THE MENACE OF UNCONTROLLED TRAILER/TRUCK LOADS AND THE USE OF WEIGH-IN-MOTION DEVICE ON CARRIAGEWAYS IN NIGERIA

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ABSTRACT
Unlike in the developed countries, road rehabilitation timing has recently become a subject of consideration and attracting much attention in developing countries like Nigeria. Increase in international roughness index (IRI) on Nigerian roads corroborated this fact. This study focuses on trailer/truck loads pattern, highway regulations and standard life span of highways, annual budgetary allocations to road construction and rehabilitations, and the adoption of weigh-in-motion (WIM) device on Nigerian carriageways. The study reveals that the increase in freight movement and growth in E80s/heavy vehicles (HV) traffic on inter-state roads has tripled within the last 5 years. It further revealed that the highway life span has reduced to 2 years in Nigeria, and thereby increased the national recurrent expenditure on road transport. Results from this study shows that the deplorable conditions of the national highways have resulted in the loss of about ₦175 billion to the Nigerian economy. Lastly, this setback of none implementation of weighbridges and WIM devices on Nigeria roads can be attributed to political vested interest, lack of will power and governance offered by the ruling class in the country rather than technicality.
Keywords: carriageway, highway, road capacity, trailer/truck, vehicle axle, weigh-in-motion.

1 INTRODUCTION

In the last decades, there has been a significant continued transformation of heavy-duty vehicle across the globe. This change has led to an increase in the growth in E80s/heavy vehicles (HV). Several research data have shown that there is a continued shift in composition from 2 and 4 axle's heavy vehicles to the larger 5–7 axle's heavy vehicle types [1]. This is attributed to the improvement in vehicle technology, economic growth and better utilization of heavy vehicles as well as changes in the legal permitted axle loads. Although, there seems not to be proportionate improvement in the carrying capacity of most highway carriageway designs.

The collapse of the railway system of the Nigerian transport sector about a decade ago has given rise to the number of road commuters and as well, the movement of goods and services within the country. However, it is gradually being revived and expanded after long years of neglect. The air transport is uneconomical for some freight, while the potentials of the inland waterways have not been fully exploited. The road transport subsector has continued to grow faster than other transport modes in terms of conveyor vehicle sizes and road network. Not less than 90% of Nigerian mobility needs are satisfied through the road transport mode without maximizing the potential contribution of other modes. The over dependence on the road system has contributed to the unceasingly intense pressure on the highways in Nigeria This has led to a major part of the annual recurrent budgetary allocation being expended on road construction and maintenance. This situation has been made worse by the overloading of heavy-duty trucks and vehicles on our roads [2].

Highway durability is the level of resistance to wear and tear under accumulative vehicle passage. The force exerted on the road by a given vehicle is related to the vehicle's weight (load) as transmitted through the vehicle's axles. As expected, different vehicle types and

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weights will do different amounts of damage. Engineering standard: ESAL = damage done by 18,000 lbs on a single axle (18,000 lbs = 18 kips, kilo-pounds) which may not necessarily mean that a vehicle tears up a certain volume of road surface. One significant means of evaluating the relative destructive effects of repetitive vehicular loading on highway pavements is the equivalent axle load concept [3]. Therefore, some way of standardizing these impacts is required in order to implement different vehicle weight control measures. This is the object of weigh-in motion system (WIM), which is often complemented with fixed weighbridge. This study explores the negative effect of uncontrolled truck loads and the use of WIM device on Nigerian carriageways.

2 REVIEW OF WIM USAGE ON ROADS

2.1 Weigh-In-Motion (WIM) device

A WIM system is comprised of a set of sensors and supporting instruments that are installed to measure the presence of a moving vehicle and the related dynamic tire forces at specified locations with respect to time. It estimates tire loads, speed, axle spacing, vehicle class according to axle configuration, and other parameters of a vehicle. It thereafter processes, displays, stores, and transmits this information to a server. In practice, WIM systems and static weigh stations are used to complement each other in order to enhance accuracy. WIM devices are designed to capture and record truck axle weights and gross vehicle weights as they drive over a sensor. Unlike older static weighbridges, current systems do not require the trucks to stop before measurement; making them much more efficient for the following applications:

i. Design and monitoring of pavement, as well as research,
ii. Design and monitoring of bridge,
iii. Enforcement of size and weight,
iv. Vehicular and transport legislation and regulation,
v. Transport planning and administration,
vi. Increased percentage of overweight trucks detected after deployment,
vii. Saved travel time after deployment,
viii. Reduced overweight truck accidents after deployment, and
ix. Reduced load damage and pavement cost after deployment.

