Measurement of the Traffic Wheel/Pavement Contact Characteristics for Goods Haulage; Case Study of Dangote Flour Mill PLC Ilorin, Nigeria

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Measurement of the Traffic Wheel/Pavement Contact Characteristics for Goods Haulage; Case Study of Dangote Flour Mill PLC Ilorin, Nigeria

Daniel Oluwafemi Oguntayo¹*, Idris Taiye Adelowo² and Joseph Kunle Olaleye³

Abstract: In Nigeria, goods haulage is currently dominated through heavy trucks, whose effect on the pavement deterioration can be enormous, because the truck wheel/pavement interaction plays a key role in deterioration of pavement life. This study aims to measure the truck wheel/pavement contact characteristics with a view to develop its quantitative damaging influence on a pavement structure. Axle load distribution, tyre inflation pressure and tyre/pavement contact area of selected tyre types for different axle configurations were determined for four classes of trucks being used by a major haulage outfit in Nigeria, Messrs Dangote Industries Limited. The results obtained showed that the tyre pavement contact length depends on tyre load as the length increases with increase in tyre load, while tyre pavement contact width is averagely constant with tyre load increase. It is concluded that design and use of tyres should allow for large contact areas with small tyre pressures to lessen the menace of pavement deterioration, and also there is need for a strict control for standards of truck loads that travel on Nigerian road.

Subjects: Civil, Environmental and Geotechnical Engineering; Transportation Engineering; Pavement Engineering

Keywords: pavement; tyre load; axle load; pavement contact; inflation pressure

ABOUT THE AUTHOR

OGUNTAYO, Daniel Oluwafemi is a researcher in the Department of Civil Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria. He had his Bachelor and Masters degree in Civil Engineering with specialization in Transportation Engineering and Highway Materials from the University of Ilorin, Nigeria in 2013 and 2018 respectively. He is a registered member of Council for the Regulation of Engineering in Nigeria (COREN). He has participated in many Civil Engineering projects where he worked with construction companies and have notable projects completed to his credit. He has publication in reputable journals on issues that relates to Transportation Engineering and Management. His current area of research includes: Traffic Management, Pavement Management and Highway Materials

PUBLIC INTEREST STATEMENT

The rate of deterioration of Nigerian roads has been accelerating and it has poses serious effect on the motorists. The number of heavy vehicle (truck), their weights, wheel loads and tyre inflation pressures have increased over the years due to over-reliance on road transportation for goods haulage and their effect on the fatigue life of pavements is a key issue that deals with pavement distresses. Hence, the study of these traffic wheel load parameters is important in understanding their dynamics and their damaging effect on pavement so as to set standard axle load for design purpose and to ensure strict imposition on their overloading.
1. Introduction
The economy of any area depends on shipping, and receiving products and materials at harbours and seaports, with trucks been the most common form of transportation (Wisconsin Transportation Bulletin, 2002). In Nigeria, goods haulage is currently dominated through heavy trucks (Adetunji & Atomode, 2014), whose effect on the pavement deterioration can be enormous, because the truck wheel/pavement interaction plays a key role in deterioration of pavement life.

A pavement is designed to last for 20 years (Paul, 2013), but it often does not perform as expected and, after a relatively short period of time, needs to be rehabilitated (Pais et al., 2013). Several factors are responsible for the failure on Nigerian road and they include geotechnical properties of the soil, topography and drainage, climate, geology, poor design, poor construction materials and poor construction technologies (Ebuzaome, 2015; Ede, 2014; Ifabiyi & Kekere, 2013; Latifa & Prihutomo, 2019); however, traffic loads play a key role in consumption of pavement life with trucks being the major consumers of the pavement network and applying the heaviest loads to the pavement (Chatti et al., 2004). The loads from trucks are transferred to the pavements through different combinations of axle configurations depending on the truck type. These heavy-duty wheel loads with their configuration affect the performance of pavement because they impact different magnitude of the applied wheel loads. Pavement deterioration highly depends on how Gross Wheel Load of different truck types is being distributed over the axle and its corresponding tyre/pavement interaction (Latifa & Prihutomo, 2019). In order to estimate actual pavement distress, it is important to incorporate the realistic tyre footprint area, which takes effects of tyre thread into consideration in their analysis.

