Volume 10, Number 6 (December 2017) p. 1163 – 1173 • ISSN 1983-4195
http://dx.doi.org/10.1590/S1983-41952017000600002

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IBRACON STRUCTURES AND MATERIALS JOURNAL

Single and multiple presence statistics for bridge live load based on weigh-in-motion data

Estatísticas de caminhões isolados e em múltiplas presenças para carga móvel em pontes baseadas em dados de pesagem em movimento

E. L. PORTELA [a]
ensondelima@gmail.com

R. M. TEIXEIRA [a]
ritermayer@yahoo.com.br

T. N. BITTENCOURT [a]
tbitten@gmail.com

H. NASSIF [b]
nassif@rci.rutgers.edu

Abstract

Modeling the traffic loads on bridges has been the subject of numerous studies. Defining a live load model to be used for bridge design is not an easy task. It demands among many other things a reliable dataset, a well-defined procedure for filtering data and also the determination of statistics for single and multiple presence occurrences. This study examines and characterizes the live load statistics for Brazilian concrete bridges. Single and multiple truck presence are evaluated for different bridge spans and truck daily volume. The sample is comprised of the thirteen months of data from a High Speed Weigh-In-Motion station (HS-WIM) in a resolution of one hundredth of a second currently operating on the Fernão Dias highway, also known as BR-381. The system provides eleven thousand records on a daily basis. After the filtering process three thousand trucks remain. The station takes measures in an same-direction two-lane highway, which allows the evaluation and characterization of both single and multiple presence statistics. Three case of multiple presence are considered: following, side-by-side and staggered cases. The consideration of truck multiple presence on concrete bridges is mandatory to understand and characterize live load models. The results show that with the exception of the side-by-side case, the frequency of multiple truck presence is significantly affected by span length. It also shows that the daily truck volume considerably affects the multiple presence statistics for all load patterns. The results show that the general tendency of the occurrence of all multiple presence events is to increase as the truck volume increases.

Keywords: bridges, live load, multiple presenca, statistics.

Resumo

A modelagem do tráfego em pontes tem sido objeto de inúmeros estudos. Definir um modelo de carga móvel a ser usada no projeto de uma ponte não é uma tarefa fácil. Isto demanda entre outras coisas uma base de dados confiável, uma abordagem para filtragem de dados bem definida e também a determinação de estatísticas de ocorrências de caminhões isolados e em presença de outros caminhões (múltiplas presenças). Este estudo examina e caracteriza estatísticas destas ocorrências para pontes de concreto brasileiras. As ocorrências de caminhões isolados e em múltiplas presenças são avaliadas para diferentes comprimentos de vãos e volume diário de caminhões. A amostra utilizada neste trabalho consiste de 13 meses de dados de uma estação de pesagem em movimento na rodovia Fernão Dias (BR-381). O sistema capta onze mil veículos por dia. Depois de um processo de filtragem três mil caminhões restam para analise. O equipamento realiza suas medidas em um via com duas faixass na mesma direção no sentido Belo Horizonte – São Paulo. Três casos de múltiplas presenças são analisados um caminhão seguindo o outro, dois caminhões lada a lado e dois caminhões lado a lado com defasagem. A consideração de caminhões em múltiplas presenças é mandatória no entendimento e caracterização de um modelo de carga móvel. Os resultados mostram que com exceção de ocorrências lado a lado a frequência de ocorrências de múltiplas presenças de caminhões são bastante afetadas pelo comprimento de vão da ponte considerado. Os resultados também mostra que com o aumento do volume diário de caminhões as ocorrências de múltiplas presenças também crescem.

Palavras-chave: pontes, carga móvel, múltiplas presencas, estatísticas.

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[a] *Polytechnic School, Department of Structural and Geotechnical Engineering, University of São Paulo, São Paulo, Brazil;*
[b] *Department. of Civil and Environmental Engineering, Rutgers, The State University. of New Jersey, Piscataway, NJ, USA.*

Received: 11 Jan 2017 • Accepted: 27 May 2017 • Available Online: 11 Dec 2017

1. Introduction

In Brazil, as in many other countries, roadway traffic has been characterized by the diversity of truck configurations as the considerable increase in *GVW* (Gross Vehicle Weight) and volume. Therefore, it is recommended to carry out studies that aim to ensure the structural safety of roadway bridges in the presence of current traffic since they were not designed for current loads. Therefore, it is justifiable any concern about the impact that overloading causes to concrete bridges, which can boost the development of procedures to calibrate the current codes based on actual traffic and not just from approximations and simplifications of the live loads.

Much work has been done on modeling live loads due to traffic. Among those, special attention should be given to Nowak [1] in which he uses normal probability paper technique to extrapolate traffic load effect for 75 years. There is also the work presented by Gindy and Nassif [2] in which they performed a statistical analysis to determine the truck load spectra for bridges in New Jersey. They used data from 25 weigh-in-motion sites from 1993 to 2003. In Europe, the analysis performed by O'Brien and Enright [3] and Sivakumar et al. [4] also used Weigh-In-Motion (WIM) data in order to modeling bridge loading. In the former they used data from 2 sites (Czech Republic and Netherlands) to model same-direction two-lane traffic for live loads on bridges. In the latter, they used WIM data to show the effects of non-stationary traffic data on maximum traffic load effects.

In Brazil, there is no tradition in using WIM data to characterize bridge live load, especially works about the occurrence of multiple trucks presence. The majority of Brazilian states have no WIM station operating. Most of the research on this field is related to data from stationary scales (truck weigh stations) installed along a couple of highways that belong to concessionaries. However, there is a reasonable concern that the heaviest trucks will avoid the scales, which ultimately can bias the data to less heavy vehicles. Also, Brazil has faced in 2016 its worst economy recession and since the country transports its goods mostly through highway it might be the case that the data is also biased due to an decreased of truck traffic. In Brazil, the work done by Ferreira [5], Luchi [6] and Rossigali [7] are the most relevant ones. They all used data from Brazilian roadways to evaluate the design traffic load model of the Brazilian code and compared it with international codes. None of the data were collected form WIM stations, therefore some assumptions about the axle spacing, classes of trucks and multiple presence of trucks needed to be made.