A typical WIM system is used with other commercial vehicle operation (CVO) technologies, such as automatic vehicle identification (AVI), visual cameras, and image information of a truck can also be monitored through a camera mounted at the road side. Figure 1 illustrates the arrangement of the WIM system in operation on a highway.

The use of WIM is to help capture weight violating vehicles, decrease travel time for commercial carriers, reduce congestion, reduce traffic crash risk, exchange traffic information, and eventually help achieve the goal of preserving highway infrastructure at a network level. The rate of return on the investment compared to that of quantifying the specific monetary values of all impacts on regional and national economies, the users, the agencies, and also the environment encouraging business. Reduction of the resulting stresses to a single cost-benefit-analysis (CBA) ratio are reported.

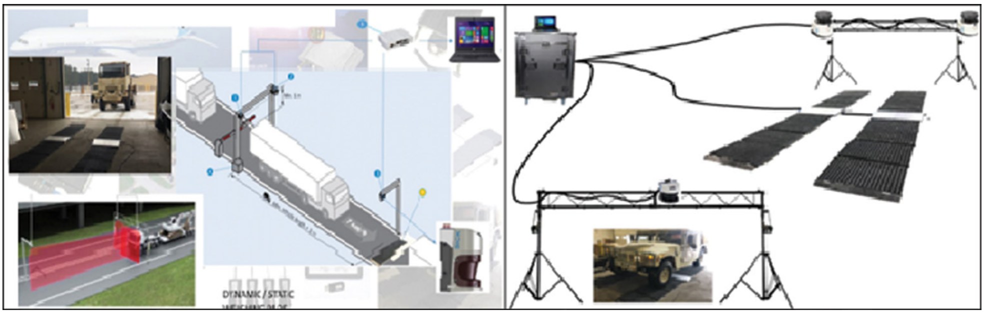


Figure 1: WIM system works on a highway main lane (General Electrodynamics Corporation, USA).

2.2 The roadway design and vehicle's axles

The AASHTO researchers noted that road wears are related to vehicle weight (load) and its distribution over the vehicle's axles. For instance, consider a truck of gross vehicle weight G (thousand pounds) operating on L_1 axles, with $L_2 = 1$ or 2 indicating whether or not the axles are in tandem ($L_2 = 2$) or not ($L_2 = 1$). The probe would be, how many times can such a truck pass over a durability road before deterioration set in? Depending on purpose, re-surfacing of such road may be necessary thereafter. The Engineering Standard Truck and Axle Load (ESAL) are given in Table 1 and eqn (1).

$$N(D) = A_0(D+1)^{A_1}\left(L_1 + L_2^{A_2} L_2^{A_3}\right) \tag{1}$$

where N (D) = number of passages from road commissioning to failure trigger point; D = pavement slab durability (inches of concrete/structural number); L_1 = vehicle weight per axle in thousands of pounds; A's: parameters to be estimated; L_2 = axle configuration factor; 1 for a single-axle vehicle, 2 for tandem vehicles.

Kwon and Suh [4] compared the actual weigh-in-motion (WIM) data to a proposed model for highway in Korea, with vehicular weight limited to 40 tons. The result revealed that 705 out of 61,090 (1.2%) vehicles were overloaded. The result further revealed stronger effect on tandem axles, 2-single axles and quadruples with a peak factor of 33. Road transport policy makers and planners in the nation should provide necessary incentives for trailers/truckers

Table 1: Engineering standard truck axle weight value.

