ATENÇÃO

AS INFORMAÇÕES CONSTANTES DESTE ARTIGO PODERÃO SER UTILIZADAS EM OUTROS TRABALHOS, DESDE QUE SEJAM CITADAS ESTA FONTE E OS AUTORES

5th INTERNATIONAL CONFERENCE
BITUMINOUS MIXTURES AND PAVEMENTS
Thessaloniki, Greece, 1-3 June 2011

COMMERCIAL VEHICLES FLEET ANALYSIS CONSIDERING AXLE LOADS DISTRIBUTION

A. F. Marcon *
Doctor Professor, Federal University of Santa Catarina (UFSC), BR
M. S. N. Moraes
Master Student, Federal University of Santa Catarina (UFSC), BR
G. Triches
Doctor Professor, Federal University of Santa Catarina (UFSC), BR
* UFSC, Department of Civil Engineering, Rua João Pio Duarte Silva, s/n,
CEP 88040-970 - PO 476. Phone: (48) 3721-7773, marcon@ecv.ufsc.br

ABSTRACT
The commercial vehicles fleet has substantial influence on country's development. In Brazil most of goods are transported by trucks, the agricultural crops or livestock products and industrialized issues. The data analysis from weigh stations along the highways can assess how these products and goods are being transported. Vehicles with new axle configurations are in circulation, such as large and wide trucks with more than six axles. However vehicles with traditional axle configuration still used in a huge number of the national truck fleet. In this paper it is presented the frequencies of various types of commercial vehicles observed at the weigh-in-motion station near Guararema (SP) town, localized at km 179+400 of Presidente Dutra Highway and about 50 km from São Paulo City - Brazil. The vehicles were analyzed according to their values of total weight and also checked the overloads in relation to maximum legal axle loads, whose limits come from the Brazilian Law of Balance. It was also analyzed load data of each axle of different vehicles and thus it was possible to observe the loading conditions of vehicles. Histograms illustrate means and modes of frequencies observed in weighing the trucks, enabling the characterization of the load values. Similar axle loads in different vehicles are also evaluated and compared in order to check possible influence of truck type.

KEY WORDS: load, commercial vehicles, axle configuration, traffic.

1. INTRODUCTION

This paper aims to present studies for axle load characterization of a commercial vehicles fleet and the loads carried in various axle assemblies. Data for the analysis was collected in the weigh-in-motion station near Guararema town, located at km 179+400 of Presidente Dutra Highway, State of Sao Paulo - Brazil. This study considers collected data from October to December 2009 period.

It should be noted that the results presented here are part of a research in progress of a master degree dissertation.

2. STUDIED FLEET OF VEHICLES

Vehicles were classified according to the new Brazilian classification, which also considers the new assemblies of vehicles axle loads currently in use in the country. This new classification is found in the publication of National Department of Transportation Infrastructure [1].

The collected data of this analysis were obtained in the period from October 1st, 2009 to December 31th, 2009. It was possible to determine the percentage of each type of vehicle in relation to the total fleet. In this study, 484,071 vehicles were evaluated on weigh-in-motion station in Guararema. According to Albano [2], the use of weigh-in-motion has grown in recent years in an attempt to increase performance and accuracy in load weight control and reduce pavement maintenance costs.

In this study it was considered those vehicles that represent more than 1% of the total fleet of commercial vehicle evaluated. The vehicles considered are shown in Table 1.

Table 1 – Vehicles Percentage

Vehicle	Percentage (%)	Vehicle	Percentage (%)
3C	31.22	3S3	5.71
2C	23.49	2C2	1.6
2S3	16.24	3I3	1.35
2S2	14.87	3D4	1.17
Total		95.65	

Note that the two vehicles with the highest percentages of the sample are trucks with two and three axles. In the study by the Land Transportation Standards Subcommittee [5] are presented as the most frequent vehicles in Canada, semi-trailer with five axles (51%) and semi-trailers with six axles (18.5%). In the United States are the semi-trailer with five axles (42.2%) followed by 2-axle trucks (35.5%) and in Mexico, semi-trailers with six axles (37.3%) and semi-trailers 5 axes (35.2%).

For all vehicles it was considered the gross vehicle weight (GVW) and the weight of each axle for each vehicle.

