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Project Report

Truck Axle Weights and Interaxle Spacings from Traffic Surveys in Mexican Highways

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Abstract

In structural and bridge engineering, the axle weights and interaxle spacings of heavy trucks are useful for assessing the capacity of existing bridges, developing live load models, and other issues. Weigh-in-motion data have become the most common source for recording axle weights and interaxle spacings; however, information is not as direct and may not be as precise as that from static surveys. Surveying vehicles by stopping them beside the highway is not common nowadays; nevertheless, surveys provide very reliable information on truck axle weights and interaxle spacing. In this study, data from three surveys on two Mexican highways recorded in 2016 and 2018 are provided. The data contain the gross vehicular weights, axle weights, and interaxle spacings of heavy trucks. The discussion is given as to how the provided information can be useful for the bridge and transportation engineering community and for reliability and code calibration tasks for Mexican bridges and a future design code for bridges in Mexico City. It is concluded that statistical values are consistent with WIM data, with differences due to different methods used, recording time, samples size and others, and that trucks heavier than the legal weight circulate in Mexican highways; static surveys are useful to strongly support this important issue. Further research to compare samples from different surveying techniques, as well as the use of the information to investigate load effects on bridges, is recommended.

Keywords: vehicle weights; loading; surveys; interaxle spacing; bridges; vehicular models; bridge design; reliability; code calibration

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1. Introduction

The weights and dimensions of heavy trucks are useful for engineering purposes. They can be used to investigate which gross vehicular weights (GVW) existent bridges are subjected to, or to compute the load effects that existent or future bridges should withstand; such load effects depend on a complex combination of axles weights and spacings, the position of the truck over the bridge, the bridge type, etc. They can also be used for extreme value projections of load effects, a reliability analysis of bridges under vehicular loads, and code calibration tasks.

Recently, most of the information on traffic weights and dimensions has been collected through weigh-in-motion (WIM) recording systems [1–5]; broadly speaking, WIM data are recorded using sensors over the highway, whose signals are transformed into the required information with the aid of software (so it is not as direct as survey information). WIM systems have been also proposed for public roadways [6]. Another variant of WIM is bridge-WIM (BWIM), in which sensors are directly located in a bridge, either for vehicular or railway bridges [7–10].

The use of WIM data is very common, in contrast to traffic surveys. However, static surveys provide more direct information that can be used to calibrate the WIM information recorded on the same highway, since they are reliable and can be used as a benchmark [11]. These traffic surveys are challenging. Nevertheless, they could still be useful, as discussed in the present study. They may also be useful for other purposes, e.g., information on freight, driving practices, aging and other truck characteristics, dimensions, etc. This project report could be useful for planning and logistics considerations. Moreover, more than one source of information could be desirable for improving the assessment of bridge reliability, for instance combining WIM data with inventory information [12].

Traffic surveys were conducted in Mexico for two highways in 2016 and another in 2018. They were part of a research project that included WIM recordings and were linked to another project for extracting concrete cores, all aimed at computing the reliability of vehicular bridges in Guanajuato (Central Mexico). Current research projects are still using this information to develop live load models for bridge design in Mexico and Mexico City. The traffic dataset can provide valuable information for engineers and possibly other experts in transportation and other fields.

The main objective of the present study is to describe the surveys conducted during 2016 and 2018 in Mexico and to provide all the information to researchers and practitioners, including some statistics, a comparison of statistics versus WIM data, and discussions. It is also pointed out that this article is part of a larger ongoing project to compute the structural reliability of Mexican highway bridges, carry out code calibration tasks, and to propose live load models for bridge design in Mexico and Mexico City [13–16].

A description of the criteria to select the highways, surveying days, and time is provided. Equipment and logistics are also described. The results are reproduced in several tables from an open platform for data storage and publishing, where information can be retrieved through a DOI, referred to as "associated DOI" thereafter [17]. These tables are described; some basic statistics are computed and compared with WIM data and with nominal trucks used by designers and discussions are included.

2. Project Description and Selection Criteria

The project was financially supported by SECIHTI (Acronym in Spanish for the Ministry of Science, Humanities, Technology, and Innovation of Mexico; formerly CONACYT) to obtain information on traffic demands for bridges in Guanajuato, Mexico, which, together with other projects to obtain information on the capacity of real bridges located there, were intended to obtain information on the reliability of highway bridges, e.g., [18]. Regarding demand, the selection of one of the highways was mainly based on the fact that previous WIM information was available for such highways, and some studies related to this information were carried out [19,20]. Therefore, the new information was considered a follow-up to investigate how much the traffic varied in about 10 years, and it was also considered convenient to have a previous reference relating to the traffic population and its characteristics (so that a larger database for the same highway could be compiled). The project included the surveys reported in this study and

WIM recordings for the highway (which could be published as data articles in the future). Other criteria were based on the days and time in which relevant information could be obtained (based on previous data); more details can be found in [21]. However, the final decision on the selected highways, date and time, number of recordings, etc., was significantly influenced by project compliance, the available budget, logistics, the suppliers' schedule, permissions of the Mexican Ministry of Infrastructure, Transportation and Communications (SICT, by its acronym in Spanish; formerly SCT), and coordination with the Federal Police, among many other partakers, paperwork, and other issues. It was quite a challenging task to coordinate all the participants, to get all the permissions, and to get all set to finally carry out the project successfully.

The surveys were carried out for an 8 h period on two highways in Guanajuato state, namely, the four-lane Irapuato-Zapotlanejo (2016 and 2018) and the two-lane Guanajuato-Los Infantes (only in 2016). The survey sites are shown in Figure 1. It is acknowledged that the time period and specific locations of the surveys limit the use of the data to developing live load models; however, it could still be employed as a benchmark [11], to correlate the information with WIM data on the same highways, because of the fact that it contains evidence of overloaded trucks (discussed later), even if the period is short and only a few locations were included. Moreover, this evidence is true, even if extraordinary events (unknown to us) like traffic accidents, strikes, and weather conditions occurred.