The load of a given set of tyres is expressed in terms of the weight supported on each tyre, the contact pressure exerted on tyre/pavement interface and the number of tyres (Morton et al., 2004). The traffic load transmitted by tyre to the pavement is assumed to be evenly distributed on a circular area, but the shape is more rectangular in reality (Fernando et al., 2006).

In Nigeria, Dangote Industries Limited (DIL) is one of the leading commercial firms, and highway transportation mode is used in conveying her goods, which results in enormous trucks plying Nigeria road. This contributes to deterioration of Nigerian highways before its design life, which calls for a new standard legal axle for pavement design approach that will take care of the lapses in the conventional design approach. Therefore, this study aim to measure the traffic wheel/pavement contact characteristics for Goods Haulage Trucks in Nigeria which will be relevant to professionals and authorities concerned with developing policy on allowable truck loadings and for setting standard axle load for pavement design.

2. Description of study goods haulage outfit
Dangote Flour Mills Plc commenced operations in 1999, as a Division of Dangote Industries Limited (DIL). DIL is one of the Nigeria's largest and fastest-growing conglomerates. Dangote Flour Mills Plc, Ilorin, was established in year 2005, and was installed with the capacity of 100 MT per day. This branch is located along Asa Dam road, North Central Geopolitical Zone of the Federation, and supplies goods to different parts of the country. The mode of goods hauling is mainly through highway transportation system with the company owned and hired trucks. These goods trucks comprise of rigid and articulated trucks with all types of axle configurations, ranging from single to tridem axle, all of which have effect on road pavement.

3. Methodology

3.1. Survey of haulage trucks and axle configuration at Dangote flour mill Plc
General information on Dangote Flour Mill’s truck type and their respective chassis was obtained by using Federal Highway Administration vehicle classification presented in Harwood et al. (2003). These are further classified in case where there is more than a truck in a class type using
alphanumeric method, in order to ease such sub-classification. This was done within the time frame of 5 hours (10:00 am-3:00 pm) per day, for one week, excluding Saturday and Sunday.

3.2. Gross wheel load, axle load and tyre/pavement contact area measurement
Gross Wheel Load and axle load distribution measurements were obtained with the aid of Weigh Bridge, located within the vicinity of the Dangote Flour Mills Plc (See Figure 1). The information on Gross Wheel Load and axle load distributions was automatically displayed on an axle meter’s screen as the trucks approach and stable on the Weigh Bridge. A computer system was provided, which confirmed the accuracy of displayed Gross Wheel Load. This data was used in the load analysis.

The tyre/pavement contact area parameters of selected tyres were measured by using two pieces of folded cardboard paper, a square ruler and a T-square. The two cardboard papers were placed at the front and rear side of the sampled tyre, and the square ruler was used to adjust the two cardboard papers such that they are parallel in both axes with the tyre. Simultaneously, the T-square was used to measure the offset between the two cardboard papers, i.e. tyre/pavement contact length. This setup was repeated in other to measure the tyre/pavement contact width, but in this instance, each cardboard was placed at both side of the sampled tyre. This is clearly shown in Figures 1 and 2. Also, the tyre thread width was measured with the aid of caliper. These measurements were carried for a two weeks period, considering only the randomly selected loaded trucks, which covered tyre in both single and dual fitments.

3.3. Load equivalent factor and truck factor
Load Equivalency Factor (LEF) is described as the ratio of damaging effect of non-standard axle load to standard axle load using AASHTO’s Forth Power Law. The LEF’s is calculated using Equation (1) (Kolo et al., 2014).

\[
\text{LEF} = \frac{W_x^4}{80\text{kN}}
\]

Where \( W_x \) is the axle load.

