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A survey study for axle Load Distribution of Full-trailer Trucks with Tandem Steering Axles-in Iraq

دراسة مسح لتوزيع الحمولة المحورية للمركبات نوع قاطرة ومقطورة ذات المحور الامامي (التوجيهي) المزدوجة في العراق

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Abstract

In Iraq, As a result of the continuous development in the manufacture of heavy vehicles in terms of the distribution of axle and their number and what it contains of the impact on the pavement, there is a need to study the distribution of axle loads of new types of vehicles type full-trailer truck. This study included the distribution of axle loads of the two new types of full-trailer truck with tandem steering axles. The study is based on an axle load survey for the two types of vehicles covered by this study. This survey was carried out in Kerbala and Hilla cities during 2016 and covered 89 full-trailer trucks type 11.2+2.2 and 11.22+2.22. By using the results of the axle load survey, the distribution of axle loads of the trucks type 11.2+2.2 and 11.22+2.22 was obtained. The maximum axle loads obtained from the axle load survey were 12.320, 21.990, 28.320 and 34.580 tonnes for front single, front tandem, rear single, and rear tandem axles respectively. The results of this work allowed the conclusion that there is a serious overloading problem of the tandem steering axle as well as each other types of axles of the above vehicle types are covered in this study. This paper showed the urgent need for a legal axle load limit for tandem steering axle load in Iraq and recommends the activation of the enforcement system on the axle load limits on Iraqi highways.

الخلاصة

في العراق، نتيجة للتطور المستمر في تصنيع المركبات الثقيلة من ناحية توزيع المحاور وعددها وما يتضمنه ذلك من تأثير على التبليط ، هناك ضرورة لدراسة توزيع الاحمال المحورية للأنواع الجديدة من المركبات نوع قاطرة ومقطورة. حيث تضمنت هذه الدراسة توزيع الأحمال المحورية للنوعين الجديدين من المركبات نوع قاطرة ومقطورة ذات المحاور الامامية المزدوجة. واستندت الدراسة إلى مسح الحمولة المحورية لنوعي المركبات المشمولة بالدراسة. وقد أجري هذا المسح في مدينتي كربلاء والحلة خلال عام 2016، وشمل 89 مركبة نوع قاطرة ومقطورة نوع 11.2+2.2 و 11.22+2.22. باستخدام نتائج مسح الحمل المحوري، تم الحصول على توزيع الأحمال المحورية للمركبات نوع 11.2+2.2 و 11.22+2.22. وقد وجدت الدراسة ان اعظم قيمة للأحمال المحورية كانت 12.32، 21.99، 28.32 و 34.58 طن لألمحور المنفرد الامامي، المحور المزدوج الامامي ، المحور المنفرد الخلفي و المحور المزدوج الخلفي على التوالي. وسمحت نتائج هذا العمل بالاستنتاج بأن هناك مشكلة خطيرة في التحميل الزائد لمحور التوجيه المزدوج وكذلك الحال بالنسبة للانواع الاخرى من المحاور لنوعي المركبات اعلاه و المشمولة في هذه الدراسة. وأظهرت هذه الورقة الحاجة الملحة إلى وضع حد قانوني لحمولة المحور التوجيهي المزدوج في العراق، وتوصي بتفعيل نظام الإنفاذ على حدود الحمولة المحورية على الطرق السريعة العراقية.

Keywords: Axle loads, Axle-load frequency distribution histogram, full-trailer truck, steering tandem axle

1. Introduction

As a result of the development all over the world after economic transformation in early 1990s, road transport has rapidly grown. The vehicle class distribution has changed significantly and trailer trucks became much more common **[1]**.

Also, from time to time, the trucking industry was introducing new axle configurations to maintain the heavy gross truck weight within legal axle load restriction **[2]**.

The traffic load has the most important impact on a pavement structural design. It depends on the characteristics of the vehicle, especially the number of axles, axle loads, axle configuration, and other factors **[3]**.

Due to the important effect of axle load on a pavement structural design, the axle load should be not exceeding the axle load limits. These limits reflect the different environmental and social conditions of each country but economic analyses have rarely, if ever, been used to justify them **[4]**.

Over time, the maximum legal weights have increased and, as a consequence, vehicles axle loads have also increased. Moreover, some parts of vehicles exceed the maximum legal loads. Tseng et al. pointed out that increasing axle load limits will aid the logistic industry by decreasing the number of trips needed to transport certain volume of goods **[5]**.