3. ANALYSIS OF GROSS VEHICLE WEIGHT (GVW)

The gross vehicle weight is a specific characteristic of each type of vehicle and depends on load type. The maximum permissible values given in Table 2 are in accordance with Resolutions 210 [3] and 353 [4] of National Transit Council.

Table 2 – Maximum Limits of GVW

Vehicle	GVW(t)	GVW + tolerance 5% (t)
2C	16	16,800
3C	23	24,150
2S2	33	34,650
2C2	36	37,800
2S3	41,5	43,575
3S3	45/48,5	47,250/50,925
3I3	45/53	47,250/55,650
3D4	45/57	47,250/59,850

For these selected vehicles, it was prepared histograms of load frequency. They are shown in Figures 1 to 8. In these figures, statistical values of mode are observed. In none of them was found symmetry in the load value distribution, which indicates no normal behavior in the distribution. The asymmetry is not always at the same side, and some distributions show that occurs of two or three modes. A vertical line in the graphs shows the maximum GVW allowed to each type of vehicle. Table 3 shows the summary of information found in the diagrams shown in Figures 1 to 8.

Table 3 – General Parameters of GVW

Vehicle	Asymmetry side	Number of Modes	Principal Mode	Secondary Mode	Mean
2C	Left	2	5t a 6t	7t a 8t	7.43t
3C	Right	2	10t a 11t	21t a 22t	15.72t
2S2	Right	2	15t a 16t	29t a 30t	20.67t
2C2	Right	1	19t a 20t	-	20.23t
2S3	Left	2	40t a 41t	16t a 17t	34.19t
3S3	Left	2	47t a 48t	36t a 37t	30.37t
3I3	Left	3	53t a 54t	29t a 30t	45.86t
3D4	Left	3	56t a 57t	48t a 49t	53.90t

In the graph of 2C vehicles (Figure 1), there are nearly homogeneous distribution of values between 6t and 9t. Few occurrences of overloaded truck 2C were observed.

The 3C vehicles (Figure 2) show two modes, both with asymmetry to the right side. They are between a 10t and 11t and 21t and 22t, for maximum load 24.15t. Trucks travelling with overload, most were weighing 24t and 26t.

