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Using Weigh-in-Motion Data to Calibrate Trade-Derived Estimates of Mexican Trade Truck Volumes in Texas

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Weigh-in-motion (WIM) sites are being installed along many highway corridors that carry international trade trucks. Estimating the numbers of trucks carrying international commodities currently relies on manipulating and adjusting trade databases. The variety of vehicle classification data measured at WIM sites provides a rich source of data with which to enhance this adjustment process. Previous WIM border data have focused on port-of-entry truck traffic axle loads, which are heavily influenced by drayage operations. Examined is how WIM data collected at ports of entry and on truck corridors can be used in the determination of standardized truck volumes (termed equivalent trade trucks or ETT) on international highway corridors. Data from the Texas–Mexico border are used to determine ETT North American Free Trade Agreement volumes.

As federal and state planners focus on the needs of trade corridors, interest has grown in how those trucks carrying international trade can be more accurately characterized and their volumes estimated. Trade flows, particularly associated with the North American Free Trade Agreement (NAFTA), can be established from a variety of databases in the public domain (*1*). The estimation of the numbers of trucks carrying international trade is more problematic, however, because of the constraints imposed by trade database limitations (*2*). This work is based on a U.S. Department of Transportation Region VI University Transportation Centers Program study conducted in Texas. The objective of the study was to consider different methods for estimating NAFTA truck volumes from currently available data (*3*). The paper focuses on truck characteristics that are available through data taken from weigh-in-motion (WIM) sites now being installed along highway corridors, as well as those sites previously installed at ports of entry, and how these WIM data can be used to improve the estimation derived from trade-based data.

Traffic data from WIM sites provide greater insight into the characteristics of those vehicles carrying international trade and the effect of drayage at the border, including a means of adjusting truck volumes to reflect actual truck types and weights measured on the corridors. Previous research has reported WIM data at sites within the port of entry, such as Laredo or El Paso, Texas (*4*). However, drayage operations and the movement of heavy loads that are reconsolidated at the border influence the axle loads and make them different from those actually measured on the NAFTA corridors. Figure 1 shows the major steps used in calculating truck volumes associated with NAFTA trade by using truck data collected at the bridges along the Texas–Mexico border. The italicized boxes show the contribution made by data collected from WIM sites and the role of these data from both border and corridor sites in the prediction of truck volumes.

Ideally, a prediction method would identify the range of different truck types (two-axle, three-axle, five-axle, etc.) that carry international trade. However, the data sources available make this problematic and imprecise. It may also be unnecessary at this time because a specific truck type, the five-axle semitrailer, or 3S2, dominates truck volumes (*5*) and weights at the border (*6*) and on corridors (*3*). It was therefore decided to express the truck volumes in a standardized format, termed equivalent trade truck (ETT), based on a loaded five-axle semitrailer (3S2). This equivalency also can be expressed in equivalent axle load factors (EALFs) that define the damage per pass to a pavement by the axle(s) in question relative to the damage per pass of a standard axle load (*7*), depending on the pavement and commodity characteristics. EALFs can provide pavement and bridge deck designers with valuable data for updating the design of highway corridors used by trade vehicles. In the process of determining ETT values, WIM data play an important role that will grow as new WIM sites become operational.

METHODOLOGY

WIM is the process of estimating the motionless (static) weight of a vehicle from measurements of the vertical component of dynamic tire forces applied to a sensor on a smooth, level road surface (*4*).

A truck characteristic database first was created with information from nine WIM sites across Texas, using information provided by the Transportation Planning and Programming Division of the Texas Department of Transportation (TxDOT). This database was complemented with data obtained from three specifically installed WIM systems at Laredo and El Paso near the northern end of the truck bridges over the Rio Grande at both ports of entry (*4, 8, 9*). The locations of the Texas WIM sites used in this analysis are given in Figure 2.