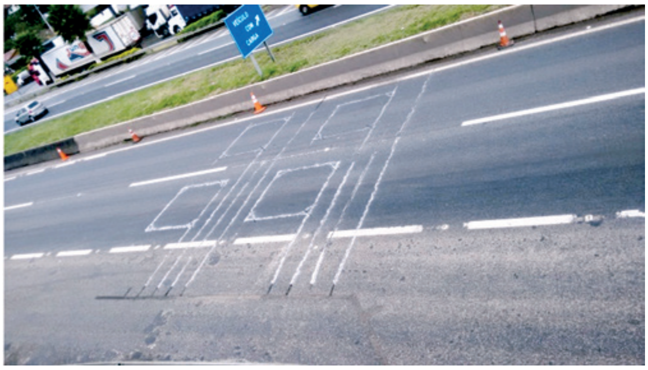

Figure 1
Final sensors layout

This study is based on WIM data collected at one station on the Fernão Dias highway (Minas Gerais to São Paulo) same-direction two adjacent lanes and recorded for over 13 months, from September 2015 to September 2016. The WIM station provided an average of 11000 records per day, which after the filtering process were reduced to 3000 trucks per day. A statistical approach is presented in order to characterize the live load for Brazilian bridges, specifically multiple truck presence. For each vehicle, several parameters are recorded, such as GVW, speed, lane, number of axles, axles weights and time of passage. Statistics for a variety of truck loading cases, including single, following, side-by-side, and staggered are shown. The effects of bridge span length and the daily volume of truck are also examined. This study focused on a range of span lengths that extending from 6.1 meters to 91.4 meters. Therefore, this work explores both cases short and long bridge spans.

2. WIM data

The data used as the basis for this study were collected at one site in the city of Extrema - south of the state of Minas Gerais in Brazil for thirteen months. As aforementioned the station is located on the highway Fernão Dias (BR-381). For each of the two lanes, the HS-WIM system is comprised of two lines of piezoelectric sensors, two inductive loops (Figure 1), temperature sensor and a device for collecting and analyzing the records. The piezoelectric sensor is 2.73 meters long and 1.27 centimeters wide. The inductive loops detect the vehicles, measure the distance between axles and the vehicle speed. This HS-WIM allows the acquisition raw generic data, which ultimately allows the management of the records as the user wishes.

One advantage of the HS-WIM used in this study is the fact that this system is inconspicuous in the sense that the truck driver does not notice the system, which obviously avoids evasion from the station. In this way one can believe that the system response is not biased. The installation of the monitoring system and the data collection is in accordance with the recommendations of ASTM E1318 [8], which deals with the guidelines of the development movement in weighing projects.

2.1 Filtering process

Even though the WIM technology is well developed, this kind of system is still susceptible to record incoherent measurements, for example, the system can interpret two trucks in the same lane as one or a single truck with long distance between two adjacent axles may be recorded as two vehicles, also, the dynamic weight can be registered beyond a physical limit. In any of these cases, the data should be filtered before performing any kind of analysis once it can generate misinterpretation of the weighing process, which ultimately would affect the characterization of traffic loads. Records that were removed from the original sample were counted and placed into a disqualification file.

The filters are developed based on Brazilian fleet and on engineering judgment. After a deep research on the most important

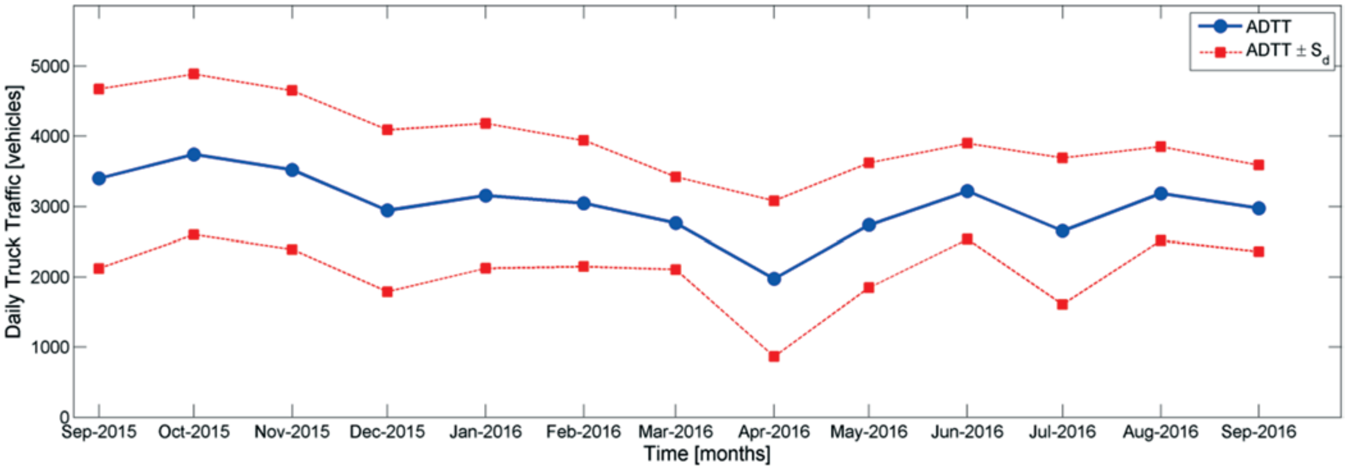

Figure 2
Evolution of ADTT over time

kind of trucks currently in use in Brazil, and on the automakers catalog the following criteria were established in order to define a filtering process:

1 – GVW less than 6.2 tf;
2 – Single axle weight less than 2.2 tf
3 – Tandem weight greater than 32 tf;
4 – Tandem axle spacing less than 0.92 meter;
5 – Total length greater than 36 meters;
6 – Truck length greater than 15.4 meters and GVW less than 10.4 tf;
7 – Any single axle weight greater than 18 tf;
8 – Difference of the GVW and sum of axle weights equal or greater than 10%;
9 – Sum of axle spacing different from total length of the truck;
10 – Total length less than 5 meters;
11 – Speed greater than 170km/h;
12 – Steering axle weight greater than 10 tf;
13 – GVW greater than 93 tf.

The next sections show the results of the statistical analysis after filtering the entire sample.

2.2 Traffic characterization based on WIM data

Traffic characterization is an important step when one is trying to know the composition of trucks in a given place. With information about the trucks weights, geometry, speed and etc it is possible to