Figure 1. Weighbridge assembly and usage.
Truck Factor (TF) is defined by the relative damage of a truck to the damage of a standard axle, and it is being calculated by summing up the LEFs of axle groups that make up a truck (Chatti et al., 2004).

\[
TF = \sum \text{LEFs of axle groups that make up a truck}
\]

3.4. Computation of tyre load, contact area and stationary vertical stresses

Tyre load was estimated assuming that axle load is uniformly distributed over the tyres that make up an axle. Thereby, divide the axle load with number of tyre present in an axle. Number of tyres that makes up an axle is two and four for single and dual tyre fitments respectively. Tyre load estimation is shown in Equation (1).

\[
T_l = \frac{W_x}{n_t}
\]

Where; \(T_l\) is the tyre load, \(W_x\) is the axle load and \(n_t\) is the number of tyre

In order to be more realistic in the computation of tyre/pavement contact area, Equation (2) was used to estimate an average tyre/pavement contact area. This equation takes tyre thread reduction in tyre/pavement contact width into consideration in its analysis.

\[
A_r = l(b - n_t b_t)
\]

Where; \(A_r\) is the realistic contact area, \(l\) is the tyre length, \(b\) is the tyre width, \(n_t\) is the number of thread and \(b_t\) is tyre thread gap

The estimated tyre load of different tyre surveyed and corresponding contact area was then used to compute the average stationary vertical stress on the pavement. This is estimated by finding the ratio of tyre load to that of its tyre/pavement contact area, and compared with tyre inflation pressure. Equation (3) was used in estimating the tyre/pavement contact area in the conventional road pavement design and Equation (4) gives the ratio of estimated stationary vertical stress to tyre inflation pressure.
\[ V_s = \frac{T_l}{A_r} \]  

(5)

\[ \eta = \frac{V_s}{T_{ip}} \]  

(6)

Where:
- \( V_s \) is the stationary vertical stress
- \( T_l \) is the tire load
- \( A_r \) is the realistic contact area
- \( T_{ip} \) is the tire inflation pressure

4. Results and discussion

4.1. Vehicle classification

In reference with the Federal Highway Administration (FHWA) vehicle classification, the survey conducted only identifies four classes of trucks being used by Dangote Flour Mill Ptc, Ilorin and their distribution is shown in Figure 3 and Table 1. Class 6 is a rigid truck, while others are articulated trucks. FHWA vehicle class type 9 is extensively used when compared to other vehicle class types. As indicated in Table 1, the estimated average weight of an axle, which revealed that all vehicle class type 9 axles are overloaded including all the tridem axles in class 10, while none of class type 6 is overloaded. Also, the entire steer axle except that of class types 6 and 8 (c) were overloaded, and only the fourth axle of class type 8 (c) was overloaded. Hence, the magnitudes of overloaded axles are averagely 5.23% and 20.68%, for front and rear and other axle respectively, thereby, making it important to raise the legal axle to approximate 96.6kN (9.66tons), at least (Kolo et al., 2014).

4.2. Axle and tyre load distribution

The axle load distribution depends on the vehicle gross weight and spacing between axles. Axle load distributions variation is more significant with an increase in distance, and increases from steer to rear axle accordingly, as shown Table 2. The load-carrying capacity of truck depends on number of axles and axle group, that is tridem axle carries more load with an average weight of 269.93kN (27tons) when compared with tandem and single axle configurations, and tandem axle
Table 1. Average weight of an axle for different vehicle types

| FHWA class type | Type | Number of surveyed vehicle | Axle 1   | Axle 2   | Axle 3   | Axle 4   | Axle 5   | Axle 6   |
|-----------------|------|----------------------------|----------|----------|----------|----------|----------|----------|
|                 |      |                            | 4        | 6.0000   | 61.7350  | 64.4730  |          |          |
| 8               | B    | 2                          | 40.5050  | 46.6550  | 65.7455  | 68.4765  |          |          |
|                 | C    | 1                          | 40.0000  | 45.0300  | 47.0500  | 80.9720  |          |          |
| 9               | A    | 9                          | 45.1570  | 93.8566  | 96.1979  | 105.1124 | 107.7212 |          |
|                 | B    | 8                          | 42.2236  | 93.6548  | 95.5526  | 102.9286 | 112.5571 |          |
| 10              | A    | 4                          | 40.4795  | 77.5848  | 79.9125  | 88.6793  | 90.6248  | 90.6248  |
| TOTAL           |      | 28                         |          |          |          |          |          |          |

This carries more load than single axle. Hence, axle load has a significant effect on tyre load, tyre load increases with an increment in axle load.