Truck Classification and Coding

Vehicles were classified by using the same coding system used to compile the data. The first coding character corresponds to the vehicle type, 1 for buses and 2 or higher for trucks. The second coding character shows the number of axles on the power unit. The third coding character is the total number of axles on the first trailer. The fourth coding character is the total number of axles on the second trailer. The fifth coding character is the total number of axles on the third trailer. The sixth coding character is always 0. For example, a three-axle tractor plus a two-axle semitrailer (3S2) has a code of 332000.

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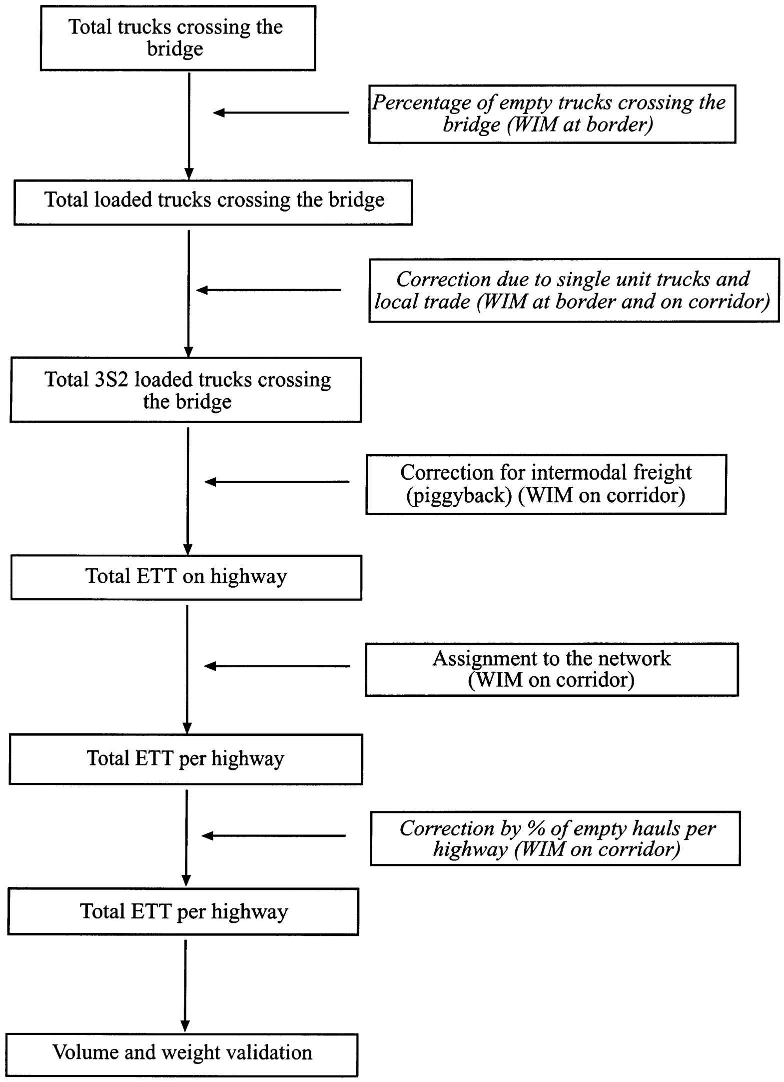


FIGURE 1 Role of WIM data in calibrating NAFTA equivalent trade truck data.

Distribution by Counting

According to the WIM data, only four truck types have a significant representation on rural Texas highways:

1. Single-unit truck with two axles (code 220000), from 12 to 25 percent;
2. Single-unit truck with three axles (code 230000), from 2 to 10 percent;
3. Three-axle tractor plus two-axle semitrailer (code 332000 or 3S2), from 62 to 78 percent; and
4. Two-axle tractor plus one-axle semitrailer plus two-axle full trailer (code 521200), from 0.5 to 6 percent.

