreased for scenario 0 or increased for scenario 2. This assumption is highly reliable because vehicle operation costs are not very different from the three scenarios, and these differences cannot have triggered any substantial newly generated traffic. The same reason may be invoked to assume that traffic diversion for the three alternatives can be neglected, also taking into account that there is hardly any alternative road for traffic diversion along the corridor. Possible traffic diversion from other transport modes (railway from Ngaoundéré to Yaoundé and Douala) cannot be analysed in this paper. It may be assumed that slight differences for truck operation costs would not have diverted traffic from/to the railway in a substantially different manner for the three scenarios.

Maintenance and improvement standards have been applied to the three scenarios. Scenario 1 corresponds to real interventions in the corridor from 2000 to 2014. These interventions have been obtained from a World Bank appraisal document for a multimodal transport project (2014), and different European Commission (EC) project documents and evaluation reports (Commission européenne, 2005; Commission Européenne, 2012; Commission européenne, 2016b). Scenario 2 interventions would not have been different from scenario 1 ones because road deterioration would have been slightly less significant and maintenance planning would not have changed. On the contrary, scenario 0 would have required more expensive interventions to maintain the corridor at the target level of scenario 1. However, because of funding constraints, it is likely that the road condition would have worsened and that maintenance funds would not have substantially increased. Therefore, maintenance and rehabilitation backlogs increase for scenario 0 to an amount that can be estimated by the HDM 4 RDM model.

Routine and periodic maintenance, rehabilitation and upgrade costs on the corridor have been obtained from the National Road Master Plan (Ministère des Travaux Publics du Cameroun, 2006b) and several road maintenance works contracts implemented between 2004 and 2015. The routine maintenance works considered in the analysis for paved road sections is patching. Patching interventions in the corridor since 2000 were scheduled so that the maximum quantity applied to the sections needing potholing repairs was 100 m^2/km/year. Since 2000, Cameroonian road authorities have not ordered other types of routine maintenance works (crack sealing, edge repairs, etc.). The rest of the routine maintenance works (drainage works, vegetation control, road sign repairs, line marking, guard rail repair, etc.) are not included in the analysis because their estimated costs are the same for the three alternatives. Periodic maintenance works on the corridor for paved road sections were double surface dressings on a responsive basis (thickness of 2.5 cm), depending on the roughness.

Between 2000 and 2015, two sections on the corridor had been gravel roads and were paved recently: Ayos-Bonis (191.5 km, paved in 2011) and Garoua Boulaï-Ngaoundéré (277.5 km, paved in 2013). For these sections, routine maintenance works ordered by Cameroonian road authorities were periodic grading, spot regravelling and gravel resurfacing. Periodic grading took place once a year on a scheduled basis. Spot lateritic regravelling and lateritic gravel resurfacing (gravel layer thickness increased by 10 cm) were carried out on a responsive basis.

Economic unit costs have been estimated in the National Road Master Plan (2006) to 8.8 €/m^2 for patching, 6 €/m^2 for double surface dressings and 19 €/m^3 for regravelling. These costs include work control (5% for paved roads, 4% for unpaved) and exclude taxes (19.25%). Appendix E summarizes periodic maintenance, rehabilitation and upgrade works in the corridor since 2000.

Road surface condition (roughness, cracking, rut depth, ravelled area, etc.) has been assessed from inspection results taken from the 2006 National Road Master Plan and studies for new investment projects in Cameroon. Condition parameters have been determined from ratings and classification included in the manual "Road Monitoring for Maintenance Management" for developing countries (World Bank-OECD, 1990).

The time periods selected for running the HDM 4 analysis are 2000–2004, 2005–2009 and 2010–2015, aiming to accurately model road deterioration, maintenance works and vehicle attributes (especially LEFs). The initial road surface condition for 2000 is necessary to run the HDM 4 analysis for 2000–2004. It has been estimated from the 2006 National Road Master Plan and existing feasibility studies. The road surface condition obtained from running the HDM 4 RDM model has been compared to inspection results and registers of rehabilitation and maintenance projects. HDM 4 has been calibrated by adjusting maintenance and improvement standards to duly represent real road surface conditions on the corridor. Initial road surface conditions for 2005 and 2010 have been obtained from running the model for previous time periods (see Fig. 2).