4.3. Axle load analysis

4.3.1. Load equivalency and truck factors
Table 3 shows the load equivalency factors (LEF). It can be seen that vehicle class type 6 with LEF value of 0.8390 contributes less damaging influence, while vehicle type 9 (B) causes most structural damage with value of 10.6499. The major and most apparent relevance of this LEF is in the selection of pavement layer thicknesses and it also provides a basis for the evaluation of relative effects of various wheel loads, tyre pressures and load configurations on a pavement's load-carrying capacity.

4.3.2. Magnitude of overloaded axle
Magnitudes of overloaded axles are averagely 5.23% and 20.68%, for front and rear and other axle respectively (Table 4). This axle overload may due to inappropriate arrangement of goods on the truck; unless the pavements have been designed to carry this extra loading, overloaded axles will inflict an exceptionally large proportion of wear on the pavements which will usually result in premature distress to a terminal condition which necessitates full structural rehabilitation or reconstruction rather than periodic resurfacing and maintenance (Stevens & Salt, 2015). Hence, it is important to raise the legal axle (Kolo et al., 2014) and also there should strict imposition of penalties on overloading so as to preserve the pavement life.

4.4. Tyre/pavement contact area parameters
In Table 5, which shows the contact area parameters, the change in length of tyre/pavement contact patch with an increase in tyre load is significant in magnitude, but the width of tyre/pavement contact area rarely changes with an increment in axle load, except the tyre is overloaded, which is less significant. This shows that tyre/pavement contact length depends primarily on applied tyre load. Hence, under a certain tyre load, the harder the surface, the more the tyre will distort and roll out, and the contact area will increase as long as the inter-tread bar area remains in contact with the ground (Diserens, 2009). That is, the estimated tyre/pavement contact area in both single and dual fitments varies depending on tyre load and its thread pattern. Though the thread deduction in contact area contributes less to the estimated realistic contact area in value, but its effects are pronounced in the computation of tyre/pavement contact stress (stationary vertical stress). This result is also inconsistent with study conducted by Hernandez et al. (2013) and Douglas (2009).
Table 2. Tyre load of selected axles and tyre type

| Tyre size | FHWA class type | Axle load | Load per tyre |
|-----------|-----------------|-----------|---------------|
|           | Single tyre     | Dual tyre | Single tyre   | Dual tyre |
|           | Case 1          | Case 2    | Case 1        | Case 2    | Case 1        | Case 2    | Case 1 | Case 2 | Case 1 | Case 2 | Case 1 | Case 2 |
| 215/75R17.5 | 6               |           |               |           |               |           |       |       |       |       |       |       |
|           | 6               | 40.00     | 58.99         | 66.41     | 20.00         | 14.75     | 16.60 |
|           | 8               | 40.00     | 45.91         | 68.53     | 20.00         | 11.48     | 17.13 |
|           | 9               |           |               |           |               |           |       |       |       |       |       |       |
|           | A               | 44.07     | 92.99         | 109.66    | 22.04         | 23.00     | 23.25 |
|           | B               | 40.10     | 90.79         | 115.20    | 20.05         | 21.82     | 22.70 |
| 11R22.5   | 6               |           |               |           |               |           |       |       |       |       |       |       |
|           | 6               | 40.00     | 64.04         | 66.41     | 20.00         | 16.01     | 16.60 |
|           | 8               | 41.01     | 47.40         | 68.42     | 20.51         | 11.85     | 17.11 |
|           | 9               |           |               |           |               |           |       |       |       |       |       |       |
|           | A               | 44.59     | 93.00         | 96.32     | 22.30         | 23.00     | 23.25 |
|           | B               | 41.95     | 106.25        | 112.49    | 20.98         | 21.82     | 26.56 |
| 295/80R22.5 | 6               |           |               |           |               |           |       |       |       |       |       |       |
|           | 8               |           |               |           |               |           |       |       |       |       |       |       |
|           | 9               |           |               |           |               |           |       |       |       |       |       |       |
|           | A               | 44.99     | 105.00        | 106.17    | 22.50         | 22.84     | 26.25 |
|           | B               | 40.10     | 101.27        | 104.00    | 20.05         | 21.76     | 25.32 |
| 315/80R22.5 | 6               |           |               |           |               |           |       |       |       |       |       |       |
|           | 8               |           |               |           |               |           |       |       |       |       |       |       |
|           | 9               |           |               |           |               |           |       |       |       |       |       |       |
|           | A               | 105.09    | 108.74        |          | 26.27         | 27.19     |       |
|           | B               | 94.00     | 102.44        |          | 23.50         | 25.61     |       |
|           | 10              | 91.89     | 94.17         |          | 22.97         | 23.54     |       |
### Table 3. Load equivalency and truck factors