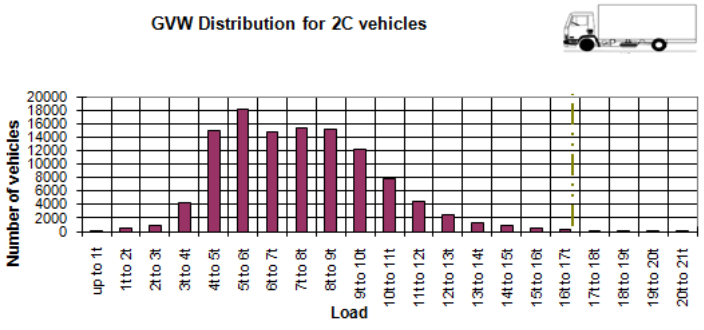

Figure 1 – GVW to 2C vehicles

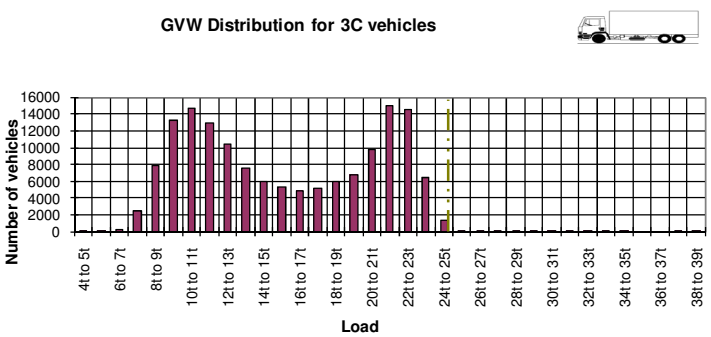

Figure 2 – GVW to 3C vehicles

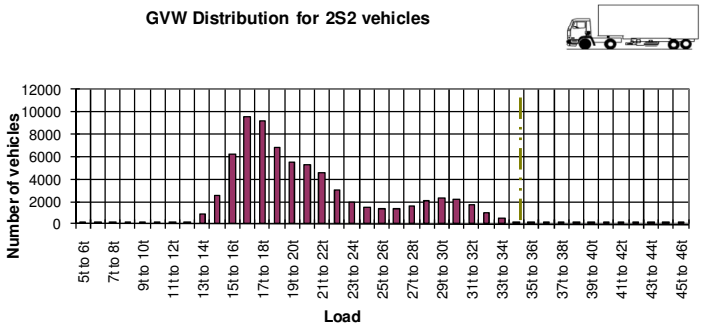

Figure 3 – GVW to 2S2 vehicles

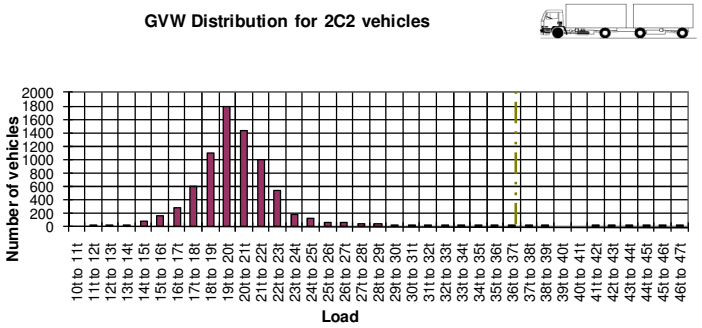

Figure 4 – GVW to 2C2 vehicles

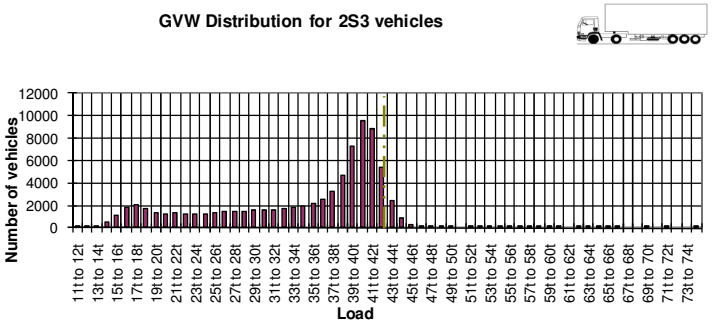

Figure 5 – GVW to 2S3 vehicles

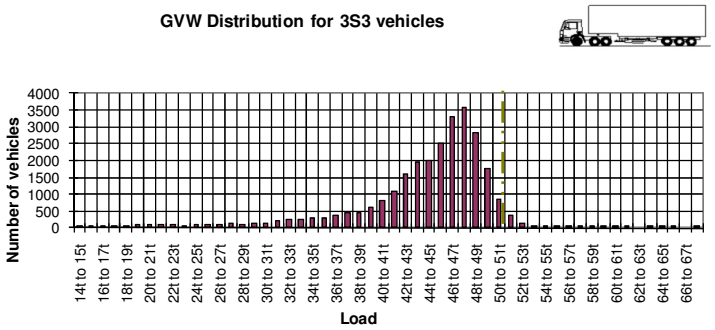

Figure 6 – GVW to 3S3 vehicles

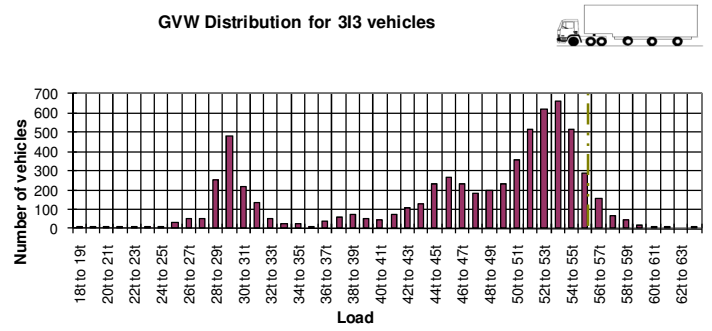

Figure 7 – GVW to 3I3 vehicles

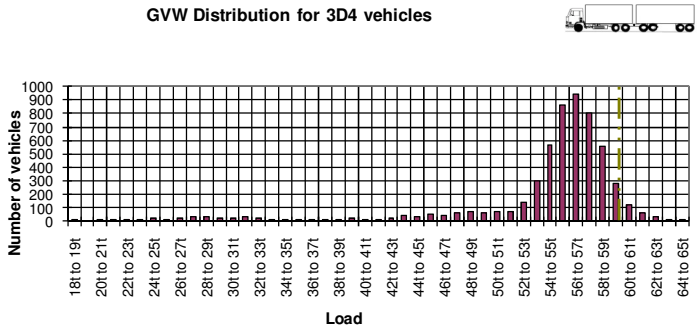

Figure 8 – GVW to 3D4 vehicles

The 2S2 vehicles graph (Figure 3) presents two modes. The main is between 16t and 17t while the secondary is in the range of 29t to 30t. The 2C2 vehicles (Figure 4) have single mode and asymmetry to right side, between 19t and 20t and it was registered one vehicle with gross weight load 46,112t.