However, the pavement distress depends not only on the percentage of overloaded vehicles but also on the probability distributions for vehicle loads greater than the legal load limit **[6]**.

2. Types of Full-Trailers

The full-trailer trucks are and were the most type of trucks in use for transportation of goods on Iraqi highway network **[7]**. It is a trailer unit that is pulled by a drawbar attached to the preceding unit **[8]**. However, full-trailer trucks can have different axle configuration leading to different types of full-trailer.

Jones and Robinson developed a code used for representing axle configuration of commercial vehicles. Each vehicle is given an axle configuration code for ease of defining and processing the axle load data. This code is simple and each axle is represented by a digit, 1 and 2 depending on how many tires are on the end of each axle. Tandem axles are indicated by recording a digit directly after each other. A decimal point is placed between code digits for a vehicle's front and rear axles. The codes for semi-trailers or articulated trailer are recorded in the same way as for trucks but is separated from the truck code by a minus sign **[9]**. For the full-trailers a plus sign is used. Accordingly, full-trailers truck types observed in this study were type 11.2+2.2 and 11.22+2.22.

3. Axle Load Survey

The axle load survey that is carried out to determine the axle load distribution of the full-trailer trucks on level pavements will also provide important information about the degree of overloading.

There are three main ways of measuring axle loads using either a fixed weighbridge (permanent weighbridge), portable weigh pads, or weigh-in-motion equipment **[10]**.

In this study, permanent weighing stations were selected for weighing the axles of full-trailer trucks. Kerbala and Al-Hilla silo were selected for this purpose. This survey covered 89 full-trailer trucks including 46 type 11.2+ 2.2 and 43 type 11.22+ 2.22.

The procedure for weighing the full-trailers to get axle load individually was as follows **[10]**:

The full-trailer truck must be driven onto the platform and must be stopped and weighed as each axle in turn mounts the platform. In this way the weight of each axle can be calculated by difference.

The steps of weighing process followed during this study were as follows:

1. Weighing the front axle (F_1) of the tractor alone as shown in Figure (1.a).
2. Weighing all axles of the tractor (W_1) together as shown in Figure (1.b).
3. Weighing the axles of tractor together with the front axle of the trailer (W_1’) as shown in Figure (1.c).
4. Weighing the whole vehicle (W_t) as shown in Figure (1.d).
5. Advancing the front axle of the tractor outside the platform for weighing the rear axle of the tractor unit together with trailer unit as shown in Figure (1.e).
6. Advancing the rear axle of the tractor unit outside the platform for weighing the trailer unit (W_2) alone as shown in Figure (1.f).
7. Advancing the front axle of the trailer unit outside the platform for weighing the rear axle of the trailer (R_2) alone as shown in Figure (1.g).

Accordingly, the individual axle loads (which were not measured individually) were calculated as follows:

$R_1=W_1-F_1$ (1)

$F_2=W_1'-W_1$ (2)

Where R_1 is the rear axle load for tractor unit and F_2 is the front and rear axle load for trailer unit. Table (1) shows the typical axle load survey performed during this study.

4. Phenomenon of Overloading

Overloading truck traffic is an untenable problem around the world. In developed countries such as U.S. when the enforcement was effective, Taylor et al. showed that the overloaded vehicles level in U.S. interstates was about 20–30% when there was no enforcement while high enforcement level decreased the overloaded vehicles level from 1% to 2% **[11]**. This phenomenon in developing countries is more serious than developed countries as enforcement and inspection are not as effective **[12]**.

The application of effective enforcement system can reduce the percentage of overloading vehicles; therefore the pavement can achieve the design life. Rys et al**.** reported that the decrease of percentage of overloaded vehicles by 10% may cause the increase of service life of the pavement from 4 to 6 years **[1]**. Most of overloaded vehicles exceed their axle load limit, whereas the gross weight is exceeded less frequently **[1]**. The axle loads surveys of commercial vehicles carried out in many Arab countries (such as Iraq, Abu-Dhabi, Qatar, Kuwait, etc.) have shown excessive overloading **[13]**. Table (2) shows the maximum axle load results from previous axle load studies in Iraq.

5. Axle Load Distribution

In order to study the characteristics of axle loads, the collected data is to be represented by histograms and the corresponding distributions should be determined.

For tractor unit type (11.2), Figures (2.a) and (2.b) show the front tandem and rear single axle load frequency distribution histogram respectively.