| FHWA type | Class | Load equivalency factors (LEF) | Total LEF (TF) |
|-----------|-------|---------------------------------|---------------|
|           |       | Axle 1 | Axle 2 | Axle 3 | Axle 4 | Axle 5 | Axle 6 | TF |
| 6         |       | 0.0625 | 0.3546 | 0.4218 |        |        |        | 0.8390 |
| 8 B       |       | 0.0657 | 0.1157 | 0.4961 | 0.5368 |        |        | 1.1743 |
| 8 C       |       | 0.0625 | 0.1004 | 0.1196 | 1.0495 |        |        | 1.3320 |
| 9 A       |       | 0.1015 | 1.8945 | 2.0908 | 2.9803 | 3.2873 |        | 10.3544 |
| 9 B       |       | 0.0776 | 1.8783 | 2.0352 | 2.7402 | 3.9186 |        | 10.6499 |
| 10        |       | 0.0656 | 0.8846 | 0.9956 | 1.5098 | 1.6467 | 1.6467 | 6.7491 |

### Table 4. Magnitude of Overloaded Axle

| Front axles | Percentage overload (above 40 kN) | Rear axles | Percentage overload (above 80 kN) |
|-------------|----------------------------------|------------|----------------------------------|
| 40.5050     | 1.26                              | 80.9720    | 1.22                              |
| 45.1570     | 12.89                             | 93.8566    | 17.32                             |
| 42.2236     | 5.56                              | 96.1979    | 20.25                             |
| 40.4795     | 1.20                              | 105.1124   | 31.39                             |
|             |                                   | 107.7112   | 34.65                             |
|             |                                   | 93.6548    | 17.07                             |
|             |                                   | 95.5526    | 19.44                             |
|             |                                   | 102.9286   | 28.66                             |
|             |                                   | 112.5571   | 40.70                             |
|             |                                   | 88.6793    | 10.85                             |
|             |                                   | 90.6248    | 13.38                             |
|             |                                   | 90.6248    | 13.28                             |
| Average percentage overload | 5.23 | 20.68 |