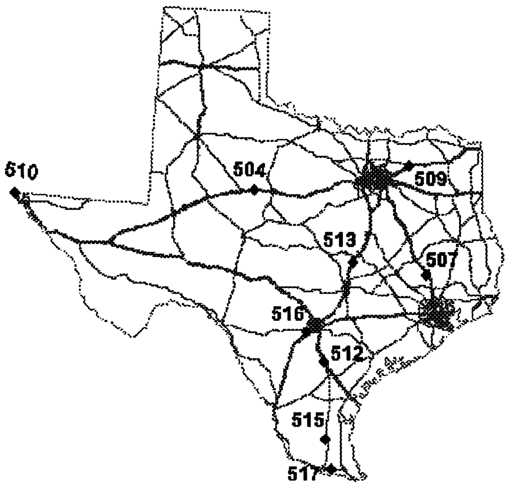
Distribution by Total Weight

Semitrailer and combination trucks clearly account for the highest proportion of weight; the importance of single unit trucks decreases as shown in Table 1 for station 504. The heaviest loads were encountered in connection with truck types 332000 and 333000. Significant loads were registered for some truck semitrailer and trailer combinations such as 533100 and 532400; however, the frequency of these vehicles is low. Truck type 332000 (3S2) accounts for between 70 and 90 percent of the total weight at the WIM stations, and it was chosen as the representative ETT to estimate the number of trucks transporting NAFTA trade.

Truck Weight Histograms

Total truck weight is composed of two elements: the net weight of the truck or tractor semitrailer and the weight of the cargo. Net weights vary from the average value because of characteristics that are linked to the truck type, make, and model. Cargo weight basically depends on the density and the volume of commodity carried. Three possible situations occur when calculating the total weight of a truck for use in determining NAFTA truck flows:

1. The truck or semitrailer does not carry any load (empty);
2. The truck or semitrailer carries a load, and the total weight is under the weight limit (partial load or cube out commodity); or



Station	Highway	County	Location
LW504	IH 20	Nolan	IH 20 West of Sweetwater
LW507	IH 45	Walker	IH 45 South of Huntsville
LW509	IH 30	Hunt	IH 30 East of Greenville
LW510	IH 10	El Paso	IH 10 North of El Paso
LW512	IH 37	Live Oak	IH 37 North of Three Rivers
LW513	IH 35	Bell	IH 35 South of Salado
LW515	US 281	Hidalgo	US 281 North of Edinburg
LW516	IH 35	Bexar	IH 35 South of Loop 1604
LW517	US 83	Hidalgo	US 83 West of FM 1426
Laredo		Webb	International Bridge
El Paso		El Paso	International Bridge

FIGURE 2 WIM station locations in Texas.

3. The truck or semitrailer carries a load, and the total weight is equal to or over the weight limit (weigh out commodity).

Histograms representing total truck weight versus frequency were plotted for vehicle type 3320000, the type chosen as the ETT, as shown in Figure 3, which refers to a single site. As expected, the histograms reflect the three possible situations for a truckload weight, which manifest as different zones, namely,

1. A peak and distribution that corresponds to the tractor and semitrailer net weight;
2. A peak and distribution around the truck weight limit; or
3. Observations that correspond to trucks that are partially loaded or that carry lighter commodities that cube out (between the two mentioned peaks).

The minimum feasible weight of an empty truck or tractor semitrailer determines the lowest weight value; the heaviest truck on the road (a certain percentage over the weight limit) determines the highest weight value. Extreme values may be caused by misclassification: a smaller vehicle in a bigger category (or vice versa), overweight trucks or exceptionally light vehicles, exceptionally heavy authorized vehicles, or simply errors in the weight measure. Statistically, for truck type 332000, records with weights less than 11 800 kg (26,000 lb) and more than 41 770 kg (92,000 lb) are improbable and constitute less than 1 percent of the records in all the stations analyzed.