The 2S3 semi-trailer trucks (Figure 5) show a high incidence of weights between 40t and 41t. The excesses are mostly between 42t and 46t. The 3S3 semi-trailer vehicles (Figure 6) show significant number of loads between 42t and 50t. The excesses are concentrated in the range between 51t to 54t.

The 3I3 vehicles (Figure 7) show the overloads are concentrated between 56t and 60t. It has three modes, the main between 53t and 54t, the secondary in the range of 29t to 30t and the tertiary between 45t and 46t. Finally, for the 3D4 vehicles (Figure 8), the range of weights was between 18t and 65t. Being the limit of 47.25 tons and 54,8 t for trucks below 19.80m long and over 19.80m respectively. 54,8 t is the average and main mode in the range of 56t to 57t. The excesses range mostly between 60t and 64t.

4. AXLES WEIGHT ANALYSIS

The axles loads analysis also considered weights determined in each axle according to the axle configuration of each vehicle type. Table 4 presents the values of axle load limits according to the rules in CONTRAN [3].

Table 4 – Maximum Legal Axle Load Limits

Axle		Maximum Load Limit (t)	Maximum Limit + Tolerance 7,5% (t)
SASW	Single axle with single wheel	6	6,4500
SADW	Single axle with double wheel	10	10,7500
DTA	Double tandem axle	17	18,2750
TTA	Triple tandem axle	25,5	27,4125

Figures 9 to 16 show the percentage distribution of axle load for different types of vehicles. From the data analysis shown in the graphs it is possible to make the following comments.

2C Trucks: A greater portion of axle weights of the SASW is near 2.5t as shown in Figure 9 with asymmetry to the right. For rear axles (SADW) the highest rate of axle load values is between 2t and 3t. Has significant portion of axle weight between 3t and 8t.

3C Trucks: The vehicle data are shown in Figure 10. Higher percentage of steering axle loads (SASW) is close to 4.5t. Has asymmetry to the right side. For rear axles (SADW) the most of the percentage of axle loads is between 6t and 7t, however, there is another mode between 16t and 17t.

2S2 Semi-trailer Trucks: Most of the percentage of loads in the directional axle (SASW) is close to 4.5 t as shown in Figure 11. For rear axles (SADW) the highest percentage of axle weight is between 4t and 5t. The rear axles (DTA) have asymmetry to the right and significant percentages from 5t to 16t.

2C2 Trailer Trucks: Figure 12 shows most of the directional axle load (SASW) is approximately 4.5 t with slight asymmetry to right. Has three SADW, the higher portion of axle load is between 6t and 9t for the first, for the second between 3t and 6t and for the third between 3t and 5t.

2S3 Semi-trailers Trucks: Figure 13 shows most of the percentage of the steering axle load (SASW) is about 5.5 t. For rear axles (SADW) the highest load found is between 9t and 10t. For rear axles (TTA) most of them are between 25t and 26t, with strong asymmetry to the left side.

3S3 Semi-Trailers Trucks: Figure 14 shows a larger percentage of the steering axle load (SASW) near 5.5 t. For rear axles (DTA) percentage, the highest is between 15t and 17t. The rear axles (TTA) have high percentage of loads between 25t and 26t. It has asymmetry to the left.