### Table 5. Measured tyre parameters

| Tyre type | Single | Dual |
|-----------|--------|------|
|           | Length (m) | Width (m) | Thread gap (m) | Area, $A_n$ (m$^2$) | Length (m) | Width (m) | Thread area, $A_n$ (m$^2$) |
| 215/75R17.5 | 0.18 | 0.24 | 0.0055 | 0.0392 | 0.1009 | 0.239 | 0.0055 | 0.0219 |
|            | 0.18 | 0.24 | 0.0055 | 0.0392 | 0.1009 | 0.239 | 0.0055 | 0.0223 |
|            | 0.18 | 0.24 | 0.0055 | 0.0392 | 0.132 | 0.239 | 0.0055 | 0.0286 |
|            | 0.181 | 0.24 | 0.0055 | 0.0395 | 0.1485 | 0.239 | 0.0055 | 0.0322 |
|            | 0.193 | 0.24 | 0.0055 | 0.0421 | 0.155 | 0.239 | 0.0055 | 0.0336 |
|            | 0.21 | 0.2408 | 0.0055 | 0.0459 | 0.175 | 0.239 | 0.0055 | 0.0380 |
|            | 0.179 | 0.24 | 0.0055 | 0.0459 | 0.179 | 0.24 | 0.0055 | 0.0392 |
|            | 0.195 | 0.24 | 0.0055 | 0.0425 | 0.206 | 0.24 | 0.0055 | 0.0425 |
|            | 0.209 | 0.24 | 0.0055 | 0.0449 | 0.209 | 0.24 | 0.0055 | 0.0449 |
|            | 0.24 | 0.2409 | 0.0055 | 0.0525 | 0.24 | 0.2409 | 0.0055 | 0.0525 |
|            | 0.2497 | 0.2409 | 0.0055 | 0.0567 | 0.2497 | 0.2409 | 0.0055 | 0.0567 |

(Continued)
Also Table 6 shows the actual and realistic contact area as well as the vertical pressure. It can be seen that the vertical pressure for dual tyre fitment is greater than the single tyre fitment for the tyre type except for 11R22.5 tyre type. The vertical pressure is significant because of its dominant effect on induced horizontal strains at the pavement (HMA) layer as well-induced vertical strain at the top of the sub-grade which are the desirable pavement responses (Moazami et al., 2011).

### 4.5. Average Tyre Loads and Vertically Stresses of Selected Tyre Types

Figure 4 and 5 show average tyre load and average Vertical stress-tyre inflation pressure ratio. It can be seen that the average tyre load of type 215/75R15 and 11R22.5 on dual tyre fitment is less than that of its single tyre fitment but reverse is the case in tyre type 295/
80R22.5, which may be due to overloading of rear axle. However, tyre type 315/80R22.5 on dual tyre fitments has the highest average tyre load. Also, the average contact stress of tyre type 295/80R22.5 and 215/75R17.5 on dual tyre fitments is more than that of its single fitment, while that of dual tyre fitment in tyre type 11R22.5 is less compared to the average vertical stress of its single fitment. The maximum and minimum estimated average vertical stress to tyre inflation pressure ratio is 0.7500 and 0.5578, for 215/75R17.5 and 315/80R22.5 tyre (dual fitment) respectively, which shows significant discrepancies in their comparison.

5. Conclusions
It is important to measure and know the effects of traffic wheel/pavement contact characteristics of trucks on pavements because their effect is not only needed in pavement design but also for development of legislation. From the survey of traffic wheel/pavement contact characteristics of a typical good haulage outfit in Nigeria conducted, it was discovered that the tyre pavement contact length depends on tyre load as the length increases with increase in tyre load, while tyre pavement contact width is averagely constant with tyre load increase. There are exceptional situations where there is a partial increment in tyre pavement contact width, which is due to overloading. This result implies that tyre dimensions and load are significant in relation to pavement deformation. Therefore, to lessen the menace of pavement deterioration, design and use of tyres should thus allow for large contact areas with small tyre pressures, maximum legal weights of trucks should be increased for design purposes in Nigeria and truck weight regulations to control the rate of pavement damage should be enforced.
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Author details
Daniel Oluwafemi Oguntayo 1
E-mail: oguntayo.daniel@lmu.edu.ng
ORCID ID: http://orcid.org/0000-0003-0400-6103
Idris Taiye Adelowo 2
E-mail: idrisadelowo@gmail.com
Joseph Kunle Olaleye 3
E-mail: josepholaleye123@gmail.com

1 Department of Civil Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria.
2 Lekki Gardens Estate Limited, Lagos State, Nigeria.
3 Department of Civil Engineering, University of Abuja, Abuja, Nigeria.

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