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USING WEIGH-IN-MOTION DATA TO CALIBRATE TRADE DERIVED ESTIMATES OF NAFTA TRUCK VOLUMES IN TEXAS

Miguel A. Figliozzi
and
*Robert Harrison
Center for Transportation Research
The University of Texas at Austin
3208 Red River, Ste. 200
Austin, Texas 78705
Tel (512) 232-3113; FAX (512) 232-3153

and

John P. McCray, P.E.
Division of Management and Marketing
The University of Texas at San Antonio
San Antonio, Texas 78249
Tel (210) 458-5384; FAX (210) 458-4308

*Corresponding author

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ABSTRACT

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 trade databases, making some adjustment for empty vehicles. The variety of vehicle classification data measured at WIM sites provides a rich source of data to enhance this adjustment process. Previous WIM border data has focused on port of entry traffic heavily influenced by drayage operations. This paper examines how WIM data collected 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 NAFTA volumes.

INTRODUCTION

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, due to the constraints imposed by trade database limitations *(2)*. This paper 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 of estimating NAFTA truck volumes from currently available data *(3)*. The paper focuses on truck characteristics that are now available from weigh-in-motion (WIM) sites now being installed along highway corridors and how these can be used to improve the estimation derived from trade-based data.

Traffic data from WIM sites provides a greater insight into the characteristics of those vehicles carrying international trade, 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, like 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 to those actually measured on the NAFTA corridors. Figure 1 shows the major steps in calculating truck volumes associated with NAFTA trade 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 when predicting 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 since a specific truck type, the five-axle semi-trailer, or 3S2, dominates truck volumes *(5)* and weights *(6)* on corridors. It was therefore decided to express the truck volumes in a standardized format, termed equivalent trade truck (ETT), based on a loaded five-axle semi-trailer (3S2). This equivalency can also be expressed in equivalent single axle loads (ESALs), depending on the pavement and commodity characteristics, which can provide pavement and bridge deck designers with valuable data for updating the design of highway corridors used by these vehicles. In the process of determining ETT values, WIM data play an important role that will strengthen as new sites become operational.

METHODOLOGY

Weigh-in-motion 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 was first created utilizing information from nine WIM sites across Texas, using information provided by the Transportation Planning and Programming division at 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 *(7, 8, 9)*. The locations of the Texas WIM sites used in this analysis are given in Figure 2.

Truck Classification and Coding

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

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) between 12-25 percent;
2. Single-unit truck with three-axles (code 230000) between two to ten percent;
3. Three-axle tractor + two-axle semi-trailer (code 332000 or 3S2) between 62-78 percent;
4. Two-axle tractor + one-axle semi-trailer + two-axle full trailer (code 521200) between one-half to six percent.

Distribution by Total Weight

Semi-trailer 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/semi-trailer/trailer combinations such as 533100 and 532400; however, the frequency of these vehicles is low. Truck type 332000 (3S2) accounts for most of the total weight in all the stations (between 70-90 percent of the total weight), and therefore 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 tractor/trailer and the weight of the cargo. Net weights vary from the average value due to characteristics that are linked to the type, make, and model of truck. 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/trailer does not carry any load (empty);
2. The truck/trailer carries a load, and the total weight is under the weight limit (partial load or cube out commodity); or
3. The truck/trailer carries a load, and the total weight is equal 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 semi-trailer *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/trailer determines the lowest weight value; the heaviest truck on road (a certain percentage over the weight limit) determines the highest weight value. Extreme values may be caused by misclassification that includes 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 weight less than 26,000 pounds and more than 92,000 pounds are improbable and comprise less than one 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 32,000-34,000 pounds can be set as an upper weight limit for an empty tractor-semi-trailer, and 72,000-76,000 pounds 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 between those limits. For the purposes of this paper, empty trucks are those that weigh less than 32,000 pounds, while cube out trucks are those that weigh between 32,000-72,000 pounds. The lower limit for trucks that weigh out was established as 90 percent of the maximum load (80,000 pounds). Overloaded trucks were those with gross weights higher than 80,000 pounds, the U.S. 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, ten percent of the northbound trucks were overloaded *(8)*, a figure that is clearly above the average of Texas highways in the WIM data set (4.3 percent), as shown in Table 2.