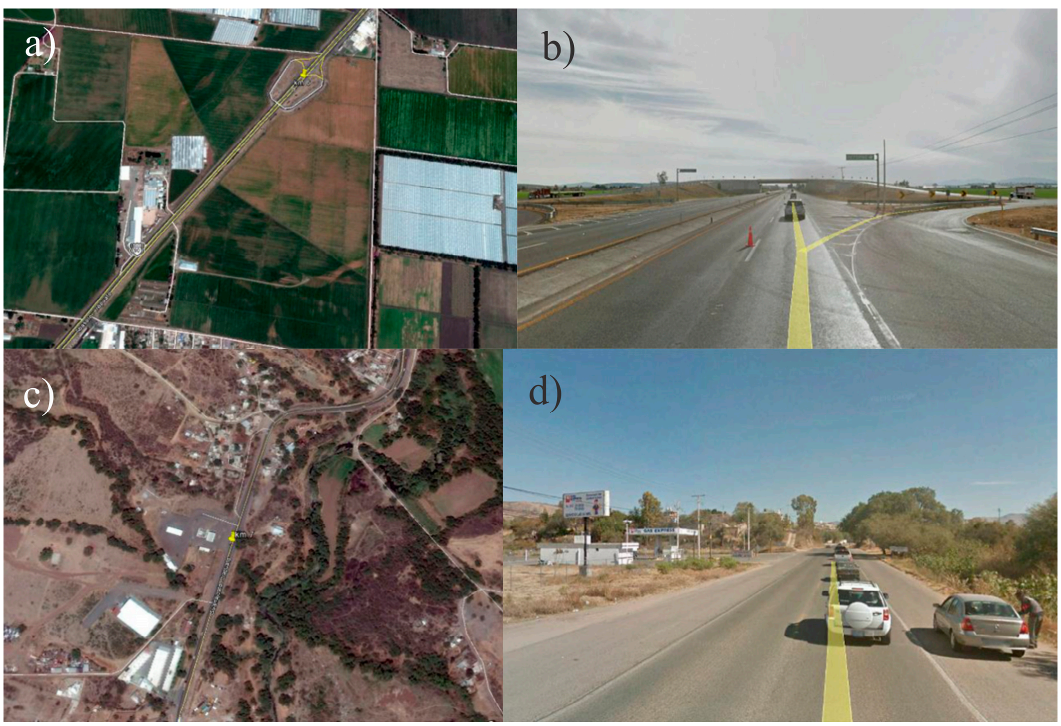

Figure 1. Surveying sites. (**Top**) Irapuato-Zapotlanejo highway, (**a**) plan view and (**b**) profile. (**Bottom**) Guanajuato-Los Infantes highway, (**c**) plan view and (**d**) profile. Through Google Maps.

In the following, the description focuses on the surveys carried out by the Mexican Institute of Transportation (IMT, by its acronym in Spanish), which we hired with the project budget. The University of Guanajuato (UG) crew were present throughout the survey process.

3. Logistics, Equipment, and Survey Procedure

3.1. Survey in 2016

The first survey was conducted on 13 September 2016, from 11 a.m. to 7 p.m. (local time) on the Irapuato-Zapotlanejo (designated as MEX 90, type A4) highway approximately at km 7 + 000 (i.e., at km number 7 with zero extra m; this format applies to other cases below). This is a two-way, four-lane highway that allows heavy traffic [22]. The location was chosen based on a previous inspection by IMT; the decision was also based on space, visibility, pavement conditions, and for security reasons, among others.

The equipment was a portable PAT scale, model DAW 300 PC, NS 291 [22], with a calibration certificate IC-IP-039/14 issued in October 2014. The equipment weighs loads, statically or dynamically (for low speeds), by means of two platforms, axle by axle. According to the manufacturer the precision is around 3%; nevertheless, the IMT reports that from their laboratory calibration and adjustments [22], they obtain deviation no larger than ± 50 kg by axle with a resolution of 10 kg. Traffic devices for signaling were used as aids in the surveys. Figure 2 shows images of the equipment (e.g., platforms, software, and other devices).