The boundaries overlap among the three zones, and it is difficult to establish precise limits to each zone. However, these limits are needed to quantify the incidence of each part and to compare weight and truck traffic characteristics among stations. Some limits can be drawn from observing the values of the peak modes and their standard deviations. For example, a value of 14 530 kg (32,000 lb) to 15 440 kg (34,000 lb) can be set as an upper weight limit for an empty tractor–semitrailer, and 32 690 kg (72,000 lb) to 34 500 kg (76,000 lb) can be set as a lower limit for trucks carrying heavy cargo that weighs out. Trucks partially full or carrying cube out commodities will lie

TABLE 1 Station 504 Vehicle Classification and Weight (*3*) [45.4-kg (100-lb) units]

Type	Total Count	Count (%)	Maximum Weight	Minimum Weight	Average Weight	Standard Deviation	Weight (%)
190200	1	0	188	188	188		0
190300	51	1	532	263	335	42	0
220000	1,084	13	353	48	118	57	3
230000	137	2	509	60	237	97	1
321000	16	0	321	75	210	71	0
322000	113	1	308	85	176	41	0
323000	2	0	314	215	265	70	0
331000	39	0	444	170	283	73	0
332000	6,499	**76**	1,071	127	581	174	**87**
333000	38	0	959	352	604	176	1
421000	59	1	438	85	198	91	0
423000	1	0	481	481	481		0
431000	23	0	373	169	252	40	0
521200	364	4	813	296	575	125	5
522100	5	0	612	208	450	208	0
531200	82	1	783	340	544	122	1
532400	1	0	1,410	1,410	1,410		0
533100	2	0	514	426	470	62	0
632100	78	1	787	373	623	94	1
Total	8,595	100					100

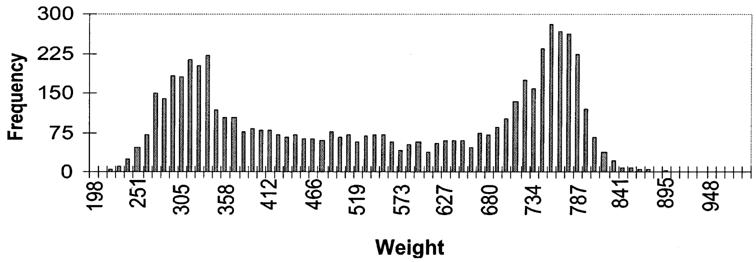


FIGURE 3 Truck 3S2 weight histogram; weight in 45.4-kg (100-lb) units (Station 512, US-28).

between those limits. For the purposes of this report, empty trucks are those that weigh less than 14 530 kg, and cube out trucks are those that weigh between 14 530 kg and 32 690 kg. The lower limit for trucks that weigh out was established as 90 percent of the maximum load [36 320 kg (80,000 lb)]. Overloaded trucks were those with gross weights higher than 36 320 kg, the federal truckload limit on most U.S. Interstate highways.

TRUCK CHARACTERISTICS

The screening of the WIM database permitted the development of several characteristics of significance to those modeling NAFTA truck flows, and these are now described.

Overloaded Trucks

In Laredo, 10 percent of the northbound trucks were overloaded (*9*), a figure that clearly is above the average for Texas highways in the WIM data set (4.3 percent), as shown in Table 2.

Station 516, located south of San Antonio on I-35, shows the highest percentage of overloaded trucks (9.4 percent), as shown in Table 2. Knowing that station 516 lies on the main corridor to Laredo, this value could be related to the 10 percent figure recorded in Laredo.

Empty Trucks

The incidence of empty trucks increases close to the border. Station 517, located near Hidalgo, has the highest number of empty 3S2 trucks (26.2 percent) and the second-highest number of empty 3S3 trucks. This increase may be caused by NAFTA drayage, a higher proportion of interwarehouse trips, or maquiladora trade in which specialized parts or inputs are being delivered.