4. Results

4.1. Equivalent single axle loads and load equivalency factors

ESALs are intermediary results of the methodology, which feed the HDM-4 models. ESALs have been calculated and converted into 13-ton axle loads in Table 3, which also displays LEFs per vehicle type from 1998 to 2015 at the Nomayos station. Fig. 3 shows equivalent 13-ton axle loads evolution from 1998 to 2015.

These results reveal a significant decrease of equivalent 13-ton axle loads per vehicle (from 2.87 to 1.43) associated with the short-term repressive measures applied in 1998. Furthermore, a continuous decrease was observed from 1998 to 2007 as a result of long-term axle-load control (from 1.43 to 0.69).

From 2007 to 2015, the damage to the road structure caused by the increase of overloaded trucks within the tolerance of one additional ton (13–14 tons) has increased by approximately 23%. This has added to a sharp 16.8% average annual traffic growth rate. Both factors have multiplied by 4.3 the number of annual equivalent 13-ton axle loads. This increase corresponds to a new vehicle type distribution, with a significant traffic increase of the heaviest vehicles (articulated S113, S122, S123).

The ESAL calculation procedure has subsequently been applied to the nine other fixed weighing stations along the Douala-Yaoundé-N'Djamena international corridor. The road structural numbers (SNs) shown in Table 2 have been recalculated by applying the HDM-4 road deterioration model. Final SNs calculated by HDM-4 RDM are not very different from those that have been initially estimated for ESAL calculation. To verify the stability of the results, the sensitivity of the LEFs to SN variation has been checked. An

Table 3
Annual estimated equivalent 13-ton axle loads and load equivalency factors per vehicle type. Edéa-Yaoundé road section.

Vehicle type	Apr-98	Nov-98	2003	2007	2011	2015
P11	9604	12,810	8055	6126	31,485	29,258
P12	7455	3051	4023	3670	14,600	14,338
P13	0	0	468	986	108	326
S111	0	0	0	0	162	421
S112	6021	7872	2671	1698	5552	9273
S113	1894	931	5856	8456	26,138	75,323
S122	1,35,857	66,725	31,243	26,464	63,042	60,083
S123	643	694	1966	3336	18,452	28,525
Total annual estimated	161,474	92,083	54,282	50,734	159,537	217,548
Vehicles/year	56,210	64,446	61,253	73,299	167,804	255,329
Axles/year	244,394	270,256	285,062	338,747	755,647	1,183,721
LEF per axle (13 ton)	0.661	0.341	0.190	0.150	0.211	0.184
LEF per vehicle (13 ton)	2.87	1.43	0.89	0.69	0.95	0.85