Vehicle type	ESAL value
S-U2 truck	236
S-U3 truck	183
C-S3 truck	1,081
C-S4 truck	820
D-S5 truck	2,898
TT-5 truck trailer	665

AASHTO [5].

to share their freights over large number of vehicles and recommend the use tandem axles, which minimize forces on the carriageway. Unfortunately, the policy in practice encourages truckers to minimize axle number, thereby increasing tolls with the number of axles (all things being equal). This study, therefore, focuses on the relevance of WIM in relation to: the menace of uncontrolled trailer/truck loads, highway regulations, and standard load bearing capacity of highways, standard life span of highways, road rotting and folding, and the annual cost of road rehabilitations.

2.3 Trailer/Truck Load and Carriageway Capacity

Generally, in road transport planning, the carrying capacity of a road is the maximum potential capacity of a given roadway section to allow the presage of vehicular flow without internal interruption of traffic. Extreme vehicle loads have been researched using methods such as the distribution models and simulations. González *et al*. [6] analysed the critical load scenarios determined from a Monte Carlo simulation which can be expressed in terms of vehicles per hour or per day. While Gu *et al*. [7] presented a Bayesian distribution model of overloading.

Convenient and free online tools are available to help the freight carrier industry and others determine how to comply with legal gross and axle weight limits when travelling on MN and/or ND highways. The calculator shows what a vehicle or vehicle combination can legally weigh. The allowable weight on a vehicle/vehicle combination may increase by coupling additional axles or by increasing the axle distance as shown in Table 2. The formula for the calculation is weight-to-length ratio, which is limits, the weight-to-length of a vehicle crossing a bridge and is given by the expression:

$$W = 500\,(LN/N - 1 + 12N + 36) \tag{2}$$

Table 2: Trailer design and weight.

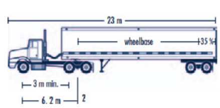
Trailer parts	Design	Description
Tandem axle		A set of two axles attached to the vehicle by a suspension system designed to distribute evenly, within 1,000 kg
Tractor		A motor vehicle, equipped with a fifth wheel, used to haul one or two semitrailers or a semitrailer and a trailer.
Triple axle		A set of three equally-spaced axles, attached to the vehicle by a suspension system designed to distribute evenly, within 1,000 kg at all the times
Trailer		A motor vehicle, equipped with a fifth wheel and one semitrailer.

Table 3: Axle load and limits for trailer.

Old load permit	Front T/T	Rear T/T	Rear T/r	Total
Illustrative/expected load (fully loaded)				
Minimum legal load (kg)	5,200.00	16,000.00	21,000.00	
P – axle load (kN)	50.96	160.72	205.80	
n – relative damage exponent	4.0	4.0	4.0	
F – load equivalent factor (E80)	0.16	2.04	1.62	3.82
New load permit				
Minimum legal load (kg)	6,000.00	18,000.00	24,000.00	
P – axle load (kN)	58.80	176.40	235.20	
n – relative damage exponent	4.0	4.0	4.0	
F – load equivalent factor (E80)	0.29	3.02	2.77	6.01

where W = maximum weight (pounds) on any group of two or more axles; L = distance (feet) between extremes of any group of two or more consecutive axles; N = number of axles in the group being considered (1 ton = 1,016 kg/2,240 lb).

The Vehicle Load and Size Limits Regulation's major aim is to ensure road users' safety as well as protect the roadways and bridges. The regulations are in conformity with the Federal-Provincial-Territorial Agreement on Vehicle Weights and Dimensions. This regulation defines limits of dimensions, axle loads and gross weight for vehicles using public roads excluding fire-fighting trucks.

Load limit of the axle class

Axle load capacity is 5,500 kg for a front single axle (B.1) and 11,000 kg for a front tandem axle (B.2) or front multiple axle (B.3). This capacity can be increased when such capacity is indicated by the vehicle manufacturer. To clearly reveal the impact of an increase in formal or informal axle load limit, as shown in Table 3, the expected axle load and E80 factors for the same truck (using the different formal or informal axle loads) were calculated to show the impact that the newly increased limit has on the average E80/HV type. The truck is assumed fully loaded. Until the last century, for a 'tanker' type semitrailer carrying liquid, the limit is increased to 30,000 kg under normal weather conditions and to 24,500 kg during spring thaw period.