It is quite obvious from Figure (2.a) that the front tandem axle load range is wide. The maximum front tandem axle load obtained from the survey of this study was 21.99 tonne (125.65 kN) which is indicating the need for a legal axle load limit for such axle in Iraq.

However, from Figure (2.b), it is obvious that the rear single axles suffer from a serious overloading problem. Whereas, the maximum rear single axle load obtained from the survey of this study was 26.430 tonne (259.170 kN) which is greater than the legal limit of 13 tonne (127.49 kN) according to State Commission of Roads and Bridges (SCRB) **[14]**.

For tractor unit type (11.22), Figures (3.a) and (3.b) show the frequency distribution histogram of the front tandem and rear tandem axle load respectively. The maximum front tandem axle load obtained from the survey of this study was 20.71 tonne (203.1kN). However, the maximum rear tandem axle load obtained was 28.33 tonne (277.82kN) which is greater than the legal limit of 20 tonne (196.13) according to SCRB **[14]**.

For trailer unit type (2.2), Figures (4.a) and (4.b) show the front single and rear single axle load frequency distribution histogram respectively.

It is obvious from Figure (4.a) that the maximum front single axle load obtained from the survey of this study was 14.07 tonne (137.98kN) which is close to the legal limit of 13 tonne (127.49kN) according to SCRB **[14]**. However, from Figure (4.b), it is obvious that the maximum rear single axle load obtained from the survey of this study was 24.63 tonne (241.54kN) which is much higher than the legal limit in Iraq of 13 tonne (127.49 kN) indicating serious overloading.

On other hand, for trailer unit type (2.22), Figures (5.a) and (5.b) show the front single and rear tandem axle load frequency distribution histogram respectively. The maximum front single axle load obtained from the survey of this study was 14.16 tonne (138.86kN) which is close to the legal limit of 13 tonne (127.49kN). However, the maximum rear tandem axle load obtained from the survey of this study was 25.52 tonne (250.27kN) which is greater than the legal limit of 20 tonne (196.13 kN) according to SCRB **[14]**. Accordingly, it can be concluded that the phenomenon of overloading is quite obvious.

(a) Weighing the front tandem axle (F_1) of the tractor alone.

(b) Weighing all axles of the tractor together (W_1).

(c) Weighing the tractor's axles together with the front axle of the trailer

(d) Weighing the whole vehicle (tractor and trailer) (W_t).

(e) The front axle of the tractor outside the platform.

(f) Weighing the trailer unit alone (W_2).

(g) Weighing the rear axle of the trailer (R_2) alone.

Fig. (1) Vehicle weighing Procedure for (11.2+2.2) truck

Table (1) Typical axle load results obtained from the survey for full-trailer trucks type 11.2+2.2 and 11.22+2.22

Full-trailer truck type	L= loaded E= empty	Tractor unit			Trailer unit			Total weight of full-trailer track W_t (tonne)
		F_1 (tonne)	R_1 (tonne)	W_1 (tonne)	F_2 (tonne)	R_2 (tonne)	W_2 (tonne)	
11.2+2.2	E	9.88	5.68	15.56	5.41	6.44	11.85	27.41
11.2+2.2	L	18.46	25.70	44.16	14.07	23.71	37.77	81.93
11.22+2.22	E	9.48	8.34	17.82	5.23	7.89	13.12	30.94
11.22+2.22	L	19.09	33.43	47.43	12.41	23.97	36.38	83.80

Where: F_1 is front axle load of tractor unit, in tonne, F_2 is front axle load of trailer unit, in tonne, R_1 is rear axle load of tractor unit, in tonne, R_2 is rear axle load of trailer unit, in tonne, W_1 is total weight of tractor unit, in tonne $=F_1+R_1$, W_2 = total weight of trailer unit, in tonne $=F_2+R_2$, W_t is total weight of full-trailer truck, in tonnne = W_1+W_2.

Table (2) Maximum axle load results obtained from previous axle load studies in Iraq

Axle type	Legal limits (tonne)*	Max. axle load observed (tonne)				
		1982(1)	1997(2)	1999(3)	2002(4)	2008(5)
Front single axle	7	-	11.78	11	12.48	12.32
Front tandem axle	-	-	-	-	-	-
Rear single axle	13	22	23.2	30	27.8	28.32
Rear tandem axle	20	34	37.4	49	31.58	34.58

* According to State Commission for Roads and Bridges in Iraq [14],
(1) According to Razouki et al. [19], (2) According to Al-Shefi [20], (3) According to Mohee [21],
(4) According to Radeef [22], (5) According to Al-Muhanna [7]

6. Normality of Axle Load Distribution

In order to study the characteristics of axle loads, the collected data is to be represented by histograms and the corresponding distributions should be determined. This requires the selection of suitable class intervals and testing the normality of the frequency distribution for the collected data.