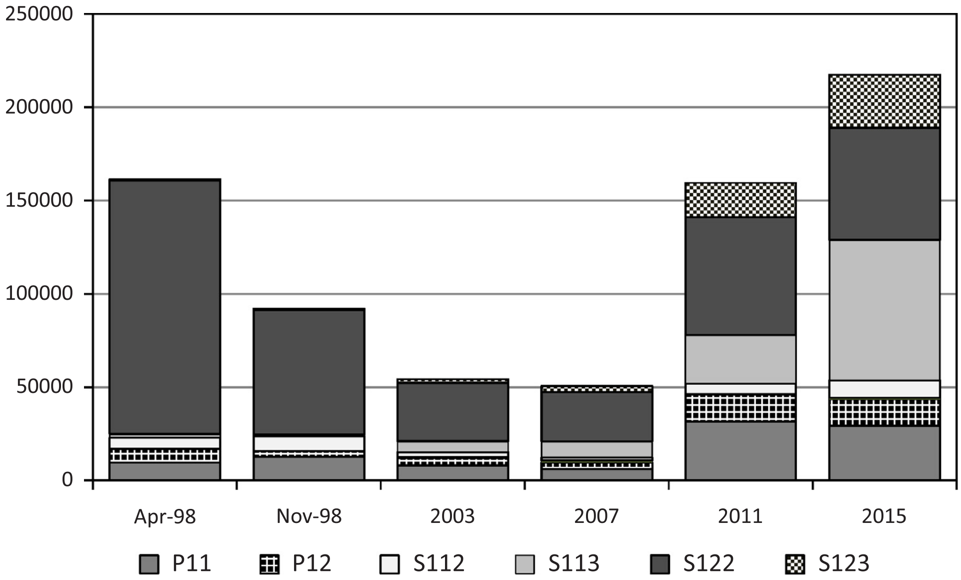

Fig. 3. Evolution of annual estimated equivalent 13-ton axle loads per vehicle type Edéa-Yaoundé road section.

SN decrease of 20% in the Edéa-Yaoundé road section (from 5.3 in 2003 to 4.3 in 2015) involves an LEF decrease per vehicle (13 tonnes) of 0.9% (from 0.852 to 0.844). The sensitivity is therefore very low, and recalculation of ESALs and LEFs is not necessary.

4.2. Economic benefits from implementing axle-load control

Results from running the HDM 4 model for the three scenarios, by section and for three time periods, are shown in Appendices F and G. Appendix F shows total road user economic costs per section and alternatives. Appendix G displays figures showing the estimated International Roughness Index (IRI) per alternative and section. IRI has been selected amongst the seven deterioration parameters that are provided by HDM 4 RDM. The Ministry of Public Works assessed the IRI on the corridor in 2016. The average results per section fit with Appendix G. Differences are observed by sub-section, which is normal when taking into account the sub-section lengths. For example, in Bonis-Garoua Boulaï (253.46 km), HDM 4 RDM estimates that the IRI = 5.4 for scenario 1 at the end of 2016. The 2016 road inspection reveals that the IRI is approximately equal to 5 for 80% of the length, but for 20%, there are potholes that have not been patched, and the IRI is estimated to be between 7 and 8. Thus, the average IRI is close to the model results.

Benefits from implementing axle-load control are twofold: reduction of road user costs (vehicle operating costs and travel time costs) and reduction of periodic maintenance and rehabilitation backlogs. The first benefits have been calculated directly by the model and are extracted from the table in Appendix F. The total vehicle operation undiscounted benefits provided by axle-load control are estimated at €411.83 million for the analysis period of 2000–2015 (scenario 1). Fig. 4 shows the amount of the discounted benefits depending on the economic discount rate. Applying the equivalent inter-annual inflation rate in 2000–2015 (2.44%), the net present value of road user benefits reaches €470.42 million. For the economic discount rate traditionally used by the World Bank for transport projects in developing countries (12%), the net present value of these benefits reaches €852.29 million.

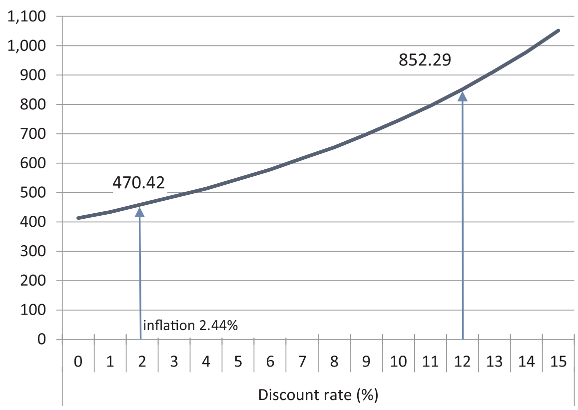

Fig. 4. Net present value of road user benefits provided by axle-load control, in millions EUR.

Table 4
Savings in periodic maintenance and rehabilitation costs in the corridor in 2000–2015 per consolidated section and scenario compared to scenario 0 (millions EUR).