Station 516, located south of San Antonio on IH 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 ten percent 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 inter-warehouse trips, and/or maquiladora trade where specialized parts or inputs are being delivered.

Station 515 registers a lower number of empty trucks. Since this station is located on the corridor that connects the Hidalgo port with Texas, the number of empty trucks may be smaller due to the consolidation of loads that occurs in the warehouses close to the ports of entry. This implies that volume of NAFTA trucks close to the border and bridges is different than the volume of NAFTA trucks in the rural main corridors. It is also important to notice that station 515 on US 281 and station 512 on IH 37 are both on the route serving Hidalgo NAFTA trade and register around 21 percent of empty trucks. This value is higher than the average of around 15 percent. The lowest percentage of empty trucks is found on IH 45 with only about nine percent.

Another explanation is related to the truck 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 seems 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 Weight out Percentages

IH 35 has a higher average percentage of cube out vehicles than the average for the WIM database, and IH 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 show that the stations close to the border have an important difference in the percentage of overloaded trucks according to the direction of travel, as demonstrated in Table 3.

Station 516, located on IH 35 close to San Antonio, shows the largest difference in the percentage of overloaded trucks and direction of travel. Contrary to what might 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 than the northbound trucks, with ESAL values higher southbound. 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 IH 20, IH 35, and US 281, suggesting that it is easier for southbound trucks to pick a cargo than for northbound trucks, 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, this type of analysis was not possible 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 the months of May and June. The same tendency was found at border and non-border stations, coinciding with the effect noticed at the WIM stations in Laredo and El Paso, where the highest loads and percentage of overloaded axles was found in the spring. This increase seems to be related to the movement of agricultural products, which have three important characteristics: (1) they generally weigh out, (2) they are a relatively low value commodity, making truck overloading more appealing, and (3) they have important seasonal variations with spring being 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.

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 and 18:00 hours, 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, though 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 34 kip, and the limit for tridem axles is 42 kip (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. Even though 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 of 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 IH 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 in the U.S., and possibly shippers may load trailers over the U.S. weight limit when moving product into Mexico.

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 must be taking place at the border. When an overloaded truck coming from Mexico enters the U.S., the trailer weight is reduced to meet U.S. standards. If this process takes place, it is only in trucks carrying weigh out commodities, since 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 U.S., 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. Though there are large numbers of overloaded axles on Texas highways (around eight 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 *(9)*, an equivalent single axle load (ESAL) unit was developed to determine an equivalency between different truck types and axle loads. 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 paper was a five-axle, semi-trailer vehicle loaded to a maximum gross weight of 80,000 pounds, depending on the commodity carried. WIM data can be used to characterize ETT units in a number of ways, including deriving ESAL impacts. This would enable ETT volumes to be related both to congestion effect and pavement/bridge deck consumption, both important cost elements in the management of highway corridors.

Finally, it is noted that the objective of this study was to estimate NAFTA truck flows, and related characteristics like axle weights, moving on the highway trade corridors in Texas.

The work reported in this paper enables a planner to estimate broad numbers from trade data and then calibrate them using border and corridor WIM sites. Using this approach, we derived adjusted truck volumes across the key Texas NAFTA corridor segments, and these are reported in Table 6. Differences in ETT volumes by direction of travel are clearly captured and these are based on the approach reported in this paper.

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Table 1. Station 504 Vehicle Classification and Weight (in 100 Pounds)

Type	**Count**	**Count %**	**Max. Wt.**	**Min. Wt.**	**Ave. Wt.**	**St. Dev..**	**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%

Table 2. Type 3S2 Truck Weight Categories (Percent)

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%	

Table 3. Direction of Travel Effect on Truck Weight Classification (3S2)

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

Table 4. Percentage of Overloaded Axles (3S2)

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

Source: (6)

Table 5. Percentage of Overloaded Axles (Truck Type 332000)

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 Truck Volumes on Major Texas Corridors