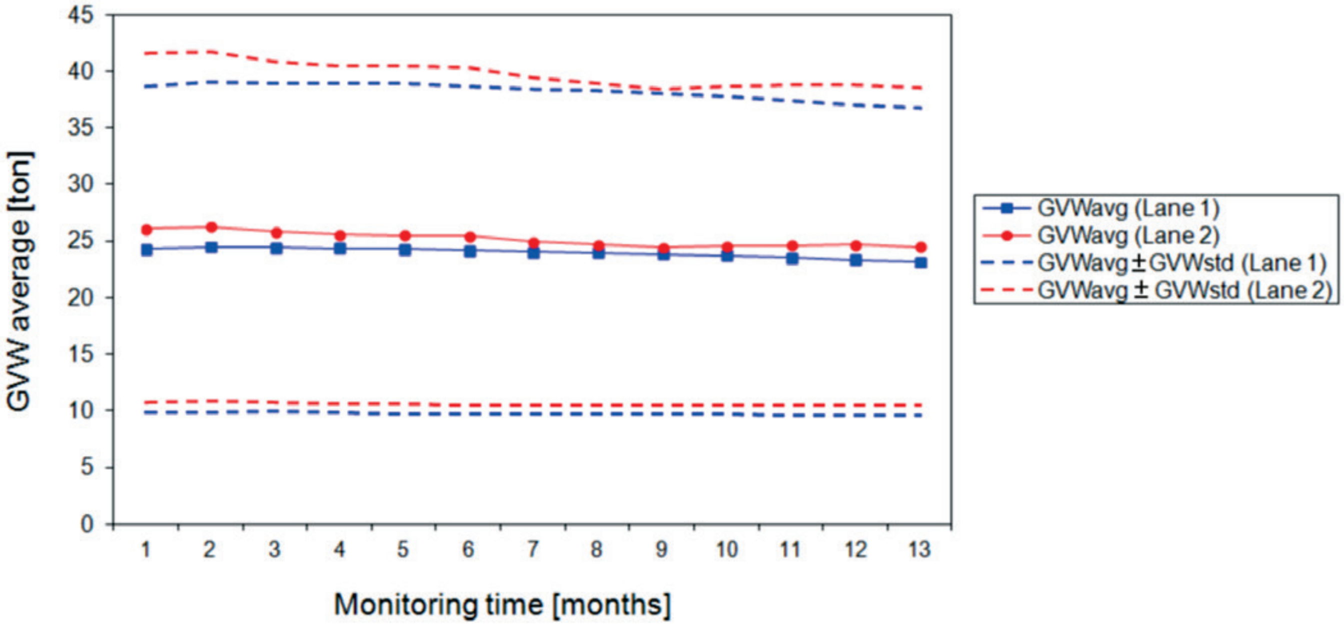

Figure 3
Variation of GVW mean over time (09/01/2015 - 09/30/2016)

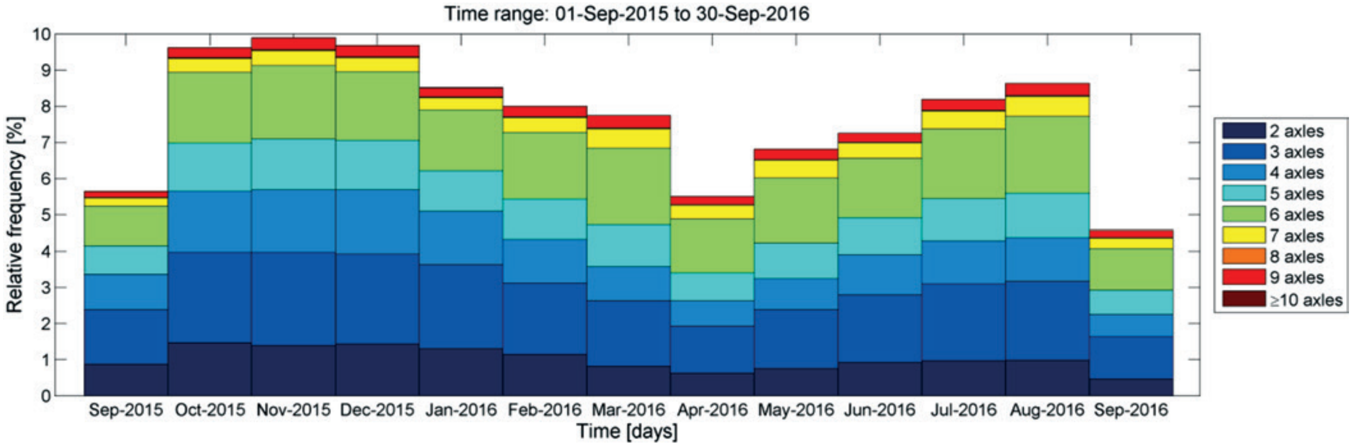

Figure 4
Traffic composition accordingly to the number of axles

evaluate the load effect that a concrete bridge will be subject to. In order to obtain a detailed overview of the characteristics of the traffic, a survey was conducted to collect statistical parameters necessary for the definition of a live load model. Among these parameters we can highlight: Average Daily Traffic Truck (ADTT) in both situations total and per traffic lane, GVW, average speed, truck configurations and weight distributions of the most common trucks. Figure 2 shows the ADTT statistics for each month between 09-01-2015 to 09-30-2016 considering the entire truck population. S_d denotes the ADTT standard deviation for each month. It is important to mention that all the results presented here is based only on the truck sample that remains after the filtering process as presented in the previous section. The results show that the ADTT varies from 1972 to 3743 trucks with coefficient of variation between 21% and 56%, approximately. Figure 3 shows the evolution of the GVW mean (GVW_{avg}) over time – the mean is cumulative over the months. It also shows the curves that represent the mean value minus/plus the standard deviation. It is noted that the values of GVW_{avg} stabilize with only one month of monitoring, indicating that the sample is representative of the traffic even for a few months of monitoring.

From the analysis of the WIM data is also possible to see that the left lane – overtaking lane – has approximately 16% of the truck traffic while the right lane holds the remaining 84%. The left lane has the greater mean value of speed – 85 km/h – while the mean speed value in the right lane is around 78 km/h. Figure 4 depicts the trucks distribution when clustered according to their axle numbers. The results show that trucks with only three axles are the most common ones. This cluster also includes the trucks with one axle and one tandem; which represent 24% of the heavy traffic. Another important cluster is the one for 6-axle trucks (semi-trailer with 1 single axle + a tandem axle + a tridem axle). They represent 17% of the heavy traffic.