A class interval of convenient size is obtained using the following formula **[15]**:

$$C = \frac{R}{1 + 3.322 \log_{10}(N)} \qquad \textbf{(3)}$$

Where C is a class interval, N is a number of observations, R is a range between largest and smallest value for a given set of observations.

For testing the normality of axle load, the chi-square (χ^2) goodness of fit test is to be used.

Table (3) shows the details of this test for the cases of the front axle load of the tractor unit of the 11.22+2.22 full-trailer trucks.

Using the chi-square (χ^2) goodness of fit test, it is shown that the frequency distribution curve of each axle type (see Figure 2 to5) followed the normal distribution for a level of significance (α=5%)**.**

The critical chi-square (χ^2) was taken at a level of significance (α) of (5%) for a degree of freedom (DF=g-3) where (g is a number of classes after regrouping) **[16]**.Note that there are two ways to regroup frequency, the first one makes regrouping for the absolute frequency **[17]** and the second way makes regrouping for the expected frequency **[16-18]**. Adopted regrouping in this work followed the expected frequencies less than 5 **[19]**.

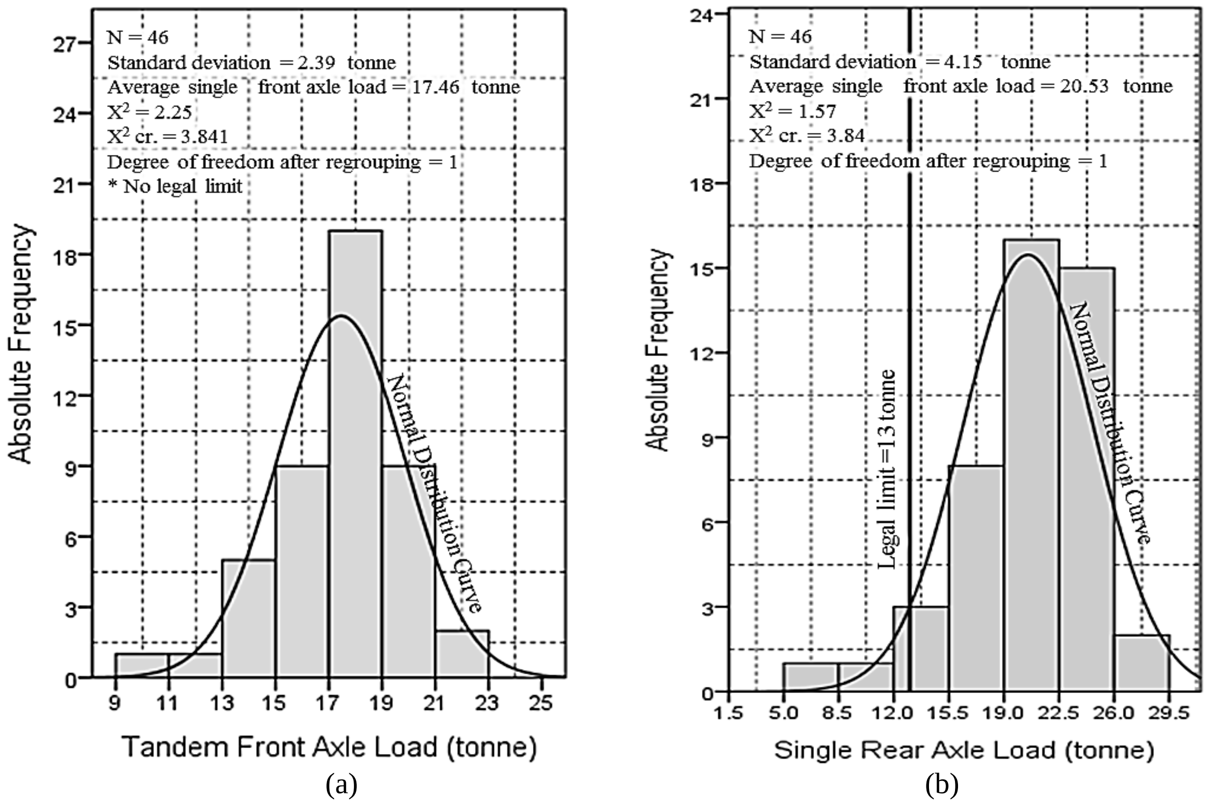


Fig. (2) Frequency histograms and normal distribution curves for (a) front tandem axle load (b) rear axle load of tractor unit type 11.2 of full-trailer truck type 11.2+2.2