Station 515 registers a lower number of empty trucks. Because station 515 is located on the corridor connecting the Hidalgo port with Texas, the number of empty trucks may be smaller because of load consolidation occurring in the warehouses close to the ports of entry, implying that the number of NAFTA trucks close to the border and bridges is different from the number of NAFTA trucks on the rural main corridors. It is also important to note that station 515, on US-281, and station 512, on I-37, are both on the route serving Hidalgo NAFTA trade and register around 21 percent of empty trucks, a value that is higher than the average of around 15 percent. The lowest percentage of empty trucks is found on I-45, with only about 9 percent.

Another explanation is related to truck average daily traffic (ADT). Figure 4 shows the relationship between daily 3S2 truck ADT and the percentage of empty trucks per station, per day, for all sites in the database. A slope change appears to occur around an ADT of 2,500. As ADT decreases, the percentage of empty trucks tends to increase. This is reasonable, because as trip attractions and productions increase, both truck volumes and possibilities to quickly pick up a return load also increase.

Cube Out and Weigh Out Percentages

I-35 has a higher average percentage of cube out vehicles than the mean for the WIM database, and I-20 has a higher average number of weigh out vehicles. Cube out and weigh out percentages are clearly related to the commodity transported, although the cube out percentage seems to increase with ADT; weigh out and overloaded percentages show an erratic response to ADT, as shown in Table 2.

Direction of Travel Effect

The results indicate that the stations close to the border register an important difference in the percentage of overloaded trucks accord-

TABLE 2 Type 3S2 Truck Weight Categories (Percent) (*3*)

Station	Highway	County	Empties (%)	Cube Out (%)	Weigh Out (%)	Overload (%)	Count
LW504	IH 20	Nolan	10.0	57.2	29.4	2.9	6,499
LW507	IH 45	Walker	8.8	61.8	24.0	5.1	16,342
LW509	IH 30	Hunt	11.0	62.5	18.2	8.0	8,766
LW510	IH 10	El Paso	10.4	64.1	22.9	2.2	30,045
LW512	IH 37	Live Oak	21.1	49.8	26.4	2.3	10,849
LW513	IH 35	Bell	12.5	68.1	17.9	1.2	36,333
LW515	US 281	Hidalgo	20.8	57.6	19.0	2.3	7,934
LW516	IH 35	Bexar	12.7	62.2	15.3	9.4	13,030
LW517	US 83	Hidalgo	26.2	52.6	15.6	5.6	11,992
Average			14.8	59.6	21.0	4.3	

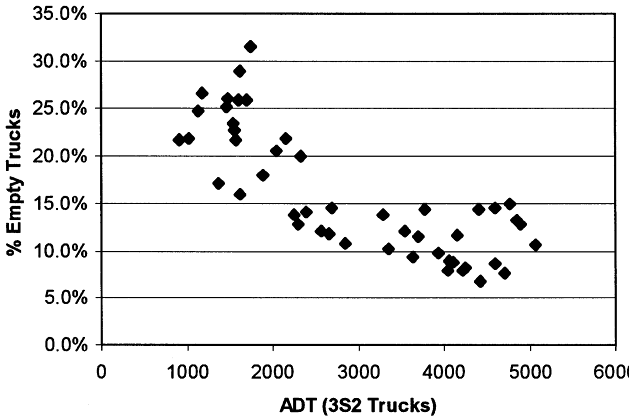


FIGURE 4 ADT effect on percentage of empty trucks (*3*).

ing to the direction of travel, as demonstrated in Table 3. Station 516, located on I-35 close to San Antonio, shows the largest difference in the percentage of overloaded trucks and direction of travel. Contrary to what may be expected, given the concern about Mexican truckloads, a higher percentage of overloaded trucks travel southbound than northbound. Perhaps carriers, knowing that Mexico is more flexible with truck weight limits, tend to overload trailers going into Mexico.