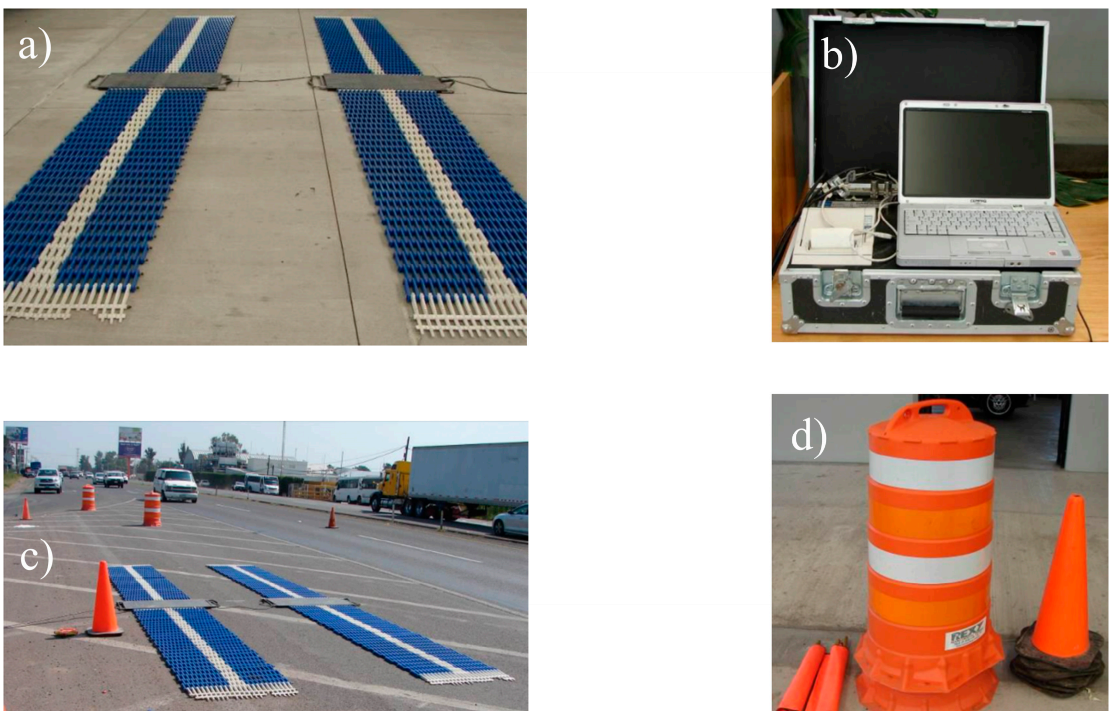

Figure 2. Surveying equipment. (**a**) Portable PAT, (**b**) Recording hardware, (**c**) PAT in site, (**d**) Signaling devices. Pictures are either by the authors and/or by the IMT reports hired by UG, e.g., [22].

To carry out the survey, equipment was installed beside the highway in one of the traffic directions (Irapuato-Abasolo direction). Originally, it was planned to carry out the survey in both directions with the aid of the Federal Police; however, the attempt was unsuccessful because aid was not obtained in time. Therefore, it was decided to ask heavy truck drivers at a nearby gas station to help us by allowing the IMT crew to weigh their vehicles. This resulted in only 19 vehicle axle weights being recorded. The total weights along with the axle weights are listed in Table 1 in the DOI associated with this data [17]; they are also reproduced, described, and discussed later. Unfortunately, for the 2016 surveys, the axle spacings were not measured; nonetheless, IMT provided typical axle spacing for each truck designation in Table 1 based on different sources [22], as shown in

Table 2 given later (see also the associated DOI [17]), and spacings were designed by axle number to axle number (from the front part to the rear part of the trucks). Figure 3 illustrates the execution of the survey.

The second survey was conducted on 5 October 2016, on the Guanajuato-Los Infantes (designated as MEX-110-GTO, type C) highway at km. 6 + 000. This is a two-way, two-lane highway where heavy traffic is not allowed [22]. In this case, the equipment was installed from 11 a.m. to 4:30 p.m. (local time) in the direction of Guanajuato and from 5 p.m. to 7 p.m. (local time) in the opposite direction. Due to weather conditions, the survey was interrupted from 2 p.m. to 3 p.m. (local time). The survey equipment description is identical to that given above. As in the previous survey, no information on axle spacing was recorded; typical spacings in Table 2 (discussed later) are also applicable to trucks on this highway. Unlike the previous survey, in this case, assistance from the Federal Police was obtained through a policeman in a police car, who pulled over cars for weighing. This significantly affected the number of recorded vehicles (considering that the heavy traffic volume of this highway is much smaller), leading to a total of 49 vehicles: 39 in the first direction (reported in Table 3 in the associated DOI [17] and discussed later) and 10 in the other direction (reported in Table 4 in the associated DOI [17] and also discussed later). The fact that very heavy trucks are not allowed on this highway is reflected in the vehicle designations listed in Tables 3 and 4 in Section 4.

Table 1. Weights [kN] obtained at Irapuato-Zapotlanejo highway in 2016.

Truck Designation	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	Axle 8	Axle 9	GVW
C2	34.32	41.38	-	-	-	-	-	-	-	75.71
C2	36.77	126.80	-	-	-	-	-	-	-	163.57
C3	34.81	121.01	118.66	-	-	-	-	-	-	274.49
C2R2	30.30	47.07	17.16	8.73	-	-	-	-	-	103.26
T3S2	32.56	26.87	16.57	20.30	22.16	-	-	-	-	118.46
T3S2	40.70	34.62	34.03	18.04	23.63	-	-	-	-	151.02
T3S2	44.62	38.74	32.56	21.08	30.89	-	-	-	-	167.89
T3S2	41.58	38.15	35.79	27.46	29.52	-	-	-	-	172.50
T3S2	41.78	31.97	39.81	29.13	32.17	-	-	-	-	174.85
T3S2	44.91	44.13	43.54	36.19	35.60	-	-	-	-	204.37
T3S2	41.09	69.73	64.04	32.46	29.71	-	-	-	-	237.03
T3S2	44.33	42.95	59.04	73.35	74.92	-	-	-	-	294.59
T3S2	51.39	79.14	70.90	64.14	67.08	-	-	-	-	332.64
T3S2	37.95	89.14	88.75	56.88	78.65	-	-	-	-	351.37
T3S3	41.58	31.19	31.68	14.42	21.48	21.97	-	-	-	162.30
T3S2R4	50.11	42.56	40.99	33.93	33.54	35.60	31.19	31.97	32.46	332.35
T3S2R4	46.09	55.31	52.96	50.99	47.56	40.50	40.01	49.62	40.40	423.45
T3S2R4	43.84	82.96	56.19	59.53	78.55	57.66	59.43	92.08	78.75	608.99

Table 2. Typical interaxle spacings [m] for truck configurations in the study.

Truck Designation	1 to 2	1 to 3	1 to 4	1 to 5	1 to 6	1 to 7	1 to 8	1 to 9
C2 light	3.40							
C2	4.64							
C3	4.68	6.03						
T3S2	4.70	6.04	14.65	15.92				
T3S3	4.23	5.53	15.73	16.97	18.22			
T3S2R4	4.56	5.92	13.38	14.59	17.55	18.84	26.60	27.81

Note: “1 to 2” denotes the column with distance between axle 1 and 2, “1 to 3” between axle 1 and 3, etc.

Table 3. Weights [kN] obtained at Guanajuato-Los Infantes highway in 2016 (direction to Guanajuato).