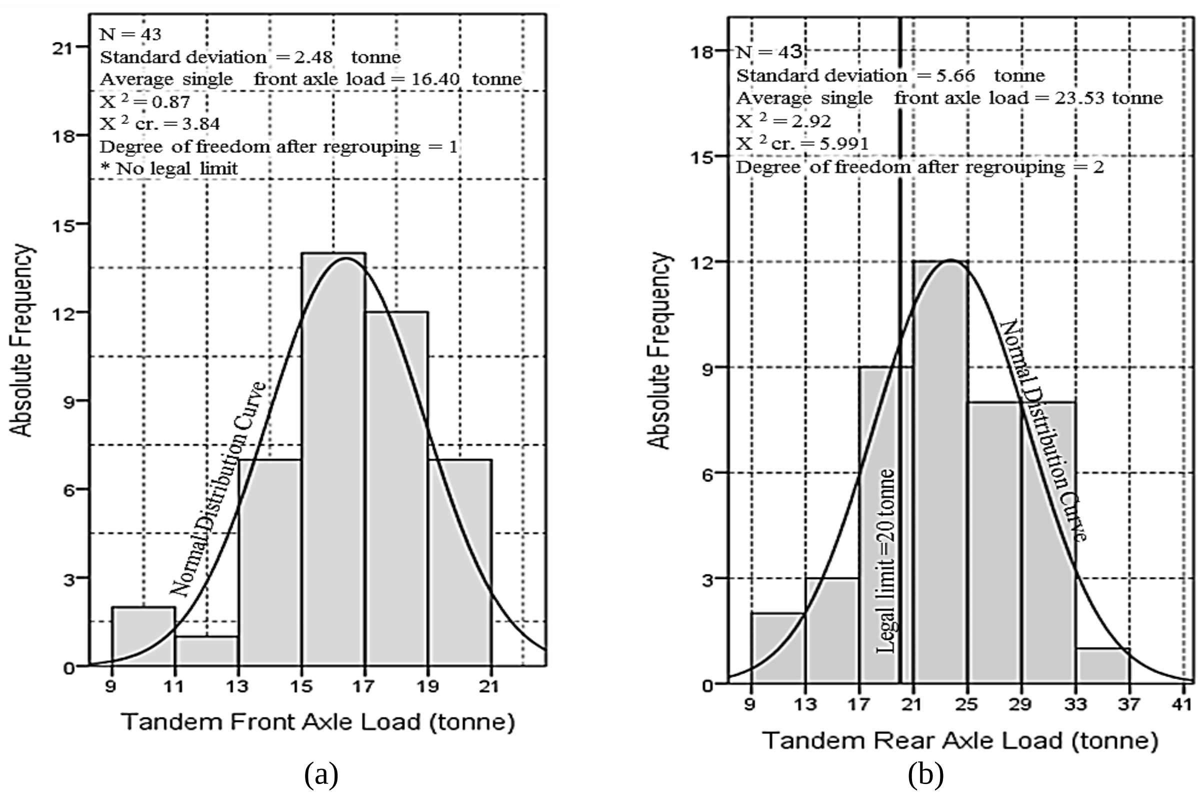
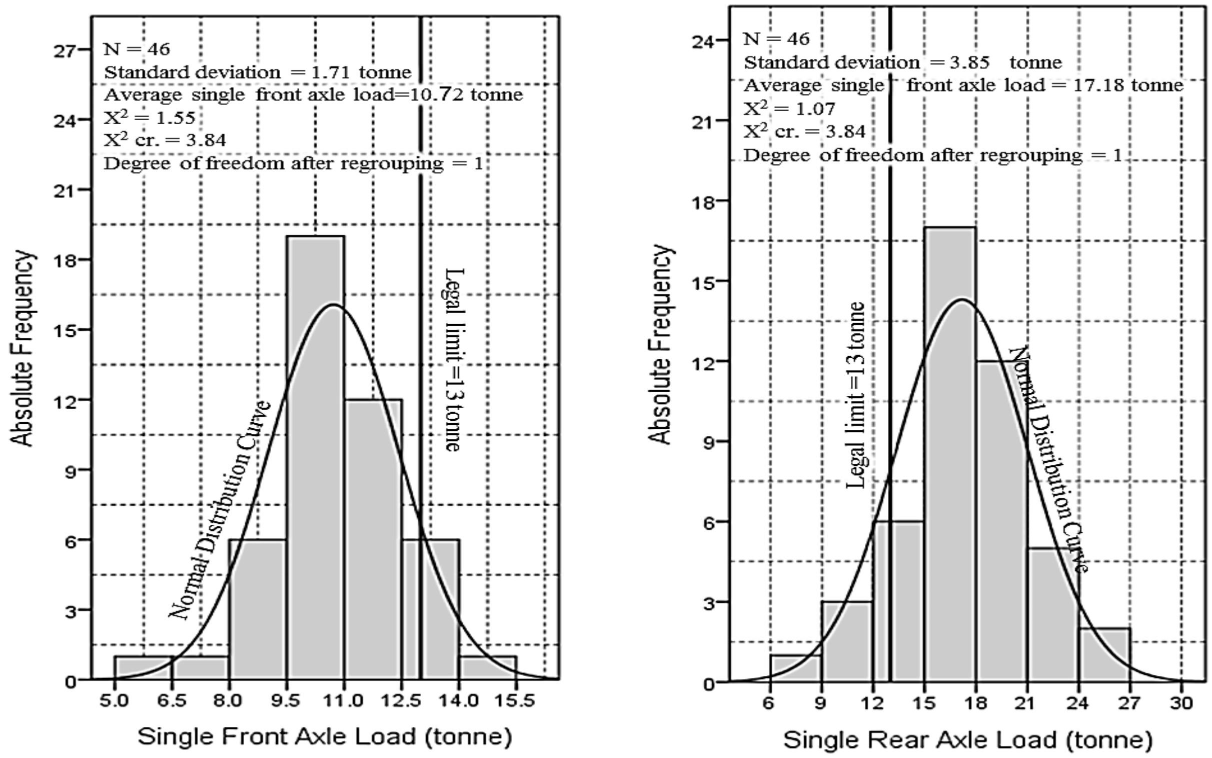