3 METHODOLOGICAL APPROACHES

Several variables were considered in assessing the menace of commercial trailer/truck freight carriers on the highway carriageway in relation to the capacity of roadways design along countries classified roads. For examples, there are trunk A, B, C, D, E and F roads from mega cities, cities, towns, satellite towns, communities and villages. Trunk 'A'–'E' is defined from urban to rural settlements.

A reconnaissance survey was carried out on the Mokwa – Kaduna road, which is a trunk 'A' road that links the North-west to South-west of Nigeria. The survey was carried out to determine the appropriate survey nodes and trip distribution of the road. The tandem and triple axle frequency were also considered in determining the safe-stopping-distance required for the survey nodes.

In evaluating the pavement design, unsoaked CBR values of ≤10%, ≤30% and ≤80%, respectively, are recommended as thresholds for fill or sub-grade, sub-base and base materials was employed in accordance Pavement Evaluation of the Federal Ministry of Works [8]; General Specification [9] and juxtaposed with TRL Overseas Road Note 31 [10]. The service year lifespan according to TRL [10] is 20 years, while the Nigerian specifications FMW [8] specified 25 years. Twenty-five trial/test pits were dug at selected failed and good sections along the carriageway of the road under consideration.

Assessment of truck/trailer loads were based on the Federal Road Safety Corps (FRSC) of Nigeria standard. The weigh bills of those trucks and the en-route load attachments were considered to determine the super imposed load on the carriageway since the major menace on the major road that promotes rapid deterioration of the pavement condition is the overloading of vehicles beyond the approved axle load as exemplified in Nigeria. Other secondary data sets from the Federal Road Safety Corps (FRSC), Federal Ministry of Works (FMW) and from relevant literature. Oral interviews on the existing control measures effectiveness and condition of the road network were elicited in assessing the impacts of such menace along the road to determine the HDV traffic composition and volumetric flow for average daily traffic.

4 RESULTS AND DISCUSSION

4.1 National budget and the road expenditure

In Nigeria, road infrastructure projects financing remains a major constraint in the delivery of efficient and improved road networks across the country. Funding of road projects has been through the budgetary provisions and executed by direct contract award that pave the way for fund racketeering and creating a funding gap for execution of road projects. On average, the annual funding requirement is estimated at ₦500 billion against an average budgetary allocation of ₦120 billion with a deficit of ₦380 billion. In 2012, out of the ₦143 billion budgetary allocations for road infrastructure development, only ₦110 billion was released with deficit of ₦33 billion not released.

Within a 4-year period, the allocation to the transport sector decreased from ₦107.7 billion in 2013 to ₦72.3 billion in 2014 and further decreases to ₦29.7 billion in 2015 before the ₦202.3 billion allocation in 2016 which is not unconnected to the deplorable condition of most federal roads resulting from the trailer/truck load menaces. The average allocation to recurrent expenditure over the 4 years was 23.22% while 76.79% went to capital expenditure. These allocations do not seem to be sufficient to tackle the challenges of the sector, especially from the carbon reduction perspective. This sector attracted 5.84%, 5.18%, 2.54% and 11.88% of the overall federal capital expenditure for the years 2013, 2014, 2015 and 2016, respectively. In the year 2017 again, the sector attracted the sum of 14,860,103,581 for recurrent expenditure while Nigerian ₦262,000,000,000 was for capital expenditures. Also in the year 2018, the sum of ₦15,725,582,503 was for recurrent and Nigerian ₦251,420,000,000 went for capital projects. More specifically, the sum of Nigerian ₦10.00 billion went for the 2nd Niger Bridge; and Nigerian ₦300 billion was for the construction and rehabilitation of the strategic roads [11]. *(₦362 NG = $1USD Depending on currency fluctuations)*

Against this background, Nigeria has been reported as having the second highest road traffic accident fatalities among 193 countries in the world [12]. The available data shows that Nigeria records 152 deaths for every 100,000 people, making road accidents the third highest killer in the country. In terms of road project fund approval, road projects in Nigeria are usually plagued with the following factors:

i. The award of contracts many years after the design were made of which the road would have deteriorated much more than it was when the rehabilitation design was carried out [13], [14].
ii. Determination of minister of Transport's project award limits that will require the National Executive Council, NEC approval thereby causing more delay.
iii. Incessant cabinet reshuffle in government in which new ministers who were not part of initial contract award feeling reluctant to defend another man's error.
iv. Most projects often have political linkages; whose constituencies interface the project areas. The interference of political juggernauts cannot be wished away.
v. Projects financing is usually influenced by the political class positive or negative. What is professionally right may not be politically acceptable [12].