Truck Designation	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	GVW
PICKUP 3 1/2	13.93	18.53	-	-	-	32.46
PICKUP 3 1/2	21.57	32.26	-	-	-	53.84
PICKUP 3 1/2	16.38	48.25	-	-	-	64.63
PICKUP 3 1/2 with two-axle towing	12.36	30.89	32.36	5.30	-	80.90
C2	15.98	17.06	-	-	-	33.05
C2	21.48	21.77	-	-	-	43.25
C2	22.46	22.16	-	-	-	44.62
C2	19.71	25.01	-	-	-	44.72
C2	27.07	24.81	-	-	-	51.88
C2	28.15	33.73	-	-	-	61.88
C2	26.28	41.48	-	-	-	67.76
C2	30.69	39.13	-	-	-	69.82
C2	28.83	42.76	-	-	-	71.59
C2	22.75	50.80	-	-	-	73.55
C2	44.82	31.77	-	-	-	76.59
C2	33.34	45.11	-	-	-	78.45
C2	43.44	59.62	-	-	-	103.07
C2	43.64	65.61	-	-	-	109.25
C2	33.24	79.24	-	-	-	112.48
C2	33.54	84.24	-	-	-	117.78
C2	41.38	76.69	-	-	-	118.07
C2	38.74	83.85	-	-	-	122.58
C2	37.36	96.30	-	-	-	133.66
C2	38.05	101.79	-	-	-	139.84
C2	39.32	108.85	-	-	-	148.18
C2	40.11	109.93	-	-	-	150.04
C2	35.89	119.54	-	-	-	155.44
C2	44.52	111.40	-	-	-	155.93
C2	42.56	113.86	-	-	-	156.42
C2	49.62	109.25	-	-	-	158.87
C2	51.68	128.96	-	-	-	180.64
C3	44.62	32.75	31.28	-	-	108.66
C3	42.36	34.03	32.36	-	-	108.76
C3	46.29	34.52	33.64	-	-	114.44
C3	44.42	36.48	33.93	-	-	114.84
C3	45.90	37.07	35.50	-	-	118.46
C3	47.37	46.68	37.46	-	-	131.51
C3	73.75	71.88	69.14	-	-	214.77
C3	66.39	83.45	77.57	-	-	227.42
T3S2	45.52	37.87	25.51	21.39	22.56	152.84

Table 4. Weights [kN] obtained at Guanajuato-Los Infantes highway in 2016 (direction to Los Infantes).

Truck Designation	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	GVW
C2	16.38	15.98	-	-	-	32.36
C2	26.58	29.62	-	-	-	56.19
C2	26.38	32.75	-	-	-	59.13
C2	25.11	46.29	-	-	-	71.39
C2	36.77	47.56	-	-	-	84.34
C2	40.40	46.09	-	-	-	86.49
C2	41.38	53.35	-	-	-	94.73

C2	42.56	56.88	-	-	-	99.44
C3	35.40	26.09	29.91	-	-	91.40
T3S2	41.38	39.62	39.13	31.09	45.21	196.43

Figure 3. Implementation and execution of surveys. (**a**) Placement of portable PAT. (**b**–**g**) Some measured trucks. Pictures are either by the authors and/or by the IMT reports hired by UG [22,23].

It is interesting to note that during the surveys, engineers and researchers noticed details not captured in the traffic reports (e.g., data from WIM). For instance, a vehicle with an axle spacing of less than 1 m (normally disregarded in data filtering) was observed, although it was a very light vehicle. In Tables 1, 3, and 4, (discussed in Section 4) several vehicles with no freight were recorded, as can be inferred from the 2018 survey and WIM data.

3.2. Survey in 2018

The third survey took place on 23 February 2018, from 5 a.m. to 1 p.m. (local time), once more on the Irapuato-Zapotlanejo highway in the same place; it was decided to carry out the survey again at this site and in the same direction because very heavy trucks circulate on it, according to WIM data, as well as to facilitate logistics. The equipment used was the same, except that the calibration certificate number was IC-IP-073/17, issued on 28 August 2017 [23]. This time, help from the Federal Police was successfully obtained, which substantially impacted on the number of recorded trucks. In addition, unlike the survey in 2016, the axle spacings were measured, and the authors focused on the heaviest configurations, or those the authors knew were critical for load effects on bridges [19,20]. Another important change with respect to the 2016 survey was the time schedule; the authors decided to carry out the work very early in the morning, since we noticed from the WIM data available to us that heavy trucks on this highway circulate during this time window. The GVW, axle weights, and interaxle spacing for this survey are listed in Tables 5 and 6, respectively, for the associated DOI [17] and discussed in Section 4.

Table 5. Weights [kN] obtained at Irapuato-Zapotlanejo highway in 2018.