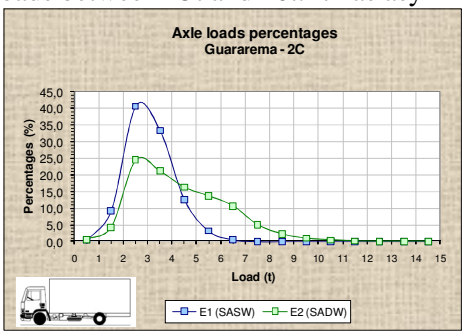

Figure 9 – Percentages to 2C

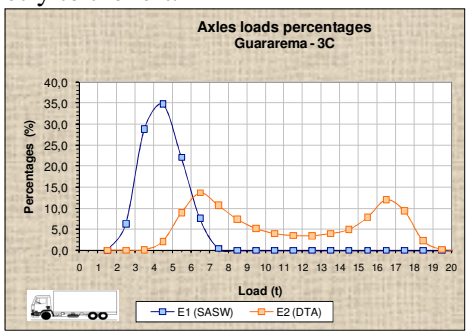

Figure 10 – Percentages to 3C

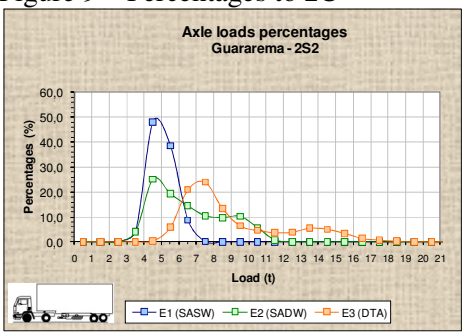

Figure 11 – Percentages to 2S2

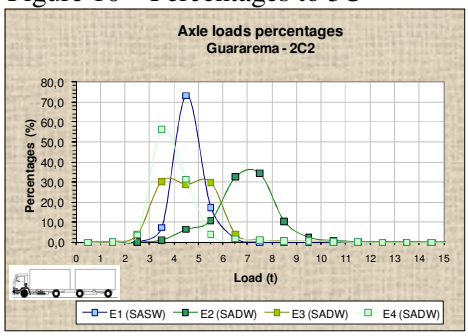

Figure 12 – Percentages to 2C2

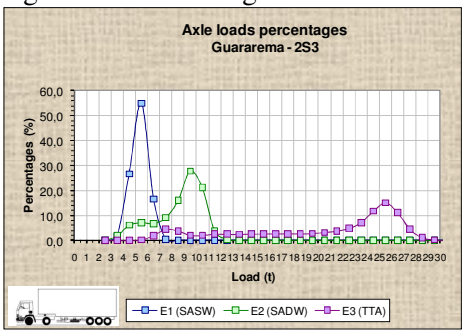

Figure 13 – Percentages to 2S3

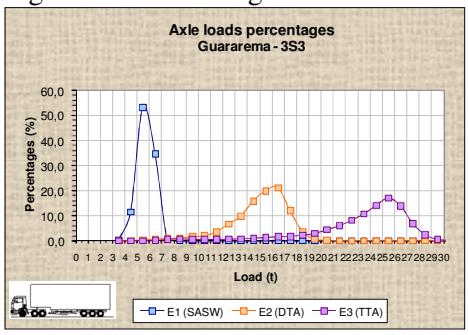

Figure 14 – Percentages to 3S3

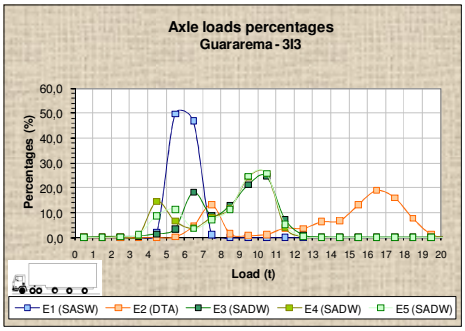

Figure 15 – Percentages to 3I3

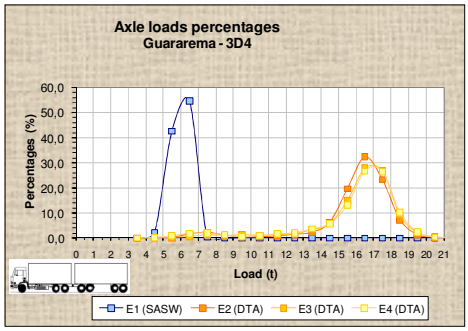

Figure 16 – Percentages to 3D4

3I3 Semi-Trailers Trucks: A larger frequency of the steering axle loads (SASW) is between 5t and 7t as shown in Figure 15. This vehicle has more four axles. The DTA mode is 16.5t. The three axes SADW have very similar behaviors and axle loads mostly between 9t and 11t.

3D4 Trailers Trucks: A higher frequency of axle loads (SASW) is near 6.5t as shown in Figure 16. It has contribution of just over 40% of axle loads between 5t and 6t. These vehicles have other three axes with similar load characteristics and a mode load of approximately 16.5 tons.