4.2 Highway Capacity Design in Nigeria

The Highway Capacity Manual defines capacity as 'the maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions; usually expressed as vehicles per hour, passenger cars per hour, or persons per hour' [15], [16].

Asphalt concrete is the primary material being used for highway surfacing in Nigeria. Either as a wearing course or as a binder course, it forms the final layer in a flexible pavement structure. Bitumen emulsion has also replaced the use of cut-back bitumen in all federal roads based on the research outcome of the Federal Ministry of Works.

To ensure the efficiency of highways in the country, the Pavement Evaluation Unit (PEU) of the Federal Ministry of Works established pavement structural design using an estimated projected standard axle and CBR values obtained during the geotechnical investigation, which recommends unsoaked CBR values of ≤10%, ≤30% and ≤80%, respectively, for fill or sub-grade, sub-base and base materials. Pavement structural design method adopted was TRL Overseas Road Note 31 [10], with 20 years life span adopted. But the lack of weighbridge installation and adequate control of the commercial freight carriers in the country, they have taken over the roles of the rail system thereby overloading the major highways.

4.3 Trailer/Truck Load Menace on highways

A blended study of Mokwa-Kaduna trunk 'A' road reveals that trailer/trucks dominate the traffic flow as indicated in Table 4. With nearly 17,000 Tons in a space of 4 h, the road pavement is overused. The dead loads supper imposed at their resting locations (on-street parking) has also impacted negatively on the road shoulders thereby aggravating the rotting rate as revealed in Fig. 2.

Table 4: Traffic survey along Mokwa – Kaduna.

Type of vehicle	11–12 noon	12–1 pm	1–2 pm	2–3 pm	Total vehicle	Vehicle weight (T)	Total weight (T)
Private cars	56	69	89	20	234	1.5	351
Pick-ups	5	11	7	2	25	3	75
Trailer	82	98	117	43	515	33	16,995
Commercial buses	25	25	28	14	92	20	1,840
Tippers	0	6	3	0	9	12	108
Special vehicles	5	4	3	0	12	25	300
Total	173	213	247	79	712	94.5	19,669

Source: Author's field survey. T = Tons.

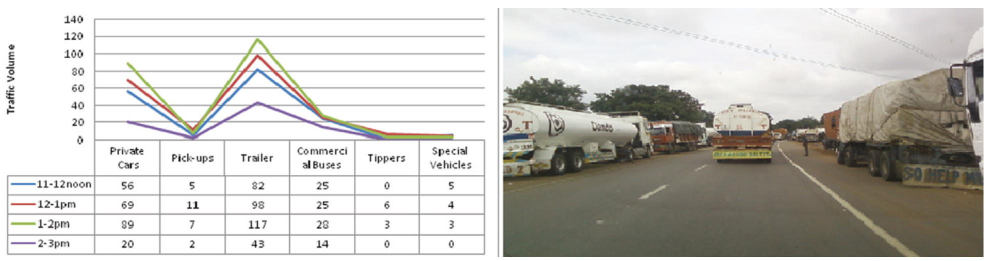


Figure 2: Road traffic composition along Mokwa – Kaduna trunk 'A' road.

Presently in Nigeria, there is no weighbridge installation on any major highway; neither do the traffic control agencies have any devices for monitoring and control of vehicular overload except for the use of reasonable visual judgement that is very controversial. The commercial freight carriers are exploiting this avenue to overload their vehicle to the detriment of the carriageway as revealed in Fig. 3.

Geotechnical investigation on the properties of the materials for the highway pavement and the road base was carried out by the Pavement Evaluation Unit of the Federal Ministry of Works prior to the rehabilitation of some selected sections. Twenty-five trial/test pits were

Figure 3: Trailer/truck menace on the Nigerian trunk 'A' road.