Truck Designation	Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	Axle 7	Axle 8	Axle 9	GVW
C2	40.21	57.57								97.77
T3S2	43.44	40.99	39.81	40.31	39.72					204.17
C3	51.78	127.78	128.27							307.83
T3S2	42.17	32.95	30.99	20.99	24.61					151.81
T2S2	38.74	57.76	40.80	39.03						176.23
T3S2	46.58	100.13	101.99	98.75	100.22					447.67
C3	68.45	136.80	128.66							333.92
C3	35.30	44.72	35.70							115.62
T3S3	46.39	107.87	102.38	84.44	87.67	82.57				511.32
T3S2R4	52.37	106.30	102.77	82.38	86.89	30.60	27.16	54.33	37.85	580.65
T3S2R4	49.43	56.68	53.74	48.15	53.94	45.80	46.58	51.29	48.15	453.75
C3	74.63	134.35	130.23							339.21
C3	65.70	141.02	131.90							338.62
T3S2R4	51.48	88.85	86.59	100.42	94.73	80.12	75.22	97.48	94.34	769.14
C3	45.90	88.06	76.00							209.96
T3S2	41.97	33.05	30.20	24.91	25.20					155.44
T3S2R4	51.39	91.10	90.03	84.53	81.49	81.49	70.61	81.69	80.51	712.85
T3S2R4 [a]	46.29	29.81	27.85		72.86		34.72		59.13	270.66
T3S2R4	48.74	85.02	81.59	88.85	85.42	78.26	72.37	81.49	87.48	709.31
T3S2R4	44.42	44.82	41.48	38.83	42.07	40.40	32.95	37.07	32.95	354.90
T3S2R4	47.56	34.91	32.07	26.87	26.28	28.83	24.42	25.40	25.79	272.23
T3S2R4	46.78	33.05	30.50	19.12	25.11	18.73	15.10	20.50	19.81	228.59
T3S2R4	51.39	87.48	82.67	94.83	94.24	67.08	62.27	89.34	92.28	721.57
T3S2	50.70	35.79	33.34	23.14	22.95					165.83
T3S3	49.82	95.22	86.00	107.68	110.62	102.19				551.62
C3	56.19	133.17	130.62							319.99
C3	63.35	112.78	124.54							300.77
T3S2R4	50.01	46.19	42.46	25.20	25.79	70.41	17.55	31.58	30.99	340.00
T3S2R4	47.37	55.11	53.15	85.12	77.37	52.56	48.94	71.69	81.49	572.81
T3S2R4	50.21	36.77	32.56	27.56	20.10	22.95	15.59	18.24	22.56	246.54
T3S2R4	48.25	55.41	55.80	83.55	78.94	44.72	46.39	82.87	84.44	580.46
T3S2R4	52.17	113.86	109.15	83.45	81.20	83.55	85.22	79.92	80.71	769.04
C3	64.14	144.45	118.66							327.25
T3S2R4	47.37	30.01	28.15	21.87	20.89	22.95	19.71	20.69	19.71	231.34
C3R2	62.96	89.53	86.79	69.82	68.84					378.05
C3R2	56.78	90.22	84.53	76.00	73.94					381.48
T3S2R4	52.76	91.59	89.24	96.30	97.09	91.79	70.31	105.23	103.56	797.97
C3	74.73	136.31	134.84							345.88
T3S2	54.43	48.15	43.74	31.97	31.58					209.86
T3S2R4	46.29	29.42	26.28	20.99	21.38	20.01	15.10	20.99	25.50	226.04
T3S2R4	53.84	66.98	64.23	36.28	34.62	32.46	28.05	28.73	27.16	372.46
T3S2R4	44.62	47.66	42.95	42.27	39.32	31.97	26.87	28.34	28.54	332.54

[a] This truck had axles 4, 6, and 8 uplifted.

Table 6. Measured interaxle spacings [m] for truck configurations in Table 5.

Configuration	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9
C2	7.2							
T3S2	4.55	1.8	10.6	1.25				
C3	5.75	1.4						
T3S2	4.68	1.4	8.52	1.2				

T2S2	4.52	10.7	1.24					
T3S2	4.56	1.3	8.31	1.31				
C3	5.35	1.23						
C3	5.06	1.28						
T3S3	5.62	1.36	6.63	1.3	1.3			
T3S2R4	4.57	1.3	8.19	1.27	2.54	1.21	4.05	1.27
T3S2R4	4.85	1.34	8.16	1.22	2.46	1.26	8.89	1.24
C3	4.79	1.36						
C3	5.18	1.33						
T3S2R4	4.79	1.34	5.22	1.29	2.7	1.28	5.52	1.32
C3	5.01	1.28						
T3S2	3.58	1.34	9.7	1.27				
T3S2R4	4.49	1.3	8.01	1.26	2.79	1.27	8.13	1.24
T3S2R4 [a]	4.34	1.35	5.78	1.24	2.59	1.25	5.37	1.66
T3S2R4	4.65	1.37	6.51	1.25	2.71	1.27	6.66	1.23
T3S2R4	4.48	1.3	7.97	1.25	2.79	1.25	8.61	1.25
T3S2R4	4.52	1.3	7.45	1.26	2.61	1.31	7.55	1.25
T3S2R4	5.24	1.32	8.76	1.23	2.32	1.31	4.05	1.28
T3S2R4	4.59	1.31	5.5	1.29	2.7	1.29	5.61	1.28
T3S2	4.47	1.38	10.29	1.18				
T3S3	5.32	1.29	3.95	1.28	1.24			
C3	3.97	1.39						
C3	5.68	1.31						
T3S2R4	4.98	1.32	8.33	1.23	2.14	1.46	8.42	1.28
T3S2R4	5.33	1.29	4.01	1.23	2.23	1.07	4.25	1.25
T3S2R4	4.08	1.36	8.68	1.24	2.38	1.25	4.16	1.25
T3S2R4	4.42	1.29	3.69	1.28	2.54	1.29	3.8	1.26
T3S2R4	4.56	1.39	7.95	1.26	2.92	1.68	6.22	1.29
C3	4.66	1.32						
T3S2R4	4.3	1.41	6.59	1.27	2.88	1.24	6.79	1.28
C3S2-mad	7.8	1.35	13.45	1.3				
C3S2-mad	7.67	1.29	12.92	1.25				
T3S2R4	4.42	1.37	7.86	1.35	2.96	1.3	7.98	1.28
C3	4.95	1.32						
T3S2	5.42	1.42	8.18	1.26				
T3S2R4	5.82	1.33	4.13	1.24	2.18	1.32	8.07	1.23
T3S2R4	4.47	1.28	7.37	1.24	2.99	1.25	6.58	1.29
T3S2R4	3.55	1.31	7.49	1.27	2.52	1.27	7.64	1.28

Note: "1 to 2" denotes the column with interaxle spacing between axle 1 and 2, "2 to 3" between axle 2 and 3, etc. [a] This truck had axles 4, 6, and 8 uplifted.