Figure 5 depicts the GVW distribution for the two clusters with the

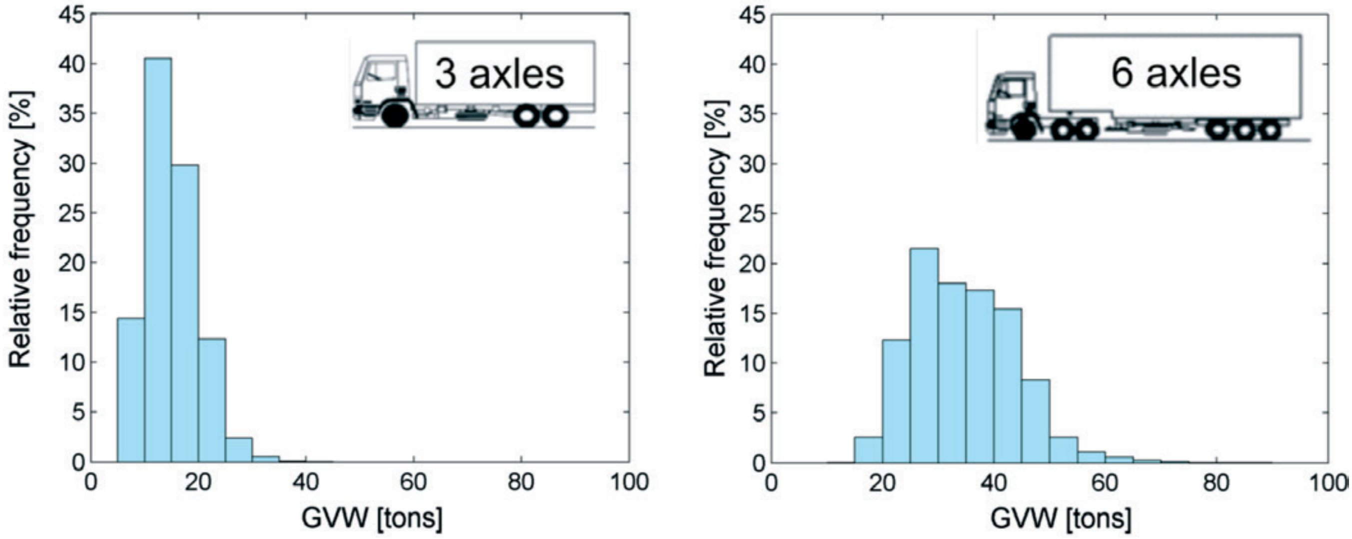

Figure 5
GVW distribution for the dominant clusters

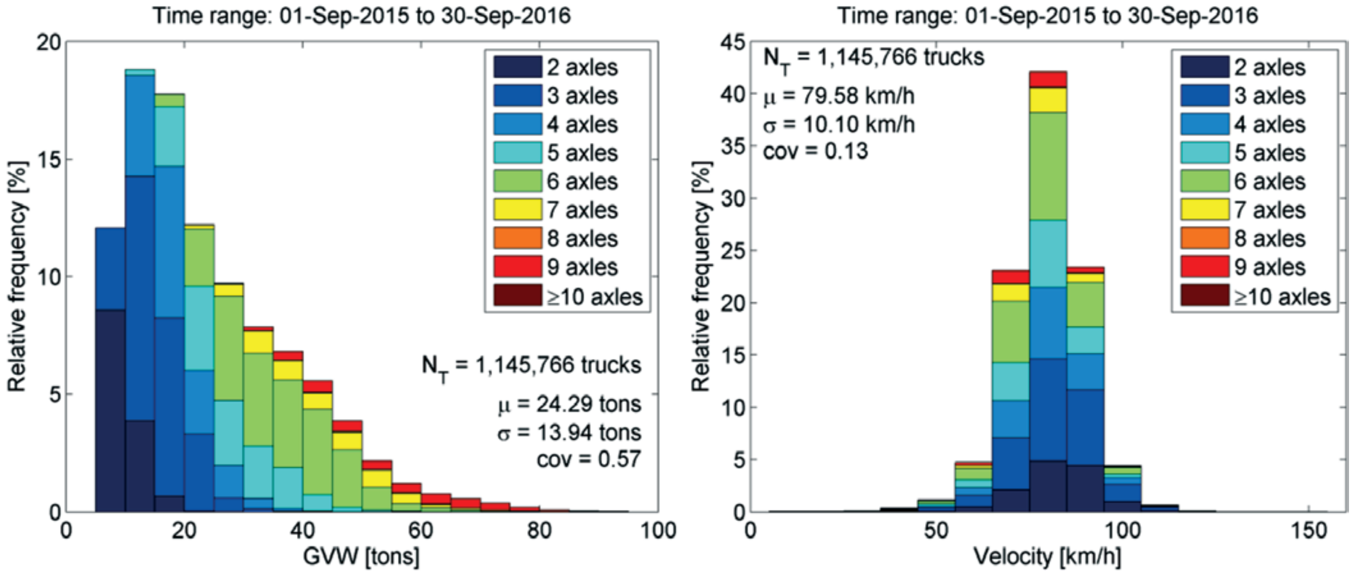

Figure 6
GVW and speed statistics for different trucks clusters base on axle number

highest frequencies. One can see that both distributions are unimodal, which is a characteristic of the interstate traffic, with long distance routes. It is important to mention that the histogram shape of the trucks weights of the dominant clusters provides an indication of the highway function as stated in Davis [9]. In general, routes of smaller distances, located near ports and distribution centers, tend to present a combination of light and heavy vehicles, which generates bi-modal histograms within the ruling cluster. Such behavior tends to be smoothed on interstate routes as a consequence of logistical and economic issues.

Figure 6 depicts the *GVW* and truck speed statistics considering the sample of traffic monitored between Sep-2015 and Sep-2016. A total of 1,145,766 trucks were considered for the analysis performed in this work. In Figure 6, the terms μ, σ, cov and N_T correspond, respectively, to the mean, standard deviation, coefficient of variation and number of qualified vehicles calculated for each of the variables.

3. Multipresence analysis

The consideration of truck multiple presence on concrete bridges is mandatory to understand and characterize live load models since its occurrence directly affects future extrapolation of live load effects as well as code calibration. According to Nowak [10], when dealing with multiple presence there are two main factors to consider: the frequency and the *GVW* of occurrences on the bridge. The frequency is related to the probability of two trucks over the

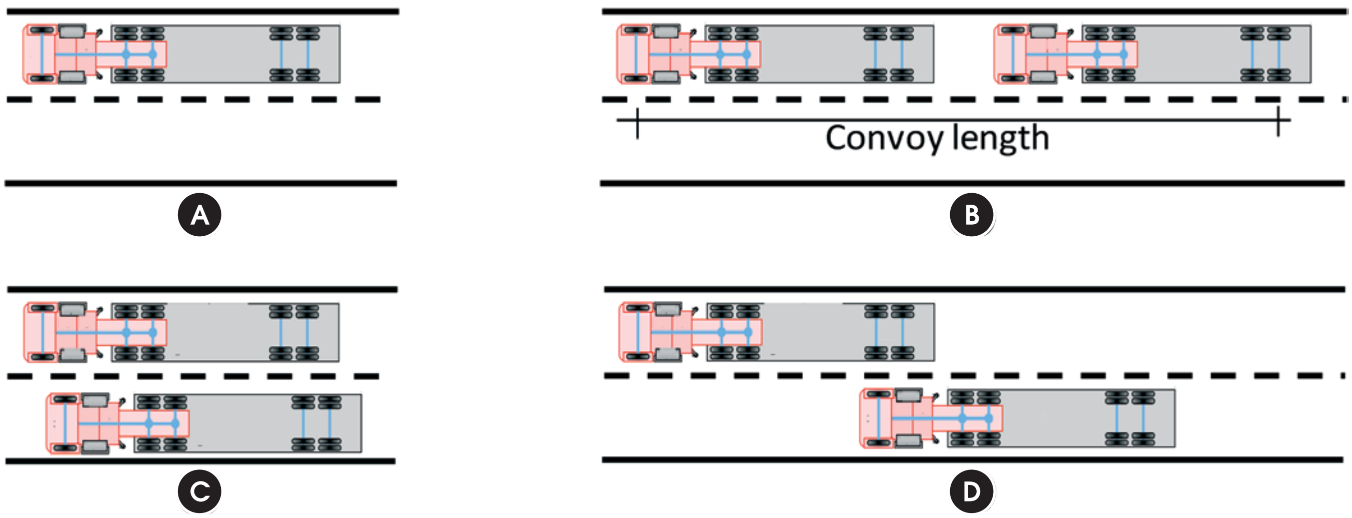

Figure 7
Traffic loading patterns – Gindy and Nassif [2]

bridge at the same time while the GVW is related to the load effect this kind of occurrence will have on the concrete structure. The frequency of the "heavy-heavy" multiple presence event has influence on the maximum expected load effect during the service life of a concrete bridge. Both factors will ultimately affect the extrapolation of live load effects.