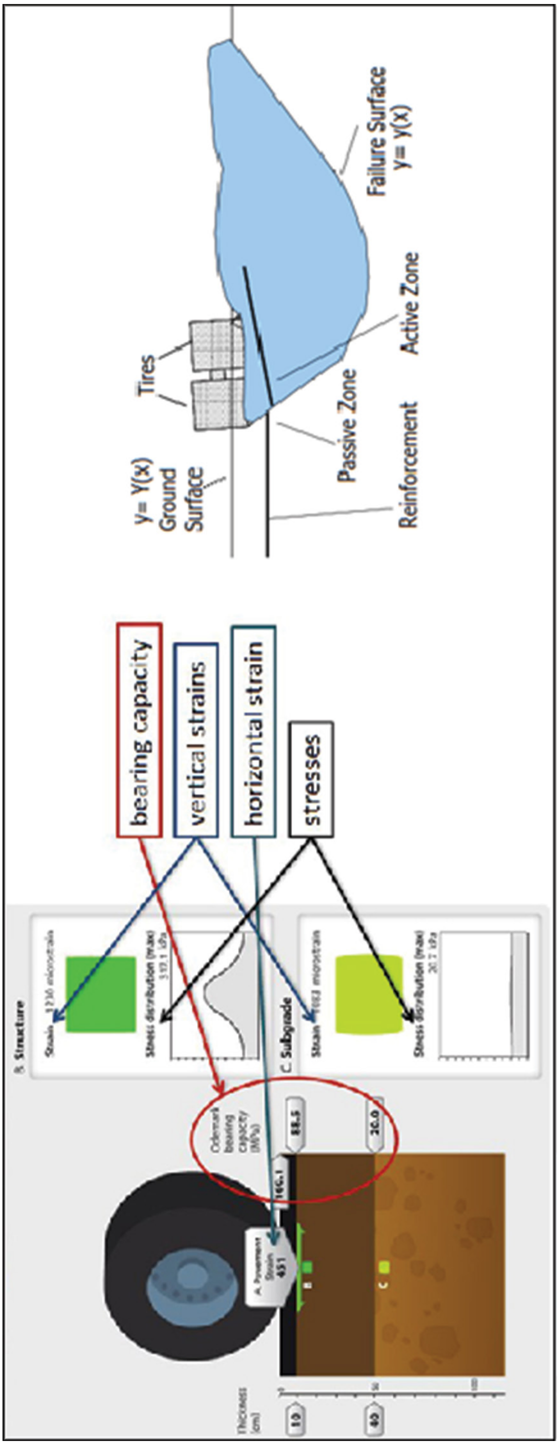


Figure 4: Configuration of bearing capacity model for analysing highway aggregate base. *(Source: Tommy et al. [17].*

dug at selected failed and good sections along the carriageway. The results of the tests were compared with FMW General Specification [9] and their findings are as follows:

i. High quality stone base material was used at the sections that were still good while the portion with soil-cement stabilized base was weak having large cracks.
ii. Generally the sub-grade layer was too fine and plastic in many locations.
iii. Failed sections of these highway pavements were due to poor drainage and vehicular overloading.

Going by these findings of the FMW, the analysis of the impacts of the present day six axle trailer-tankers and overloaded trucks in the country is as illustrated in Fig. 4 based on the load bearing capacity of the major highways and their life span. The vertical and horizontal strain exerted by the overloaded trailers and trucks on the weak sub-base leads to carriageway surface failure and continuous rotting of the highways.

4.4 Discussion

Trailer/truck menace in Nigeria has become alarming and digging deep into the national resources due to poor implementation of control measures and lack of necessary infrastructure to effectively monitor the activities of freight carriers. For instance, it has been estimated that about ₦88 billion is being lost as a result of increased Vehicle Operating Costs, ₦12 billion lost to delayed turn-around and increased travel time, while about ₦75 billion is lost to reduction in asset value. With 2.5% of GDP, the cumulative total annual lost to the economy is approximately ₦175 billion [18], [19].