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

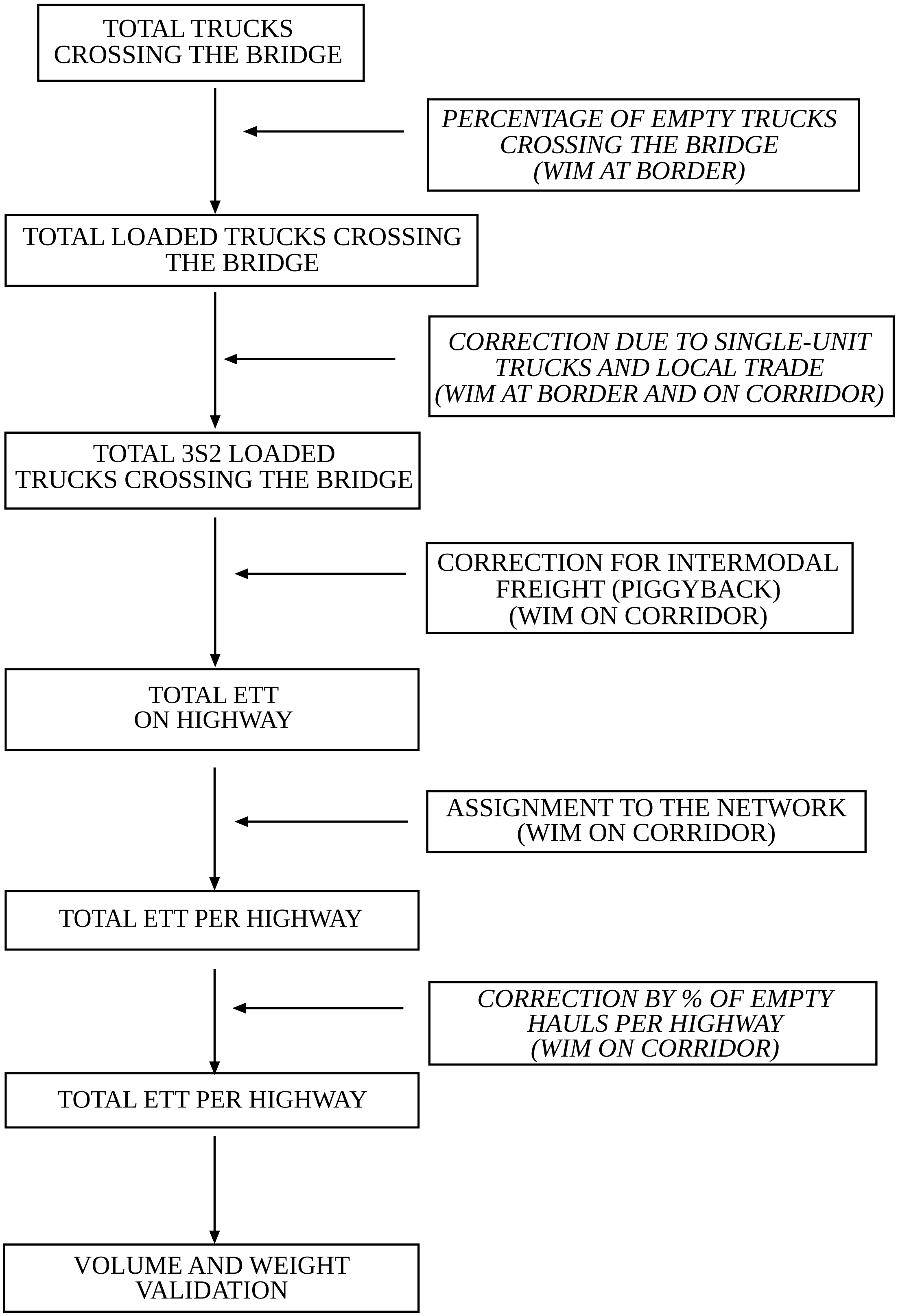
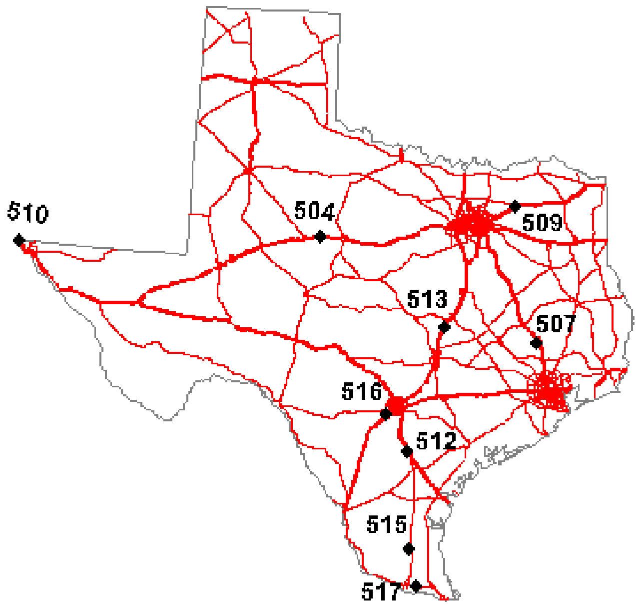