Multiple presence statistics are reported only for qualified trucks, i.e. and the remaining trucks after the filtering process. Therefore, this analysis excludes all passenger vehicles, light trucks and erroneous records. The simultaneously occurrence of trucks on a bridge can occur in many different disposals. In this paper, a very similar arrangement (Figure 7) as in Gindy and Nassif [2] will be considered. In this case, four patterns are considered:

(a) Single event: only one truck is on the bridge;

(b) Following: Two trucks in the same lane with the distance from the first axle of the first truck to the rear axle of the second truck less than a bridge span;

(c) Side-by-side: two trucks in adjacent lanes with a overlap of at least half the body length of the first truck and with the distance from the first axle of the first truck to the rear axle of the second truck less than bridge span;

(d) Staggered: two trucks in adjacent lanes with a overlap of less than half the body length of the first truck and with the distance from the first axle of the first truck to the rear axle of the second truck less than a bridge span;

The multiple presence statistics for each case: following, side-by-side and staggered are needed to quantify the trucks superposition in a given concrete bridge. The computation of those statistics is based on a definition of a range of fictitious span lengths. This allows studying multiple presence for long, medium and short bridges. The span lengths comes into consideration when specifying an upper bound for the event criteria, for example, two trucks that are in the same lane such that the distance from the first axle of the leading truck to the rear axle of the second truck is 42 meters, they would be considered as a following occurrence on a fictitious span length of 50 meters. However, the same two trucks would not be qualified as following on a 35 meters span length once both trucks would not fit on the bridge span. The percentage of each occurrence is computed as the number of occurrence divided by the total number of qualified trucks on the bridges.

One important aspect of this computation is the accuracy of the WIM system. In order to have a reliable modeling process the system must be capable of recording the trucks with a resolution of 0.01 second. This accuracy is necessary because trucks can travel at high speeds, for example, a truck at a speed of 50 km/h will travels about 13.9 meters in one second. If the truck position is known each 0.01 second this means that truck position is known each 13.9 centimeters, which is very acceptable value to define multiple presence occurrences. Thus, only three pieces of information are

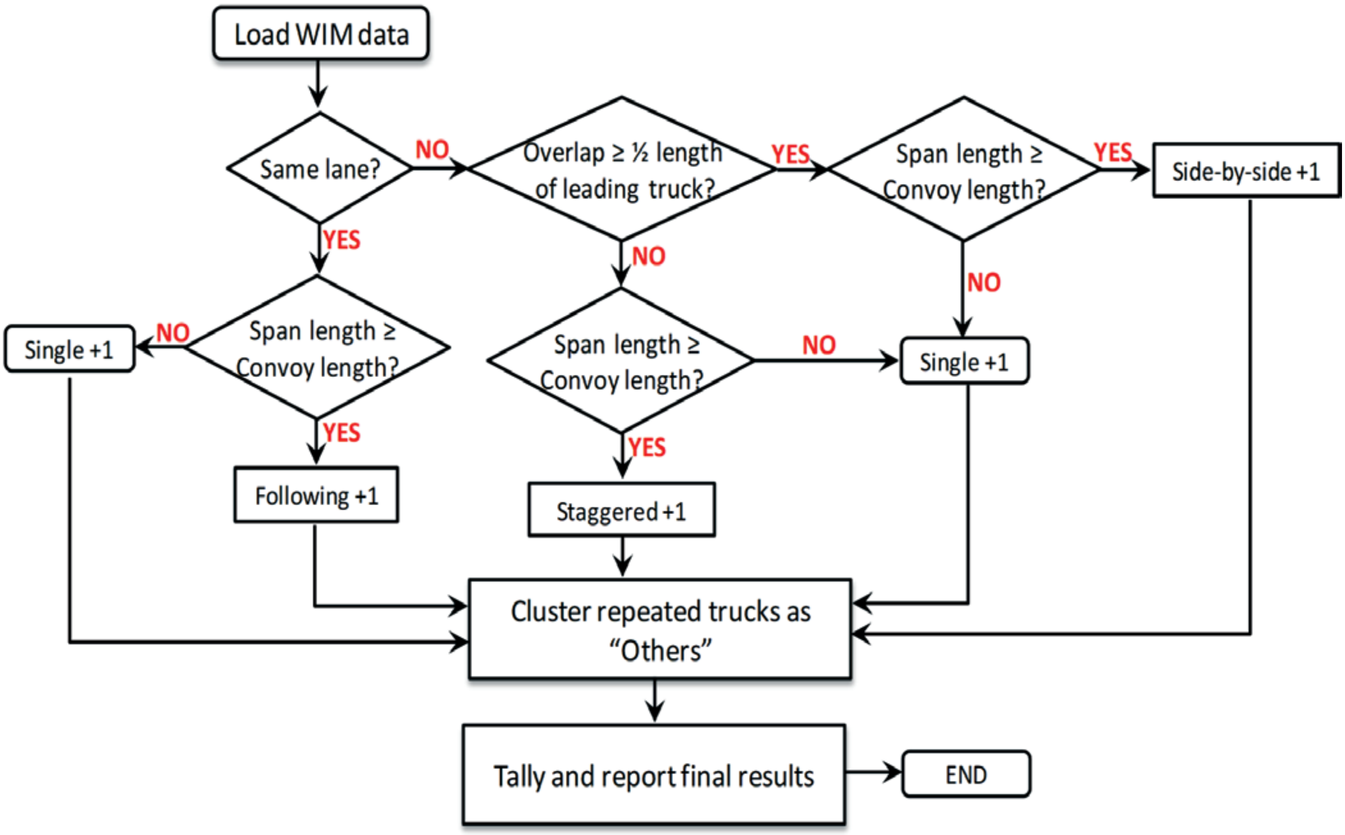

Figure 8
Flowchart of multiple presence algorithm

needed to compute the relative position of trucks to each other:

i) The travel lane;
ii) Truck speed;
iii) Time truck goes over the sensor (resolution of 0.01 sec).

Additional information such as GVW and truck length is used to refine the qualifications for each type of multiple presence occurrences.

3.1 Algorithm for calculating the multiple presence on concrete bridges

As the WIM system provides information about vehicle speed, travel lane and also a time stamp with an accuracy of one hundredth of a second, it is possible to construct computational routines to perform the multiple presence analysis for different span lengths of concrete bridges. With the input data, each truck is compared with the twenty next ones. This is important because by definition multiple presence only consider the event of two truck simultaneously over a concrete bridge. The case of three or more trucks together is not the subject of this paper not only because their occurrences are very rare, but also because the data used in this paper only accounts for two lanes.