One important aspect that is observed in the values in Table 5 is that many trucks are well over the legal weight in Mexico [24] for GVWs. The maximum allowed GVW for Mexico depends on the type of highway and truck configuration and its physical conditions; however, it normally should not exceed approximately 650 kN [24]. This aspect is important, since it proves that the overweight reported in WIM data is not due to calibration or recording problems, but that non-legal weights are actually circulating on Mexican highways; some of the GVWs in Table 5 are well over the legal weight mentioned above. This it to be disused in more detail in Section 4. It demonstrates the importance of static surveys as a support for WIM data. It is noteworthy to mention that overloads are critical not only for bridges but also for the pavement's lifespan [25]. The information contained in this study could also be useful for pavement researchers.

In addition, it was noticed in the field that several 3-axle trucks, denoted as C3 in the tables given later in this study (see also Table A1 in Appendix A and the associated DOI [17], where all truck designations used in this study are listed and depicted), were loaded with construction material (e.g., sand), well over the trucks' own height, and were deemed overloaded by simply looking (e.g., Figure 4). This was confirmed when the final report was submitted, as will be observed in Table 5 later, where several C3 trucks with GVWs of approximately 350 kN are listed; the maximum allowed GVW for this truck and highway should not be normally over approximately 270 kN [24]. Moreover, from Tables 5 and 6 listed in the next section (Section 4), it can also be noticed that the surveyed C3 trucks represent approximately a tandem load (the last two axles) of two 140 kN axle loads separated by an axle spacing of 1.3 m; which can be compared with that for bridge design in the AASHTO standards (e.g., [26] and previous versions), which is defined by two 111 kN loads with a 1.2 m spacing. Trucks with less than six axles (such as C3 trucks and others) could generate load effects on short-span bridges (e.g., 6–10 m spans) that are larger than those generated by 6- to 9-axle vehicles (whose GVWs are much larger) normally considered by bridge engineers for design [8,9] (see also Figure 5 in Section 4). This information is deemed relevant for the structural engineering field, and the data reported in this study can be used as a reference for these cases. Interested readers can use the trucks listed to compute load effects in any kind of bridge they could be interested in. These surveys also corroborate the reliability of WIM data.

As mentioned previously, this type of surveying task can be important for practitioners and researchers because details, normally unnoticed by those dealing simply with the data, emerge here; for instance, it is possible to have a notion of freight content, physical state of vehicles, etc. One interesting (and unexpected) issue that emerged during this survey is that the policeman cancelled the survey in the transition between darkness and daylight (the dawn transition), because visibility conditions in that period pose a high risk.

The next Section describes in more detail the information obtained in both surveys for 2016 and 2018, as well as some basic statistics, comparison versus WIM data and discussions. Although most information in the tables is for heavy trucks, some light vehicles were also recorded on the two-lane highway.

Figure 4. C3 truck loaded with construction material. Pictures are either by the authors and/or by the IMT reports hired by UG [22,23].

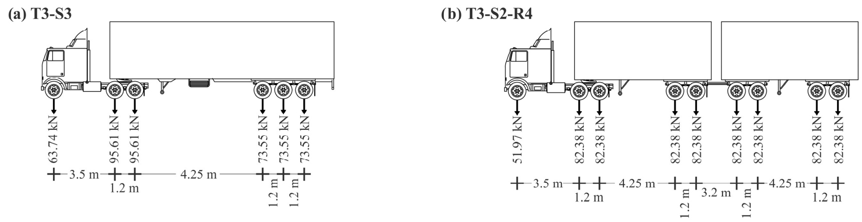

Figure 5. Nominal (**a**) T3S3 and, (**b**) T3S2R4 trucks that have been used by designers in Mexico.

4. Data and Some Statistics, Comparisons and Discussion

All information on the weights and spacings described in the previous sections can be retrieved together in the associated DOI [17]. Tables 1–4 in the associated DOI [17] correspond to the 2016 survey. Tables 5 and 6 in the associated DOI [17] correspond to the 2018 survey. In the following, these tables are reproduced from [17]; descriptions and discussions including some statistics are given. The basic statistics are mainly focused on a few representative cases. Some broad comparisons versus WIM data and nominal trucks used by designers are included. Although not exhaustive, this section shows that the data is consistent with previous information, that the static traffic surveys could be relevant in the bridge engineering field and that important percentages of overloaded trucks still occur on Mexican highways.

4.1. Discussion for the surveys in 2016

In Table 1 the vehicles surveyed, in terms of GVW and axle weights, are listed. The first and last columns in Table 1 correspond to the truck designation and the GVW, respectively, while the columns in the middle correspond, from left to right, to the axle weights from front to rear in increasing order, respectively. To exhaustively compare data in Table 1 versus WIM data is out of the scope of the present article, some broad comparisons can be mentioned though. For instance, if the 5-axle vehicles in Table 1 are considered (10 samples for T3S2), an average GVW of 220.47 kN and a sample standard deviation of 80.36 kN are obtained. Although the sample is very small, it is consistent with WIM data for the same highway recorded in 2009 and 2017, leading to sample sizes of 322,680 and 11,782 vehicles, respectively, an average of GVW of 178.36 kN and 362.09 kN, respectively, and standard deviation of GVW of 94.86 kN and 63.17 kN, respectively [16]. The smaller average value and larger variability for the 2009 WIM data could be attributed to a much longer (continuous even at nighttime) recording period, including possible seasonal effects and many more unloaded vehicles, while for the 2017 WIM data, recording heavier vehicles was deliberately pursued [21].