Section	Scenario 1	Scenario 2
1.Douala-Edéa	16.674	16.915
2.Edéa-Yaoundé	31.865	32.394
3.Yaoundé-Ayos	7.204	7.547
4.Ayos-Bonis	4.310	4.501
5.Bonis-Garoua Boulaï	6.717	6.717
6.Garoua Boulaï-Ngaoundéré	2.081	2.220
7.Ngaoundéré-Garoua	21.278	22.915
8.Garoua-Maroua	1.022	1.022
9.Maroua-Chad Border	7.487	8.538

With regard to the reduction of maintenance backlogs, the estimation is based on the main road condition parameters obtained by the model, especially the IRI (Appendix G). Considering that a threshold for road rehabilitation of paved roads may be established in Cameroon as IRI = 12, that for new paved roads IRI = 2 and that average road service life is 20 years, it is possible to estimate the amount of this backlog maintenance in 2015 by applying average periodic maintenance and rehabilitation costs in the corridor in 2000–2015. Table 4 shows this estimation per section compared to scenario 0. The total savings in maintenance and rehabilitation backlogs provided by axle overloading control are estimated in 2015 at €98.64 million for scenario 1 and at €102.77 million for scenario 2.

The following Table 5 summarizes all the benefits that scenarios 1 and 2 provide compared to scenario 0.

4.3. Estimating cost-effectiveness ratios of axle-load control

Cost-effectiveness is a technique for comparing relative costs and effects associated with two or more courses of action. To estimate cost-effectiveness indicators for the three scenarios, investments and operating costs for axle-load control in the corridor since 2000 have been obtained. These costs have been converted into economic costs by subtracting taxes. The following Table 6 summarizes them as a function of the economic discount rate:

Cost-effectiveness is typically expressed as an incremental cost-effectiveness ratio (CER), in this case, change for output savings divided by input costs. Let NPV_{ruc} be the net present value for total road user costs, NPV_{bk} the net present value for total periodic maintenance and rehabilitation backlogs, and NPV_{alc} the net present value for investments and operational expenses in axle-load control.

The CER may be expressed separately for reduction of road user costs (CER_{ruc}) and reduction of periodic maintenance and rehabilitation backlogs (CER_{bk}) as follows:

$$CER_{ruc} = \frac{NPV_{ruc}(alt_0) - NPV_{ruc}(alt_1)}{NPV_{alc}(alt_1)} \quad CER_{bk} = \frac{NPV_{bk}(alt_0) - NPV_{bk}(alt_1)}{NPV_{alc}(alt_1)}$$

It is also possible to express both reductions in one aggregate CER indicator ($CER_t = CER_{ruc} + CER_{bk}$). The results for scenarios 1 and 2 depending on the economic discount rate are provided in the following Table 7:

These results reflect the EUR gained by the national and regional economy for every EUR invested or spent in axle-load control with related policy enforcement from 2000 to 2015.

Cost-effectiveness for scenario 2 is slightly higher than it is for scenario 1. This is because full strict enforcement of axle-load regulations would mainly involve overloads between 13 and 14 tonnes. These overloads have a reduced impact on road deterioration and, thus, vehicle operating costs. However, the savings of scenario 2 compared to those of scenario 1 (almost €10 million undiscounted for road user costs and maintenance backlog in the total 1844.6 km) are very significant if it is taken into account that they could have been reached at zero cost.

Estimation of cost-effectiveness for road user costs is much more accurate than cost-effectiveness for reducing periodic maintenance and rehabilitation backlogs. Even though this study has estimated maintenance backlogs by applying the HDM 4 road deterioration model, whose results have been verified by the 2016 road inspection, future maintenance and rehabilitation costs per

Table 5
Total discounted benefits (2015) of scenarios 1 and 2 compared to scenario 0.

Reduction of maintenance and rehabilitation backlog in 2015 (millions EUR)			Reduction of road user costs (millions EUR)		Total benefit (millions EUR)	
Scenario 1	Scenario 2	Discount rate	Scenario 1	Scenario 2	Scenario 1	Scenario 2
98.64	102.77	0%	411.83	417.37	510.47	520.14
		6%	578.88	586.02	677.52	688.79
		12%	852.29	861.89	950.93	964.66

Table 6
Total discounted investments and operating costs for axle-load control in the corridor since (2000–2015).