The axle loads were also evaluated by comparing the results of each axle type, regardless of the vehicle type. So, four groups of different axle configuration were constituted: SASW, SADW, DTA and TTA.

This assessment provides important information, because the pavement performance depends on traffic load variation. According Uhimeyer et alli [6], the relationship between the axle weights and pavement damage is not linear but exponential. Those authors give an example; a single axle overloaded to 40,000 lbs (18,160kg) causes 16 times more damage than a single axle legally loaded to 20,000 lbs (9,080kg).

Figures 17 and 18 were prepared to the SASW analysis. Curves show that axle loads vary to theirs GVW limit. In the graphs, a vertical line indicates the value of the maximum legal load to the SASW. Lighter vehicles, e.g. 2C trucks, had most of axles loaded with approximately 2.5t. The 3C and 2S2 vehicles, which has GVW legal limit between 20t and 35t showed load frequencies between 4t and 5t. The vehicle 2C2 presented mode between 3t and 4t, despite having GVW of 37.8 t. Vehicles with GVW higher than 40t showed high frequencies of SASW loaded between 2t and 4t. Almost 10% of the SASW of 2S2 and 3C vehicles showed overloads higher than 6,45t.

The Figures 19 and 20 show SADW data. The 2C and 2S2 vehicles with GVW smaller than 35t present many SADW loads between 2t and 3t. The 2S3 has mode of 7.5 t. The SADW of the 2C2 had three modes. The first of 7.5t, the second and third with 3.5t to 2.5t, respectively.For 3I3 the axles 1 and 3 presented modes of 10.5t and axle 2 has mode of 9.5t. Moreover, with the exception of 2C2 vehicle, the mode increases with GVW. More than 5% axles of axles 1 and 3 of 3I3 vehicle were overloaded.