The fact that the much smaller sample of this study, but through direct static measurements on field, is within the limits of the WIM databases, could support and give confidence in the use of the WIM data for code calibration tasks, law enforcement, or other aspects. It is noted that for this truck designation (T3-S2 in Table 1), no truck was over the legal allowed weight of 456 kN for this considered highway [24]. This is expected, since the police help was not obtained and truck drivers were directly asked to be measured, as stated before. The previous discussion indicates that the traffic surveys are consistent with WIM data and can be useful, but also that a formal statistical comparison would deserve future research, since the available information corresponds to samples of different sizes and types, different recording periods under different recording strategies, and is affected by different vicissitudes. For instance, for the 2016 surveys, length and interaxle distances were not measured, but the IMT provided typical distances for recorded vehicles based on their databases. These are listed in Table 2 for the truck designation in the first column; the distances are presented in a cumulative manner, i.e., the second column lists the distance between the first and the second axles, the third column lists the distance between the first and the third axles (not between the second and the third) and so on. For example, if the typical interaxle distance for the last tandem in a truck designation T3S2R4 is of interest, the distance "1 to 8" in Table 2 can be subtracted from the distance "1 to 9" to get 1.21 m. It is indicated that a variation between approximately 10 to 20 cm could be expected for the trucks in Table 1 and others in this study [22].

It could also be of interest to compare the distances in Table 2 and others reported later (actual measured ones) with some nominal models that have been used by bridge designers in Mexico, as those shown in Figure 5 [16], which correspond also to two of the designations in Tables 1 and 2. Note that such differences could have implications in bridge design and code calibration, whether they are obtained through WIM data or, more precisely, through direct measurements in the field, as are those reported later in the present study.

Tables 3 and 4 list also GVWs and axles weights from the 2016 surveys, but in this case for the two-lane highway and both directions, respectively. As an example, the eight vehicles designated as C3 in Table 3 (see also Figure 4) are used to compute basic statistics. This resulted in an average GVW of 142.36 kN with a sample standard deviation of 49.24 kN. These can be compared with those resulting from the only available WIM data for that highway recorded in 2017 [16] that, for a sample of 1003 vehicles with 3 axles, are 141.21 kN and 33.91 kN for the average and standard deviation of GVW, respectively. As can be noted, the values are very consistent, even for a very small sample of eight trucks. This further supports the use of WIM data for decision making. Moreover, the maximum allowable GVW for this type of truck and highway is at most 196. 2 kN [24], which means that two of the C3 trucks were over the legal weight (i.e., 25%). It is noted that, as stated earlier, in this case the Federal Police helped to measure the trucks, which prevented the drivers from avoiding weighing (even if they were aware that their loads were not legal). As another example, the C2 trucks must not be over at most 142.25 kN for the case of Table 3; however, seven of them violated the legal GVW, i.e., approximately 26%, although it decreases to 20% if C2 trucks from Tables 3 and 4 are lumped together. No C2 truck is violating the legal weight limit in Table 4, which reveals that the direction also plays a role in the recordings.

A more detailed analysis would be necessary to adequately compute the rates of overloaded trucks violating the legal weights, since they depend not only on the type of highway and truck but also on the number of tires per axle, among other issues [24]. This is recommended for future studies. Nonetheless, it can be mentioned that it is well-documented that many trucks over the legal allowable GVWs circulate on Mexican highways and roads [16,19,20,27–29]. In fact, an overall rate of overloaded trucks between approximately 23% and 29% has been reported for static surveys [30]. This study confirms that, several decades later, overloaded trucks are still running on Mexican highways, and therefore over bridges. In the next section the 2018 survey is discussed.

4.2. Discussion for the survey in 2018

In Tables 5 and 6 the vehicles surveyed in 2018 are listed in terms of weights and interaxle distances for the same trucks, respectively. Unlike Table 2, in Table 6 the actual interaxle distances measured in the field are reported; the format is also different, because in Table 6 the interaxle distances are directly given, i.e., "1 to 2" denotes the column with interaxle spacing between axle 1 and 2, "2 to 3" between axle 2 and 3, etc. This survey was only carried out for the Irapuato-Zapotlanejo highway and, since experience was gained in the 2016 survey (it is larger in the number of recorded trucks), it is focused only on trucks, and on obtaining heavy GVWs by inspecting WIM data [21], and the help of the Federal Police.

In Tables 5 and 6, it can be seen that differences do exist in relation to the nominal trucks in Figure 5, which have been used for bridge design, as stated earlier. Some axle weights in Table 5 are even larger compared to the nominal trucks in Figure 5, information that we consider relevant for the readers of this Project Report.

It is once more pointed out that a rigorous statistical analysis and comparison versus WIM data is not pursued because a one-to-one correlation is not possible, and because the characteristics, decisions, and vicissitudes of each set of traffic data are very different, and an adequate statistical comparison would be challenging, though it could be approached in future studies. Nevertheless, some broad comparisons and conclusions can be drawn.

With this purpose, we focused on the trucks designated as T3S2R4 (except the one with the uplifted axles). If the average interaxle distances in Table 6 for the 19 T3S2R4 trucks are computed (front to rear), values of 4.64 m, 1.33 m, 6.94 m, 1.26 m, 2.60 m, 1.29 m, 6.47 m and 1.27 m are obtained. These are larger distances as compared to those in Figure 5b, except by the interaxle distance between axle 5 and axle 6 (3.2 m), which is 0.6 m smaller on average.

Additionally, the average and the standard deviation is also computed for the 19 T3S2R4 vehicles in Table 5, for the GVW and for the heaviest axle from each truck. This resulted in 488.01 kN and 213.11 kN for the average and sample standard deviation of GVW, respectively, and in 73.42 kN and 24.57 kN for the average and sample standard deviation of the heaviest axle, respectively. If compared, for instance, with the corresponding values from the WIM data for the same highway recorded in 2009 for 9-axle vehicles (a sample size of 71,303 vehicles) [16], that resulted in average and standard deviations for GVWs of 321.13 kN and 184.16 kN, respectively, it can be concluded that the values are consistent in average and variability; the larger average for the surveys could be explained because it was purposedly intended to record heavy trucks [21]. Regarding the statistics for the heaviest axles, the WIM data from 2009 led to average and standard deviation values of 47.61 kN and 26 kN, respectively, which are roughly consistent with those reported in this study, and similar conclusions could be drawn.