Figure 1. Role of WIM Data in Calibrating NAFTA Equivalent Trade Truck (ETT) Data



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

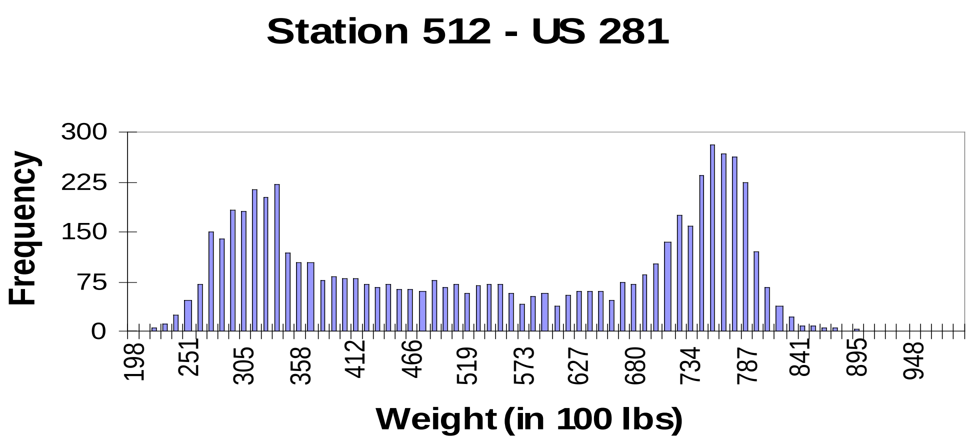


Figure 3. Weight Histogram (Truck 3S2)