Discount rate	Investment and operating costs for axle-load control in millions € (2000–2015)
0%	21.249
Inter-annual inflation rate (2.44%)	24.917
6%	31.696
12%	48.597

Table 7
Cost-effectiveness ratios for reduction of road user costs, reduction of periodic maintenance and rehabilitation backlogs and aggregated reduction of costs (discounted in 2000–2015).

Cost-effectiveness ratio	Discount rate	Scenario 1	Scenario 2
CER_{ruc}	0%	19.38	19.64
	6%	18.26	18.49
	12%	17.54	17.73
CER_{bk}	0%	4.64	4.84
	6%	3.11	3.24
	12%	2.03	2.11
CER_{t}	0%	24.02	24.48
	6%	21.37	21.73
	12%	19.57	19.85

section can only be estimated roughly, and the IRI is not the only criterion to decide when these works should be carried out. However, even if this estimation is inevitably rough, it is important to incorporate CER_{bk} in the results and to aggregate it to CER_{ruc}. This is because maintenance backlogs cannot be neglected compared to savings in RUC (they are approximately 20%), and they are a fair indicator of the road national investments that have been saved by the enforcement of axle-load control.

As a rule of thumb, useful to convey these results to African transport sector stakeholders and decision makers, every € invested or spent in axle-load control duly enforced on a main highway corridor generates approximately €20–€25 of savings for the national and regional economy.

5. Conclusions

Vehicle overloading persists in Sub-Saharan Africa after many years of strategies and high-level political decision-making measures fighting against it. This lack of results has led many observers to consider axle overload as a very complex phenomenon from which African countries cannot escape due to many overlapping problems deeply rooted in African transport systems.

However, looking at this problem from a pragmatic view, this article shows that, even in a priori unfavourable countries in the fight against overloading, such as Cameroon, it is possible to ensure substantial savings for national and regional economies in vehicle operating costs and road maintenance and rehabilitation expenditure. In the Douala-N'Djamena international corridor, every € invested or spent in axle-load control duly enforced by the authorities in 2000–2015 has generated €19.4 savings in road user costs and €4.6 savings in road maintenance and rehabilitation expenditure.

Effective action against vehicle overloading cannot be limited to the installation and operation of weighing stations, not even with the full enforcement of axle-load regulations. It must be extended to all the sector stakeholders responsible for truck overloading, especially transport companies, shippers and logistic operators. A broad set of actions are also needed to tackle the problem at the regional level and at different subsector levels (transport liberalisation, port operation reforms and coordinated regional actions) because fighting overloading in some countries and corridors and not in the others may cause distortions in competition and traffic diversions.

In Cameroon, despite the remarkable benefits of axle-load control, the situation remains difficult. Enforcement of weigh limits is still perceived by many freight operators as harassment by the authorities. Tankers can continue to circulate overloaded, and in recent years, there has been a significant increase of heavy-vehicle traffic. Taking into consideration that load tolerances are still admitted, section 4 shows that these circumstances are progressively neutralizing the damage avoided by axle-load regulations. Moreover, the growth in road traffic has had an unattended negative effect: considerable traffic jams and rapid road deterioration around some of the more transited weighing stations. This has led to the closure in 2015 of the Dibamba station located on the Douala-Edéa highway section. Cameroonian authorities should redouble their efforts to sustain a high-quality control system by improving the existing stations (weighing in both directions, weigh-in-motion systems, etc.), building and operating the foreseen new ones, fully applying the law, and better communicating the benefits of axle-load control to freight companies, sector stakeholders and the public in general. Overall, international development institutions should strengthen their use of conditions attached to transport programmes and sector policy dialogue, defining measurable and time-bound formal requirements to address vehicle overloading. These requirements should be supported by in-depth studies and research, which will provide African decision-makers with adequate justification to substantially improve the enforcement of axle-load regulations. The methodology proposed in this paper aims at contributing to the generation of empirical evidence supporting this policy-making.

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Supplementary materials

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tra.2017.11.016.

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