Although the comparisons are in general consistent, it should be noted that in [16] not necessarily all 9-axle trucks are T3S2R4 (for instance), although it is the only legal configuration with 9 axles as per [24]. Further research is recommended for a more detailed analysis.

The above basic statistical analysis and comparisons are not exhaustive, but they highlight the importance of the data. Other aspects can be highlighted once more. If, for instance, Tables 5 and 6 and the trucks designated as C3 are inspected, it can be noticed that the tandem interaxle distance is approximately 1.3 m on average and the axle weights can each be approximately over 130 kN, which is heavier than the design tandem used by AASHTO [26] and previous versions. Also, Table 5 shows that several trucks designated as T3S2R4 have GVWs well over 652.37 kN (the lower limit for the maximum legally allowed GVW depending on the truck conditions [24]). This represents 6 out of 19 trucks, i.e., approximately 36% of overloaded T3S2R4 trucks for the sample investigated in this study; if an upper allowable limit of approximately 755 kN is considered, this ratio lowers to approximately 16%, provided that the truck complies with several requirements and is in optimal condition [24]. This information is valuable by itself, as it proves that overloaded trucks do run on Mexican highways and over bridges, and that law enforcement is difficult to implement, as has been documented by the IMT in Mexico [27–30] and in other studies based on WIM data [16,19,20]. A quick comparison of the surveys in the 2-lane highway versus the 4-lane highway (Tables 3 and 4 versus Tables 5 and 6) shows that lighter trucks are recorded in the former, which implies that live load models (and future research) should consider this aspect.

Other aspects that could be investigated based on this report, like computing truck load effects on bridges, developing live load models and carrying out code calibration tasks, can be considered for future research, as has been carried out in the US, e.g., [11,31–34], Mexico [16,19,20], Brazil [35] and Korea [36], to mention only a few cases. In fact, traffic loading is a topic of wide applicability in bridge engineering and other fields worldwide, e.g., [37–39].

Supplementary materials (several videos) are available through an associated link provided with this article, for the readers interested in watching the surveys in a more vivid manner. It is planned to upload the original internal reports (in Spanish) by IMT for UG in an URL in the future.

5. Conclusions

In this study, information on gross vehicular weights, axle weights, and interaxle spacings from three surveys on two Mexican highways is described, and all data are openly provided through an associated DOI [17] and reproduced in this report for discussion. A description of the project, equipment, logistics, and other issues is provided in the body of this article. This information can be useful to engineers, technicians, and researchers from the structural engineering field, but it may be also useful for experts in other fields (e.g., transportation) and those interested in the logistics of surveys, even if they look for other types of information (e.g., freight, trucks' physical conditions, etc.). Additionally, a discussion is provided on why the information could be important and its implications for structural and bridge engineering purposes. Therefore, the main objective of the present study is not only to provide information to the structural engineering community to be used in any way that practitioners and researchers may desire but also to provide some statistics, comparisons versus weight-in-motion data, and implications for bridge design.

It is pointed out that the described project and obtained information corresponds to a larger project aimed at computing reliability and carrying out code calibration tasks for Mexican bridges, as well as at proposing live load models for Mexico and the vehicular model for bridge design in a future code for Mexico City. In fact, the information in this article has been used for discussions within the "loads and actions" committee to develop the live load model of the Mexico City bridge design code (Pozos-Estrada, personal communication, [15]).

This is a Project Report; nonetheless, conclusions include that data could be employed in future research as benchmarks, and to study possible correlations with WIM recordings for the same highways in a more detailed manner. It is also found that overloaded trucks do circulate on bridges located on Mexican highways. It is concluded from basic statistical analyses and comparisons that the statistics are consistent with WIM data in general terms, that the differences could be explained for the different methods, recording periods and samples sizes among other issues, and that the overloaded trucks do still circulate on Mexican highways with rates consistent with previous studies, even though the sample sizes in this study are very small. More rigorous correlations would require further research and adequate statistical approaches to compare samples from different sources and different sizes and recording periods, as well as different vicissitudes due to the nature of the surveying techniques, to the logistics, and even to unexpected events when carrying out the projects. This is recommended for future studies.

Supplementary Materials: The following supporting information can be downloaded at: https://ugtomx-my.sharepoint.com/:u:/g/personal/adgarcia_ugto_mx/ESA10PjLxxJElxDjgSHWbN4Bb78ieDuBkxYHeaVggWPDpw.

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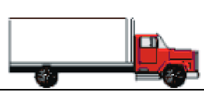
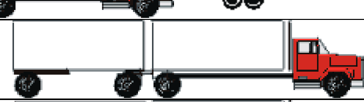
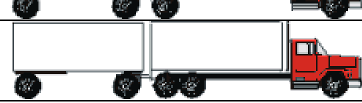
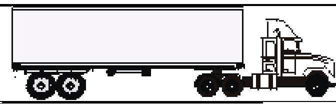
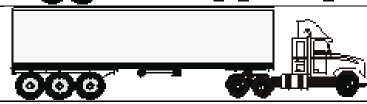
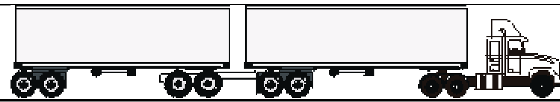
Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Vehicle classification in Mexico for the trucks reported in the study.

Designation	Configuration	Number of Axles
	TRUCKS	
C2 B2	 	2
C3 C3d B3	 	3
C2-R2		4
C3-R2 C3d-R2		5
	TRAILERS	
T2-S2		4

T3-S2		5
T3-S3		6
	DOUBLE TRAILERS	
T3-S2-R4		9

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