Regarding the WIM stations in Laredo and El Paso, only data in El Paso were recorded for both directions. Again, the southbound trucks were heavier (with higher axle load values) than the northbound trucks. As a general pattern, it is interesting to note that northbound-northeast movements in rural stations have a higher percentage of empty 3S2 trucks than southbound-southwest movements (with the exception of station 510, which carries more east-west traffic). These north-south highways are important NAFTA corridors, especially I-20, I-35, and US-281, suggesting that it is easier for southbound trucks to pick a cargo than for northbound trucks and therefore causing some trucks to return north empty. Commodity type, maquiladora operation, consolidation at the border, and import-export value at port level may also exert some influence. Another explanation could be linked to rail trade. Northbound rail flows, which are substantially higher in value than southbound trade, may contribute to the high number of empty northbound trucks on the trade corridors. As the system is unbalanced, a higher number of empty southbound railroad cars might be expected. Table 3 also shows another important difference at station 517, where the number of empty trucks is substantially higher going west (36 percent) than east (19 percent).

Seasonal Effect

To capture seasonal effects, it is necessary to have data that encompass a full year; because such data were not available, analysis of seasonal effects was not possible by using the database provided by TxDOT. However, some seasonal effects can be determined from the database. First, the highest percentage of overloaded trucks for the 3S2 truck type was found to occur during May and June. The same tendency was found at border and nonborder stations, coinciding with the effect noticed at the WIM stations in Laredo and El Paso, where the highest loads and percentages of overloaded axles were found in the spring. This increase seems to be related to the movement of agricultural products, which have three important characteristics: (*a*) they generally weigh out; (*b*) they are a relatively low value commodity, making truck overloading more appealing; and (*c*) they have important seasonal variations, with spring the peak season.

Hour of Day

The truck data captured by the WIM stations were plotted against the time of the day. For the two stations at the border, the influence of customs work hours is clearly identified.

TABLE 3 Direction of Travel Effect on Truck Weight Classification (3S2) (*3*)

Station	Highway	Direction	Empties (%)	Cube Out (%)	Weigh Out (%)	Overload (%)	Count
LW504	IH 20	Northeast	14	55	29	1	3,199
		Southeast	6	59	30	5	3,300
LW507	IH 45	North	10	63	25	2	7,740
		South	8	61	23	8	8,602
LW509	IH 30	East	13	57	16	13	4,204
		West	9	67	20	3	4,562
LW510	IH 10	North	8	65	23	3	11,089
		East	10	71	19	0	3,580
		South	11	61	25	2	11,503
		West	15	65	19	1	3,873
LW512	IH 37	North	23	45	30	3	5,654
		South	19	55	23	2	5,195
LW513	IH 35	North	16	64	19	1	17,556
		South	9	72	17	1	18,777
LW515	US 281	North	24	50	24	2	4,321
		South	17	67	13	3	3,613
LW516	IH 35	Northeast	16	71	12	0	6,336
		Southwest	10	54	18	18	6,694
LW517	US 83	Northeast	19	55	20	6	1,508
		East	19	50	21	11	4,272
		Southeast	25	58	13	4	1,620
		West	36	53	10	1	4,592

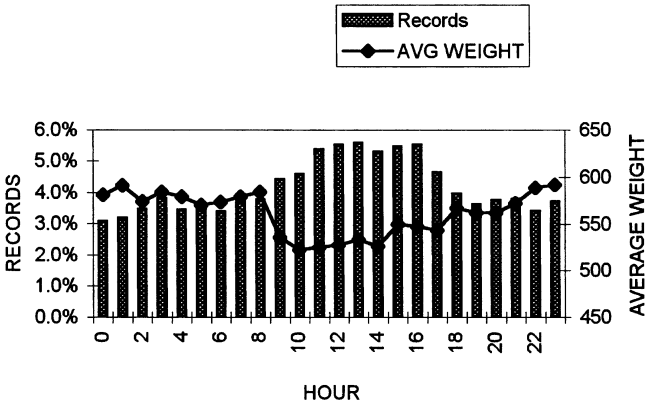


FIGURE 5 Hourly effect, truck type 3S2 (*3*); weight in 45.4-kg (100-lb) units, Station 507.