Figure 8 show the flowchart structure of the multiple presence routine used in this paper. The routine checks each possible case of multiple presence. Then it eliminates trucks that are qualified for more than one case. Initially, for the following event, the algorithm first checks whether the trucks are in the same lane, then, it checks if the distance from the first axle of the leading truck to the rear axle of the second truck is smaller than the current span length in analysis, this ensures that in fact the vehicles fit in the fictitious bridge span. If these two criteria are satisfied, then the event is classified as following.

For the side-by-side event, first the program checks if the trucks are in different lanes. Then, it checks if the second truck has a overlap of at least half the body length of the first truck as in Figure 7c. Finally, the algorithm checks if the length from the first axle of the first truck until the last axle of the second truck is less than the length defined by the span of the bridge. If all these criteria are met, then sum up a case of side-by-side. Finally, for the staggered case, the procedure is almost the same as for side-by-side. The only difference is that the trucks overlap is less than half the body length of the first truck.

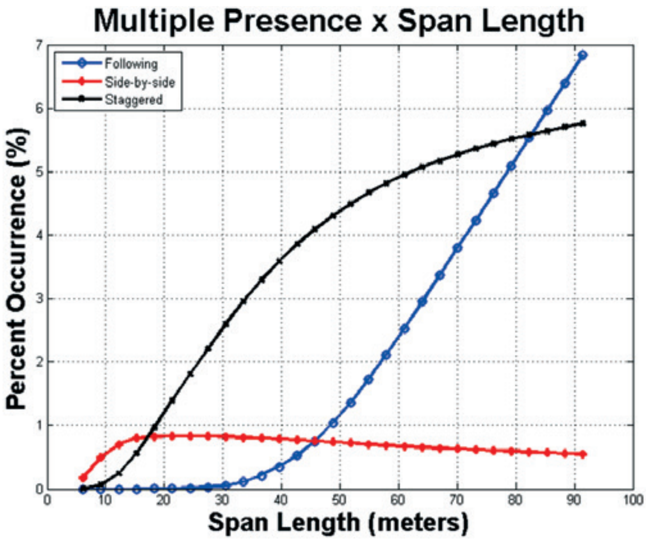

Figure 9
Multiple presence X Span length

4. Results and discussions

The entire qualified truck sample is simulated over a bridge span lengths ranging from 6.1 meters to 91.4 meters by using recorded time stamp (accuracy of 0.01 second), vehicle speed (assumed as constant), truck length and travel lane. The multiple presence statistics for the patterns of loading as in Figure 7 are computed through the algorithm described in Figure 8. The main results are shown through Figure 9 to Figure 13.

Figure 9 depicts the change of multiple presence statistics in relation to bridge span length. With the exception of the side-by-side case, the frequency of multiple truck presence is significantly affected by span length. The increase of bridge span lengths gives more opportunities for trucks to occur simultaneously. From the statistics point of view, this could be exemplified as a classical Poisson model of trucks arrivals in which the number of arrivals would be proportional to span length. However, for side-by-side loading pattern, when the span length is already above 30 meters, increasing the bridge span will slightly decrease the frequency of

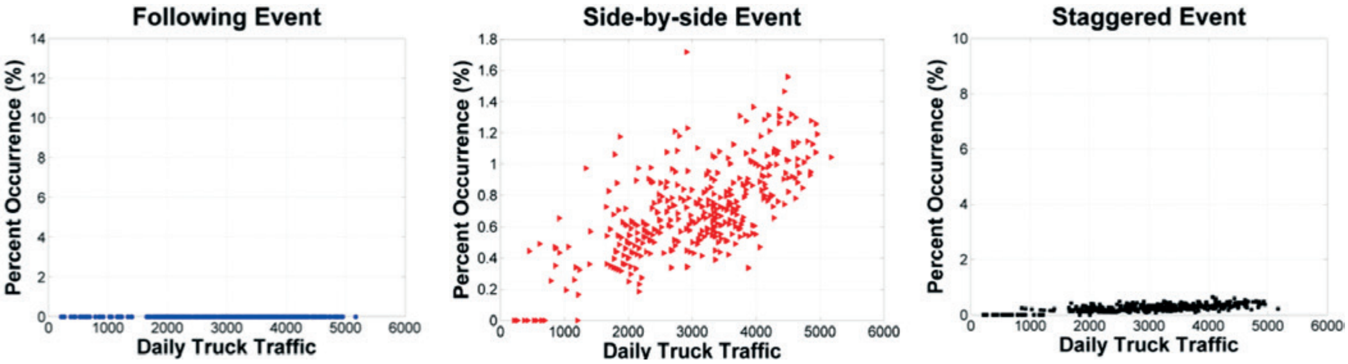

Figure 10
Variation of multiple presence for truck volumes (12.2-m span)

occurrence. This happens because a side-by-side event is by definition the overlap of exactly two trucks by at least one-half the body length of the first truck and if, for example, two trucks are said to be a side-by-side event for a span length of 40 m, these same trucks could be declassified if more vehicles enter the bridge at largest values of spans length. The frequency of side-by-side events has an average value of 0.70% for all bridge spans and volume conditions, which is in accordance with the results presented by Gindy and Nassif [2] and Davis [9].

Figure 9 also shows that the rate of increase in the frequency of following loading events is lower for bridge spans up to 30 meters as compared with longer spans. This is mainly due to the fact that bridges with spans of less than 30 meters commonly will not accommodate two trucks in the same lane once the most common truck is the six-axle semi-trailer with a body length of around 15 meters. The results also show that the occurrence of following events keeps increasing as the bridge spans increase. This is mainly due to the fact that as the span increases the opportunity

Figure 11
Variation of multiple presence for truck volumes (36.6-m span)

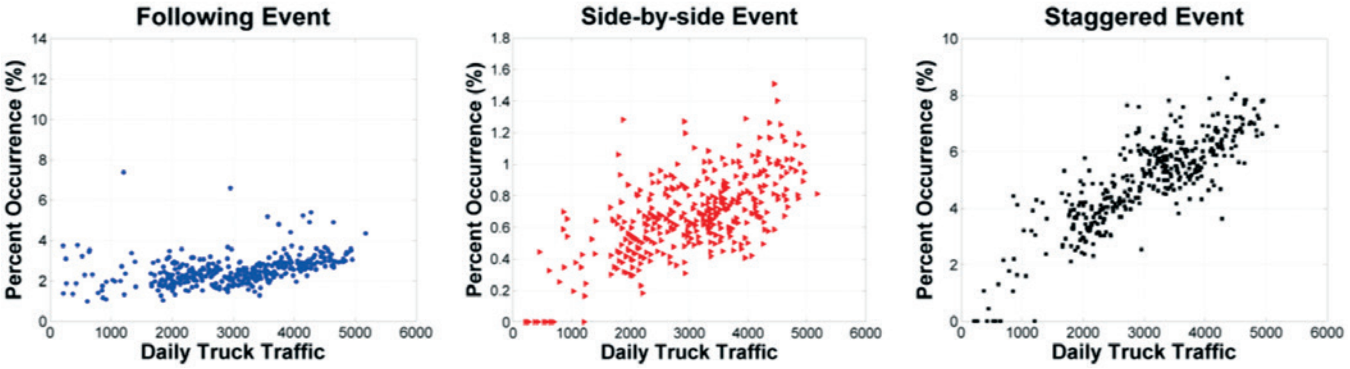

Figure 12
Variation of multiple presence for truck volumes (61-m span)