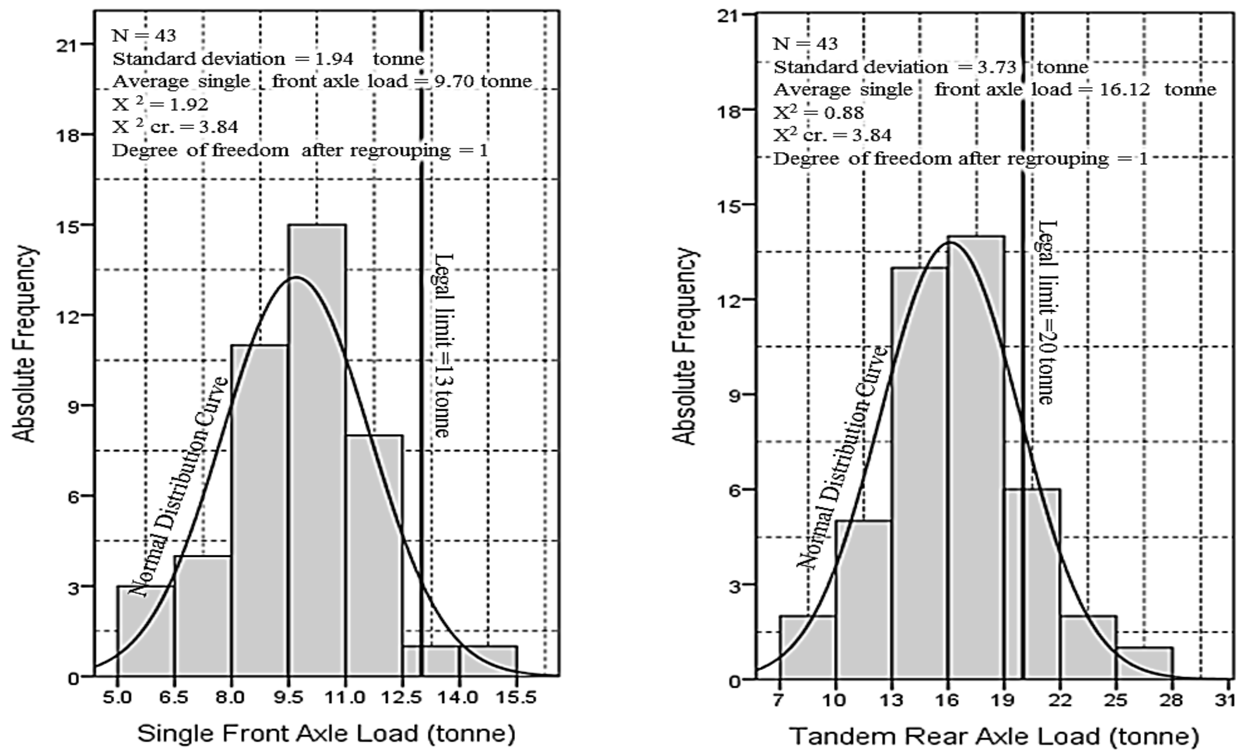