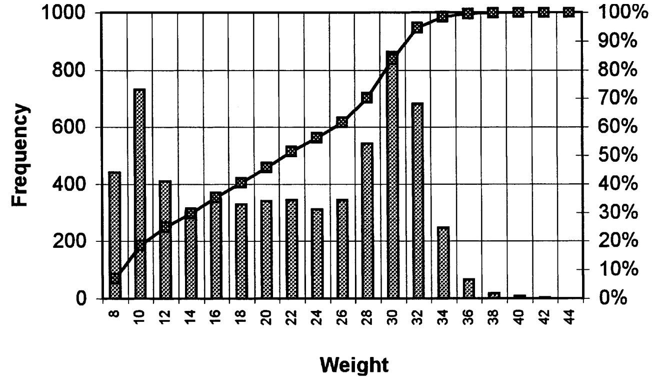


FIGURE 6 Station 516 northbound truck type 3S2—trailer tandem axle loads; weight in 45.4-kg (100-lb) units.

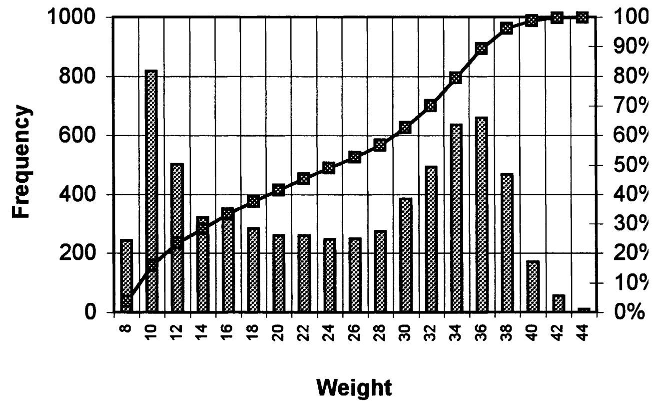


FIGURE 7 Station 516 southbound truck type 3S2—trailer tandem axle loads (*3*); weight in 45.4-kg (100-lb) units.

Rural interstates with a high percentage of long trips show less variation around the mean. Hourly variations are clear, and it appears that the average truck weight decreases between 9:00 a.m. and 6:00 p.m. and increases during the night. Therefore, more empty-haul trips take place during the day, as shown in Figure 5. The same trend can be observed with the percentage of empty trucks increasing during daylight working hours.

Analysis of Axle Load Overweight

The stations located at El Paso and Laredo captured a large number of overloaded trucks. The most notorious violators of the axle weight limits were tandem and tridem axles in the 3S3 truck configuration, although the presence of this truck type is very small in the total truck composition. The second-highest overloaded axles were tandem axles of the 3S2 truck configuration, as shown in Table 4.

The load limit for tandem axles in Texas is 15 440 kg, and the limit for tridem axles is 19 070 kg (42,000 lb) (using the bridge formula). It is important to note that the northbound and southbound directions in El Paso have almost equal percentages of overloaded trucks. At Laredo, WIM was installed only to collect Mexican northbound data.

A unique situation was detected at station 516: although the total percentage of overloaded axles does not deviate far from the mean, the directional effect on the percentage of overloaded axles shows a different pattern. When each direction is analyzed, the northbound shows no overloaded trucks and the southbound shows 18 percent overloaded trucks. This translates into different percentages of overloaded axles in each direction, as shown for the trailer tandem axle loads in Figures 6 and 7. Station 516 is located on I-35, the corridor that connects the east and northeast industrial U.S. centers with Laredo and the interior of Mexico. Mexican weight limits are higher than those in the United States, and possibly shippers may load trailers over the U.S. weight limit when moving product into Mexico.