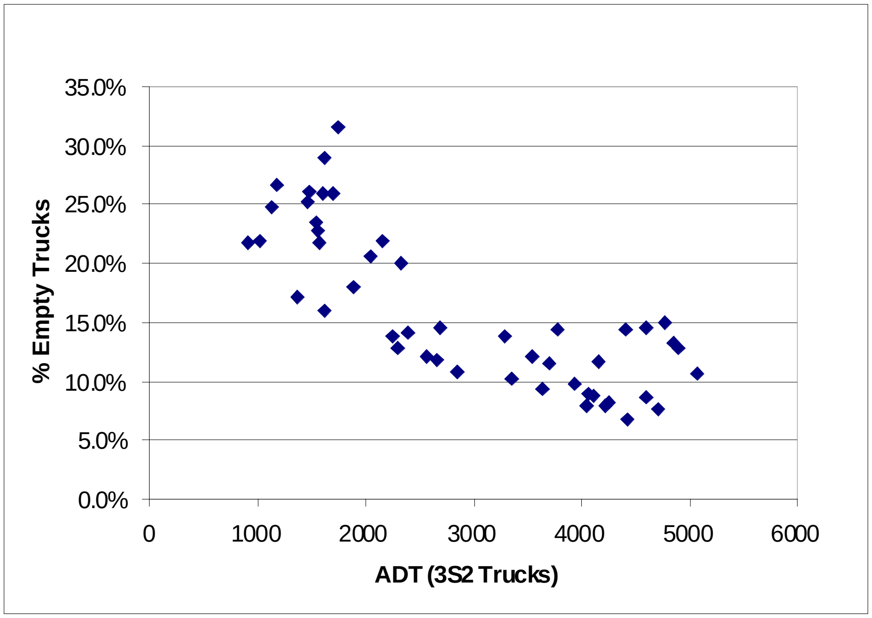


Figure 4. ADT Effect on Percentage of Empty Trucks

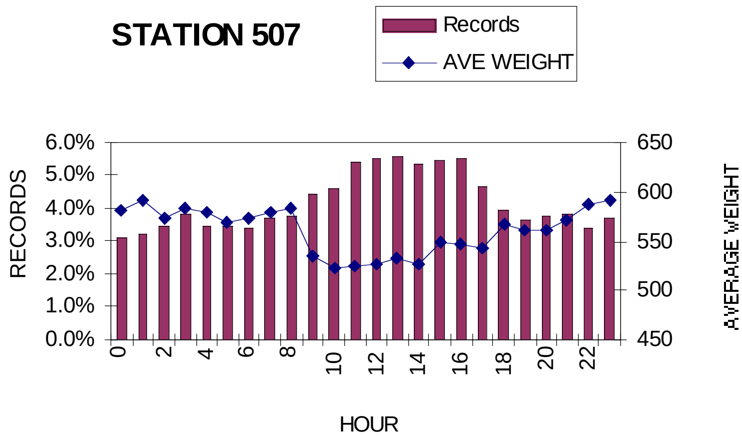


Figure 5. Hour Effect, Truck Type 3S2

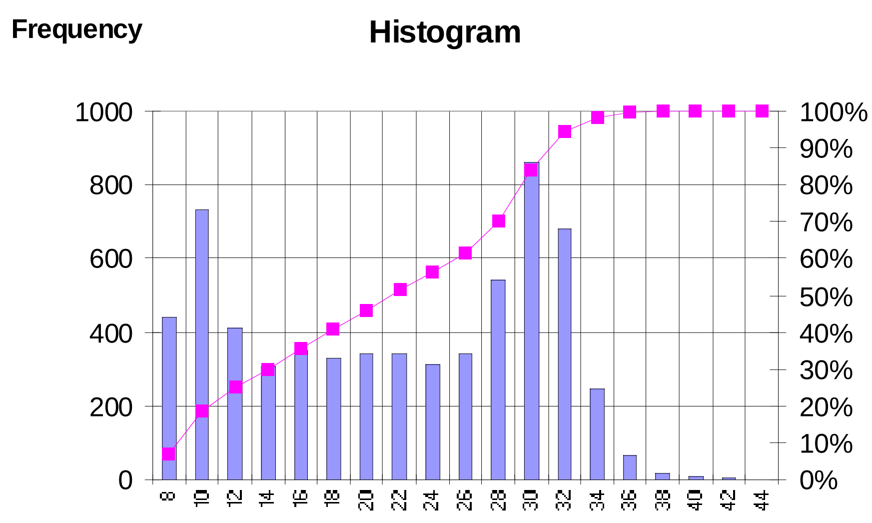


Figure 6. Station 516 Northbound Truck Type 3S2—Trailer Tandem Axle Loads

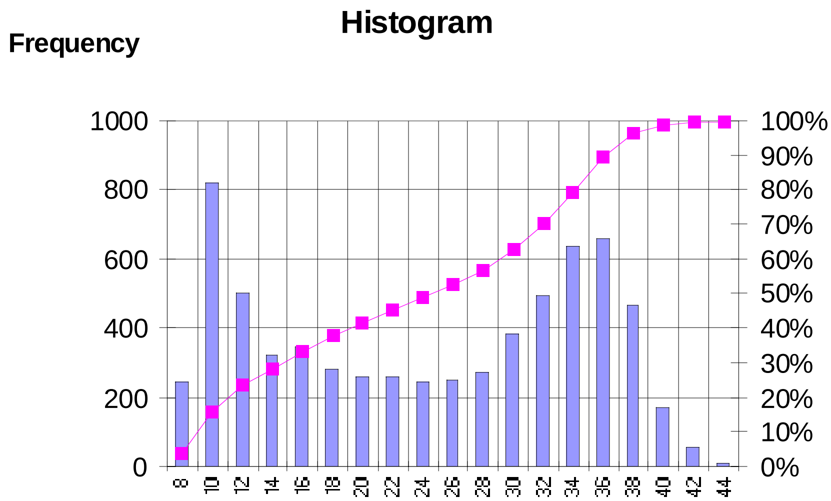


Figure 7. Station 516 Southbound Truck Type 3S2—Trailer Tandem Axle Loads

TABLE TITLES

FIGURE CAPTIONS