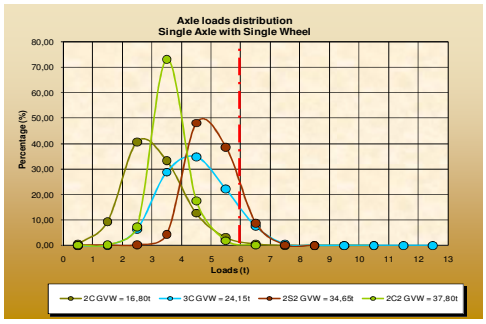

Figure 17 – SASW-GVW up to 40t

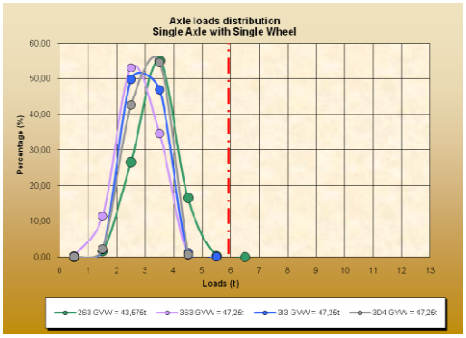

Figure 18 – SASW-GVW over 40t

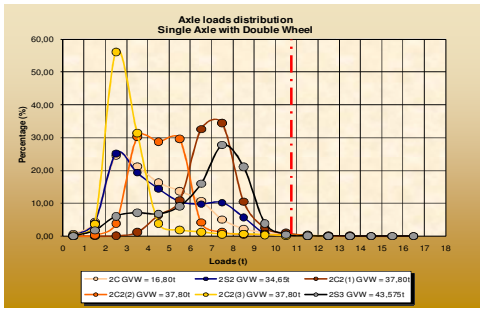

Figure 19 –SADW-GVW up to 45t

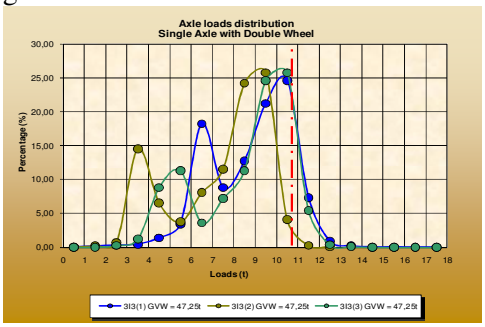

Figure 20 – SADW-GVW over 45t

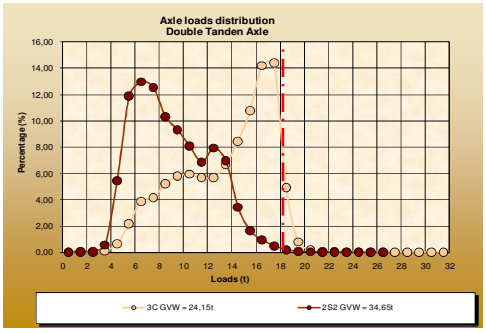

Figure 21 –DTA-GVW up to 40t

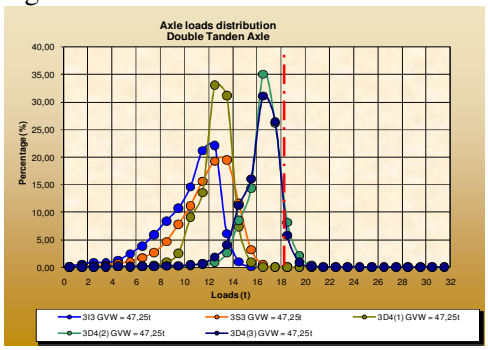

Figure 22 – DTA-GVW over 40t

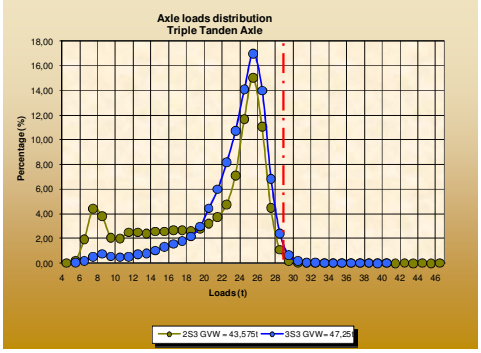

Figure 23 – TTA

The Figures 21 and 22 present DTA axles. The 2S2 trailer showed mode of 6.5 t and 3I3 vehicles mode of 12.5 t. This same type of axle of 3S3 vehicle and the first axis of the 3D4 vehicle have mode of 13.5t. Other axles of 3D4 vehicle have mode of 16.5t. The exception is the 3C truck with mode of 17.5t.

Finally for the tandem triple axles, it was analyzed 2S3 and 3S3 vehicles loads. The two vehicles present axles with similar loads, such as slight variation of the modes that is between 25t and 26t.

5. CONCLUSIONS

The GVW value distribution of vehicles indicates histograms with asymmetries, not obeying the normal curve behavior. The asymmetries are not always to the same side and do not have the same pattern of behavior. Most vehicles indicate the occurrence of two modes.

Overloads occur in all types of vehicles. These overweights are usually on ranges adjacent to the maximum legal load limit up to 2t higher the limit.

Same type of axles in the same vehicle tends to have similar pattern in concern to the weights carried. The exception was the 2C2 vehicle where the second axle had higher loads than others.

Same axle types but in different vehicles tends to have lower modes in vehicles with lower limits of GVW. Thus, although the legal load limit for a given type of axle (SASW, SADW, DTA or TTA) is always the same, the modes float more or less depending on the vehicle's load capacity. The exceptions are in fact found, however, the tendence is noticed in most all.

Overloads occur mainly in the rear axles. This fact comes from the way is made the load distribution by carriers or vehicles operators.

ACKNOWLEDGEMENTS: To NovaDutra Concessionaire for support and assistance provided.

REFERENCES:

[1] DNIT, Table of Vehicle Makers, General Coordination of Road Operation, National Department of Transportation Infrastructure, Brazil, 2009.
[2] Albano, J.F., Overload Effects on Pavement Durability, DSc Thesis, Federal University of Rio Grande do Sul, Brazil, 2005.
[3] CONTRAN, Resolution 210, National Transit Council, Brazil, 2006.
[4] CONTRAN, Resolução 353, National Transit Council, Brazil, 2010.
[5] Pearson, J., Harmonization of Vehicle Weight and Dimension Regulations within NAFTA Partnership, *Report of Land Transportation Standards Subcommittee*, North American Free Trade Agreement, EUA, 1997.
[6] Uhimeyer, J.S., Kapur, J., Strattonet, E., Legal Load Limits, Overweight Loads and Pavements and Bridges, WSDOT, EUA, June, 2006.