TABLE 4 Percentage of Overloaded Axles (3S2) (*6*)

Station Location	3S2	
	Tractor Tandem (%)	Trailer Tandem (%)
El Paso Northbound	30	23
El Paso Southbound	37	36
Laredo Northbound	40	39

Differences between axle loads measured at the border WIM sites and those on NAFTA highway corridors are so significant that they suggest a consolidation process for northbound trade must be taking place at the border. Therefore, when an overloaded truck from Mexico enters the United States, the trailer weight is reduced by consolidators to meet U.S. standards. If this consolidation process takes place, it is only for trucks carrying weigh out commodities, because cube out commodities (constrained by volume) do not produce overloaded axles.

For southbound movements, some trailers bound for Mexico are expected to be overloaded (by U.S. standards) either at the border or in the United States, and this is confirmed by the analysis of the effect of direction of travel on truck weight. The percentage of overloaded axles at the nine WIM stations located throughout Texas is presented in Table 5. Although there are large numbers of overloaded

TABLE 5 Percentage of Overloaded Axles (Truck Type 332000) (*3*)

Station Location	Truck Type 332000	
	Tractor Tandem (%)	Trailer Tandem (%)
All Stations	8.6	7.9
LW516 IH35	12.3	9.7
LW516 IH35 Northbound	3.2	1.5
LW516 IH35 Southbound	20.9	20.6

TABLE 6 1997 Annual NAFTA Truck Volumes on Major Texas Corridors (3)

Highway Segment	From	To	Southbound	Northbound	Total
IH 35	Laredo	San Antonio	585,700	523,100	1,108,800
	San Antonio	Austin	419,700	386,900	806,600
	Austin	Dallas	419,700	364,900	784,600
IH 30	Dallas	Little Rock	219,500	296,400	515,900
IH 10	El Paso	IH 20	276,000	246,300	522,300
	IH 20	San Antonio	139,300	110,400	249,700
	San Antonio	Houston	235,100	254,900	490,000
	Houston	Beaumont	171,000	241,300	412,300
	Beaumont	IH 59 (LA)	155,100	230,700	385,800
IH 20	IH 10	Dallas	90,100	136,400	226,500
IH 37	San Antonio	281	156,400	172,300	328,700
	281	77	68,700	73,800	142,500
281	IH 37	McAllen	121,500	186,600	308,100
77	IH 37	Brownsville	100,900	109,500	210,400
77	Corpus Christi	Houston	68,200	75,300	143,500

axles on Texas highways (around 8 percent for 3S2), the percentage is considerably lower than for trucks at the border stations.

SUMMARY

The analysis of WIM data and the ability to characterize NAFTA truck traffic in a variety of ways argues for the development of a standardized truck configuration for corridor planning purposes. In the AASHO Road Test (*10*), an equivalent single axle load (ESAL) unit was developed to determine an equivalency between different truck types and axle loads on the effect on serviceability of a defined pavement structure. ESALs have become important planning inputs in the selection of pavement type and design, and a similar treatment of truck types carrying NAFTA trade could be desirable. In this context, the ETT for this report was a five-axle, semitrailer vehicle loaded to a maximum gross weight of 36 320 kg, depending on the commodity carried. WIM data can be used to characterize ETT units in several ways, including estimating ESAL numbers on a given highway section. This would enable ETT volumes to be related to congestion effect and to pavement and bridge deck consumption, both of which are important cost elements in the management of highway corridors.

The objective of this study was to estimate NAFTA truck flows—and related characteristics such as axle weights—moving on Texas's highway trade corridors. The work reported here enables a planner to estimate broad numbers from trade data and then calibrate them by using border and corridor WIM sites. By using this approach, adjusted truck volumes across the key Texas NAFTA corridor segments were derived for both directions of travel and are shown in Table 6.

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