Figure 13
Variation of multiple presence for truck volumes (85.3-m span)

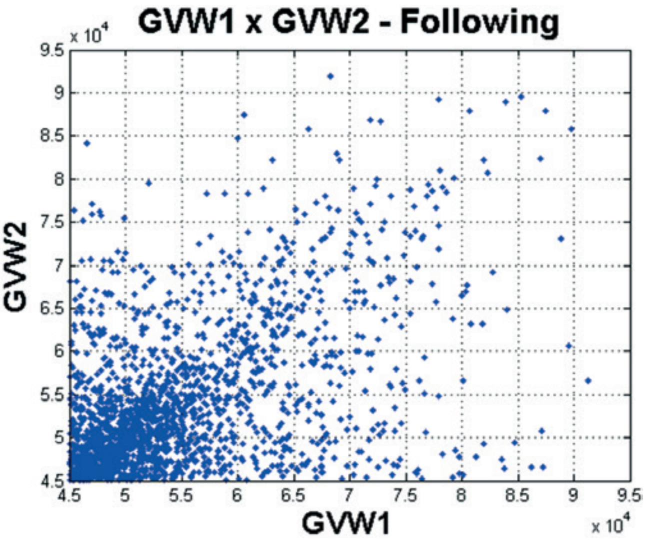

Figure 14
Relation of GVW 1 and GVW 2 in kg for following event – only heavy trucks

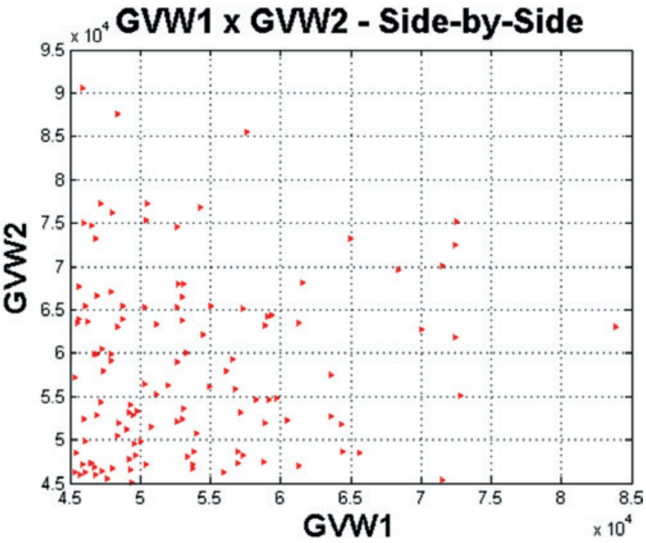

Figure 15
Relation of GVW 1 and GVW 2 in kg for side-by-side event- only heavy trucks

for following loading pattern to happens also increases. In the case of staggered events the frequency of occurrence also increases as the span lengths increases. But on the contrary of what happen to following case, the percent occurrence of staggered trucks grows at a faster rate for shorter bridge spans and at a steadier pace for longer spans - above 45 meters.

As can be seen in Figure 10 to 13 truck volume considerably impacts the multiple presence statistics for all load patterns. The results show that the general tendency of the occurrence of all multiple presence events is to increase as the truck volume increases. This is a reflection of the fact that a truck will more likely be accompanied on a given bridge span as the number of trucks increases. It is also observed that the frequency of staggered occurrences increases at a higher rate than for following or side-by-side loading patterns, Figure 13 illustrates it.

Since the frequency of multiple trucks presence can greatly influence the extrapolation of loading effects on bridges, it is important to know the distribution of the sample as the spans increase. Figure 10 to Figure 13 show that, in general, as the span increases the measurements tends to disperse. In the case of side-by-side event the change in the dispersal is very small while for following and staggered occurrences the change is quite noticeable. This also has relation with the fact that increasing bridge spans also gives more opportunities for trucks to occur simultaneously with more diversified trucks combinations.

Another important aspect of developing a live load model is to know the correlation between the total truck weights for multiple presence occurrences. These relations are depicted in Figure 14, Figure 15 and Figure 16 for each of the three types of multiple presence events and span length of 85.3 meters (280ft). Also, the lower bound for *GVW* is defined as 45000 kg which corresponds to the truck recommended in the Brazilian code NBR 7188 (ABNT [11]). For the following case, the *GVW1* corresponds to the leading truck weight and *GVW2* corresponds to the second truck. For the other two cases *GVW1* is the weight of the truck on the left lane and *GVW2* is the weight of the truck on the right lane. Although an unassuming 45-degress zone can be noted in Figure 14 there are no very strong correlations between the *GVW*s in both lanes. For the staggered and side-by-side cases the correlations are very small. This is in accordance with Brazilian traffic regulation for federal highways, which allows heavy trucks in any lane of the road.

Table 1 shows the correlations between *GVW*s for heavy trucks – above 45 tons – that have been classified as an occurrence of multiple presence for several span lengths. In general, the correlations are very small. For the span length 12.2 and 36.6 meters there are no enough occurrences that allow drawing any reliable conclu-

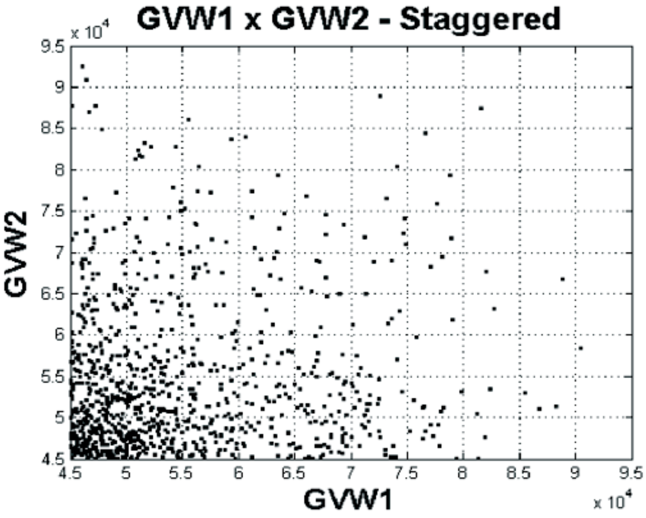

Figure 16
Relation of GVW 1 and GVW 2 in kg for staggered event – only heavy trucks