Fig. (3) Frequency histograms and normal distribution curves for (a) front tandem axle load (b) rear axle load of tractor unit type 11.22 of full-trailer truck type 11.22+2.22



(a) (b)

Fig. (4) Frequency histograms and normal distribution curves for (a) front axle load (b) rear axle load of trailer unit type 2.2 of full-trailer truck type 11.2+2.2



(a) (b)

Fig. (5) Frequency histograms and normal distribution curves for (a) front axle load (b) rear tandem axle load of trailer unit type 2.22 of full-trailer truck type 11.22+2.22

Table (3) Testing the normality of frequency distribution of the front axle loads for the tractor unit of full-trailer truck type (11.22+2.22)

<table>
<tr><th>Axle load class (tonne)</th><th>Class mark (tonne)</th><th colspan="2">Observed frequency (fi)</th><th colspan="2">Expected frequency (Fi)</th><th>$\frac{(f_i - F_i)^2}{F_i}$</th></tr>
<tr><td>9 - 11</td><td>10</td><td>2</td><td rowspan="3">10</td><td>0.48</td><td rowspan="3">11.14</td><td rowspan="3">0.17</td></tr>
<tr><td>11 - 13</td><td>12</td><td>1</td><td>2.68</td></tr>
<tr><td>13 - 15</td><td>14</td><td>7</td><td>7.98</td></tr>
<tr><td>15 - 17</td><td>16</td><td colspan="2">14</td><td colspan="2">13.54</td><td>0.02</td></tr>
<tr><td>17 - 19</td><td>18</td><td colspan="2">12</td><td colspan="2">11.55</td><td>0.02</td></tr>
<tr><td>19 - 21</td><td>20</td><td colspan="2">7</td><td colspan="2">5.15</td><td>0.67</td></tr>
<tr><td></td><td>Total</td><td colspan="2">43</td><td colspan="2">χ^2</td><td>0.87</td></tr>
<tr><td colspan="7">Average front axle load = 16.40 tonne</td></tr>
<tr><td colspan="7">Standard deviation = 2.48 tonne</td></tr>
<tr><td colspan="7">Number of classes after regrouping =4</td></tr>
<tr><td colspan="7">Degree of freedom (DF) =1</td></tr>
<tr><td colspan="7">Critical chi-square (χ^2_c) =3.841</td></tr>
<tr><td colspan="7">χ^2_c > calculated χ^2 The distribution is normal</td></tr>
</table>

7. Conclusion

Based on the results obtained from this paper, the following conclusions can be drawn:

1. The maximum axle loads obtained from the axle load survey were 12.320, 21.990, 28.320 and 34.580 tonnes (120.86, 215.51, 277.82 and 339.23 kN) for front single, front tandem, rear single, and rear tandem axles respectively.

2. The maximum axle loads of full-trailer trucks appeared in this work exceeded greatly the legal axle load limits in Iraq.

3. The front tandem axle of full-trailer truck has a wide range of load. The maximum front tandem axle load obtained from the survey of this study was 21.99 tonne (215.51 kN) which is relatively high indicating the need for a legal axle load limit for such axle in Iraq.

8. Recommendation

1. Establishing a fixed weigh stations at specific location at the boundary of Karbala city to overcome the in and out heavy vehicles.
2. Applying enforcement system on overload vehicles.
3. Developing a hard penalty system.

9. References

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