The load bearing capacities of Nigerian highways are becoming poorer-and-poorer given the highway road rehabilitation exercises of the agency concerned, Federal Roads Maintenance Agency (FERMA) and the present traffic composition of highly overloaded, greater than six axle trailers and trucks. Although the road evaluation units of the FMW are trying their best, the socio-political environment that surrounds the transport sector in the country seems to undermine their effort. For instance, the Geotechnology Section of the University of Kentucky Transportation Centre carried out a research on highway mathematical bearing capacity models that are based on limit equilibrium as stability like other researchers such as Hopkins [20] and Hopkins *et al.* [21]. Their findings among other things revealed that; clay soils have a large affinity for moisture and they often become weak after water absorption and that chemical additives are ineffective where temperature is below 40°F and in cases where traffic must be routed immediately onto the unfinished roadway. Under such conditions, as is often the case in Nigeria, weak clayey sub-grades deflect under wheel pressure, tensile stresses are developed at the bottom of the granular layer and cause deep rutting, and eventually crack in the pavement [22]. However, this may be mitigated by the introduction of geosynthetic fibres, which are rarely available in Nigeria.

In the area of the existing legislative and regulatory policies in the country, the abolishment of toll gates in 1990s, and removal of weigh-bridges at the various toll gates truncated the effective control of vehicle load tonnage till the present time. Although, there is theoretical legally permissible load tonnage of 40 tons on all Nigerian roads, the enforcement is highly subjective and even witch-hunting in operation under the Nigerian Police and Federal Road Safety Corps (FRSC) where weighbridges or other means of objectively establishing that a road user has violated are lacking. All these and many more are responsible for the deplorable rotting condition of the major highways; hence the need for urgent adoption and installation of WIM and weighbridges in carriageways in Nigeria is long overdue.

4.5 Findings

This study has examined the traffic composition along Mokwa-Kaduna trunk 'A' road and the road condition. The work looked into the transformation in the trailer/truck axle and their loading system in relation to the load bearing capacity of the existing highways that are devoid of weigh-bridges. The following are some of the major observation from the study:

i. Trailer/Truck vehicles dominated the Mokwa-Kaduna highway at some period of the day.
ii. There are not any vehicle weight determinants in place on the highway, hence the prevalence of trailer/truck over loading.
iii. That vehicle overloading is one of the major causes of highway rotting apart from the poor implementation of road projects that are below design standard.
iv. The highway is in deplorable condition thereby forcing the trailers/trucks to divert to other alternative routes like Bida-Minna-Suleja road.
v. That any upward review of the legal axle loads (E80/HV) will have more proportionate impact on the carriageway.
vi. That the country is losing approximately ₦175 billion annually due to the deplorable condition of its highways

5 CONCLUSION AND RECOMMENDATIONS

Nigeria can be said to be one of the few countries whose economy depends on a mono-transport system, where over 70% of freight movement is by road. In America, over 60% of freight movement is by inland waterways via the great lakes, while other countries fully exploit the potentials in rail transport mode. The global metamorphosis in heavy truck axle design is a major challenge to countries where there is no clear transport policy on permissible axle load or poor enforcement of such.

Highway carriageway design should be flexible responding to the automobile industries in terms of load bearing capacity and surfacing. The noncompliance to road design standard proposals by contractors due to the delay in project award funding is a major challenge in highway construction in Nigeria. The transportation system in Nigeria has been highly politicized which also cripples the effectiveness of the control agencies. The commercial freight carriers are operating with impunity without recourse to any regulatory laws since the highways lack the necessary sensors and weigh-bridges which are consistent with the findings of other researchers like Nwoye and Iyiola [23]. WIM device is a modern invention that works with other Intelligent Transport System (ITS) to complement rigid-weighbridges globally to prolong the life span of roads. Nigerian carriageways need it urgently.

Based on the foregoing discussion and findings, the following recommendations are therefore proffered:

a. The world is going green with green mobility and ITS technology, Nigeria should adopt and install WIM together with fixed-weigh-bridges on all the major highways to stop all the wastage in road rehabilitation self-awarded projects.
b. As a matter of urgency, the country should focus on the restoration of the rail transport system to its former glory where even the petroleum products are hauled by rail.

c. Alternative transport modes in the country, like the inland waterways (Baro port), should be developed without political undertows.
d. Federal agencies like the Standard Organization of Nigeria (SON), FMW and FRSC should be IT compliant in their control operation and evaluation to meet the global best practices.

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