Table 1
Correlation between GVWs for each case of multiple presence

Span length (m)	Correlation of GVW 1 and GVW 2		
	Following	Side-by-side	Staggered
12,2	None	-0,12	None
36,6	None	0,051	0,011
61	0,472	0,055	0,071
85,3	0,477	0,078	0,090

sions. For the span length 36.6 meters only two occurrences were registered for this span length. For span lengths 61 and 85.3 meters the stronger correlation between heavy trucks when they are classified as following is probably due to the fact that drivers from the same company tend to form a convoy when traveling together.
When developing a live load model for concrete bridges, the occurrence of heavy trucks over the bridge is a very important aspect that needs to be considered. Figure 17 shows the probability of two heavy trucks occurring together if they are classified as a multiple presence case. The probabilities are shown for each case of multiple presence and for a range of span lengths that stands from 6 meters to around 91 meters. For the side-by-side case one can see that above the span length of 20 meters the probabilities are basically the same. The results behave almost as a horizontal line close to the 1.6 %. The same behavior can be noted for the staggered events after the span length of 40 meters. In this case, most probabilities are around 1.4%. For the following cases the probabilities stay close to zero up to span lengths of 35 meters and then it starts to climb up. This is strictly related to the results of Figure 9 in which following cases only start happening for span lengths larger than 35 meters.
Finally, the probability of two heavy trucks occurring together in relation to the total truck traffic can be computed by multiplying the results from Figure 17 and Figure 9, in this work, heavy trucks are the ones weighing over 45 tons which correspond to the typical truck that the Brazilian code recommends. As one can see from Figure 18 the general behavior of the lines for each case of multiple presence are strongly attached to the ones in Figure 9. This is due to the fact that the occurrences of multiple presence events dictate the possibility of occurrence of heavy trucks together. Figure 18 shows that the probabilities for two side-by-side heavy trucks are always below 0.02%. This means that for a highway with an ADTT of 5000 trucks, only one event of two heavy trucks would occur for this case of multiple presence in any given day. The highest probability occurs for following event at span length of 91.4 meters. The probability value of 0.185 % implies that for a highway with an ADTT of 5000 trucks it is expected at least 9 occurrences of two heavy trucks following each other in any given day. Knowing these probabilities allows to computed and extrapolate the load effects that those trucks have over a given bridge which ultimately allows not only to evaluate the live load model proposed by the current code but also to develop a new model.

5. Conclusions

Concrete bridges are considerably affected by trucks loads, their frequency of occurrence, and their geometric features and also by their *GVW* in both situations single and multiple presence events. Data collected from a *WIM* station at Fernão Dias highway in Brazil from September 2016 to September 2017 were used to determine both single and multiple presence statistics for various loading patterns. The station provided a daily average of 11000 records, which after the filtering process end up with 3000 trucks per day.
Prior to multiple presence analysis, traffic characteristics were surveyed in order to detect the main types of trucks and statistically investigate important parameters for the definition of a representative live load model for concrete bridges. It was shown that trucks of 3 and 6 axles are the most common one and combined they

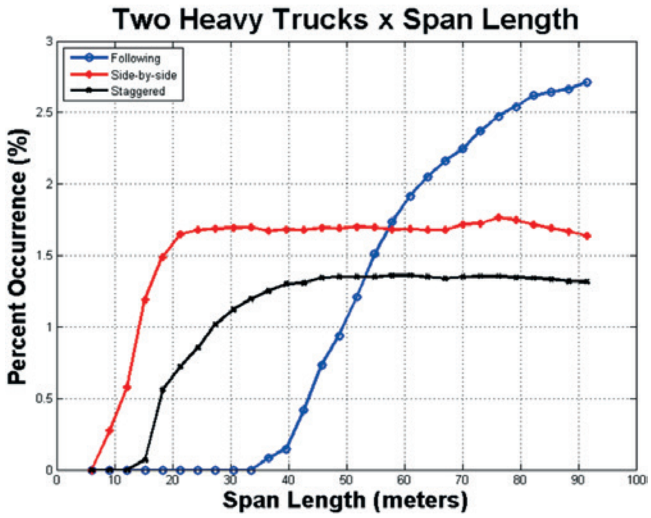

Figure 17
Probability of two heavy trucks occurrence for each case of multiple presence

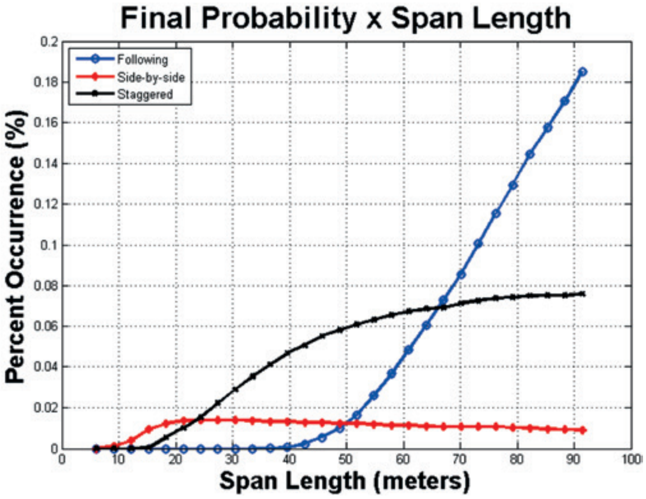

Figure 18
Probability of two heavy trucks occurrence in relation to total truck traffic

represent 41% of total valid records. The results also showed that the GVW statistics stabilize in a relatively short monitoring time – about a month.

Bridge span lengths raging from 6.1 to 91.4 meters were considered on this study for statistical evaluation of single and multiple presence occurrences. In general, multiple presence events are notably affected by the bridge span length, with the exception of side-by-side case in which the effects are almost insensitive to variations of span length. As a matter of fact, side-by-side occurrence will slightly decrease as the spans increase. This happens because more trucks will have the opportunity to fit the larger span, i.e., increasing bridge spans will increase the probability of more than two trucks to occur simultaneously. The results also show that the percentage occurrence of side-by-side stays steadily in 1% until span length of 50 meters and then starts to slowly decrease.

On the other hand, both staggered and following event have a considerable change in their percentage of occurrence. In the staggered loading event the rate of increase becomes lower for bridges with spans up to 40 meters while for following is the opposite. For bridges with span larger than 80 meters the percentage occurrence of following event will overcome the staggered values. The results presented in this paper are consistent with the ones presented in Gindy and Nassif [2].

Finally, when designing a live load model for concrete bridges it is important to know the probability of multiple presence of heavy trucks. It is important to remind that heavy truck in this work means trucks that weight more than 45 tons. The results regarding to the occurrence of two heavy trucks in adjacent lanes shows that the probabilities of a side-by-side events are very small, less than 0.02% for any given span length. It also shows that this value does not change according to the span length as for following event in which the maximum probability for two heavy trucks was 0.185%.

6. Acknowledgements

The authors gratefully acknowledge the support of Arteris S.A and CNPq.

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