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16. Abstract

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A review of the current conditions along the Texas/Mexico border, with respect to trade, infrastructure, and weight regulations, provides background information on the subject. The report contains a state-of-the-practice description of static weighing techniques currently used in Texas as well as a description of weigh-in-motion (WIM) technology that might be applicable to weight enforcement. The advantages and disadvantages of WIM sorting vs. traditional static weighing methods are itemized, and different enforcement techniques are evaluated and compared according to their capabilities, constraints, productivity, safety, accuracy, and applicability. Attention is also given to the relative cost of each method, including initial (equipment, construction) and operating (maintenance, personnel) costs. Also, a description and assessment is presented of the first weigh station in Texas (on I-35 near Devine) that utilizes WIM as a sorting device. This experience, as well as the experience of other states, provides further insight into the ability of a WIM system to aid in truck weight limit enforcement. Major highway trade corridors and potential WIM enforcement sites in Texas are identified. Finally, pavement damage implications on two major NAFTA-traffic highways are examined for hypothetical combinations of enforcement rates, violation rates, traffic growth rates, and the year of NAFTA implementation.

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Truck Weight Limit Enforcement Technology Applicable to NAFTA Traffic Along the Texas-Mexico Border

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Disclaimer

ABSTRACT

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EXECUTIVE SUMMARY

Since the mid-1980's, the growth of trade between the U.S. and Mexico has substantially risen, and this trend is expected to continue due less restricted trade between the two countries. The initial phase of the North American Free Trade Agreement (NAFTA), ratified in January of 1994, permitted U.S. and Mexican trucks to travel 12 miles (20 km) within each other's border. The subsequent phase allows for reciprocal access to the border states of each country, which will result in an even larger volume of truck traffic on U.S. highways within the four U.S. border states. Not only does the increased volume of trucks cause concern, but also the concern of potentially excessive loads carried by these trucks, since the legal limits for axle loads in Mexico are 10 to 18 percent higher than those of the U.S., and these limits are oftentimes not enforced.

In Texas, truck size and weight enforcement is one of the responsibilities of the Department of Public Safety (DPS). Their objective has traditionally been carried out using three types of static scales; the wheel-load weigher (portable scale), axle-load weigher (semi-portable scale), and the axle-scale (permanent or fixed scale). These devices are used to measure the axle, axle-group, and gross-vehicle weight of suspected overloaded vehicles. In addition to static methods, Texas has recently begun operation of its first weigh station utilizing in-motion techniques to sort suspected violators from a truck traffic stream so that only those suspect of being overweight are stopped on the static scales, while those that are not suspect are directed back towards the highway. This technology, along with its many capabilities, has some disadvantages that cause concern to the DPS and other officials.

The currently used static methods of enforcement vary in their size, setup, ease of use, cost, accuracy, and maintenance requirements. There are several WIM systems available today that vary in their ease of installation, cost, accuracy, and durability. The various WIM systems have an ASTM Standard by which they can be classified and evaluated. Static and in-motion methods of weight enforcement can be compared to the each other with respect to a number of elements. The advantages of using WIM include a faster vehicle processing rate, the ability to obtain a near-100-percent sample of truck traffic data, less bias of the truck data taken, safer conditions, continuous operation, less personnel required per truck weighed, automated data processing, and greater coverage area. The disadvantages of using WIM are concerns about its accuracy, higher initial cost than conventional static methods, susceptibility to electromagnetic disturbances, and its lack of portability. Examples of WIM station initial and operating costs in the report provide representative values of cost for comparison with static scale costs. The 1997 Comprehensive Truck Size and Weight Study (Ref 38) analyzed the number of trucks weighed nationwide with each type of scale: permanent, semi-portable, portable, and with

WIM. The figures show a substantial increase in the number of trucks weighed with WIM, while the number of trucks weighed by other techniques decreased up to 1995. This is a good indication that WIM sorting is being used more widely throughout the U.S. and that it can be used as an effective tool for weight enforcement.

A number of states have included weigh-in-motion as part of, or even a basis of, their truck weight enforcement program. In November 1997, the State of Texas opened its first WIM sorting stations along I-35 south of San Antonio, in Devine. This first WIM site in Texas has proven to be a valuable learning experience for both the DPS and TxDOT. It has enabled officers to see how in-motion weighing allows them to weigh, inspect, and possibly ticket a greater number of trucks. Although the cost of the stations was relatively high, they have enabled DPS to weigh a much larger number of trucks with minimal personnel. In addition, they have already collected a significant amount of money in fines as a result of weighing more trucks. The success of the weigh stations in Devine has prompted the construction of a second WIM site near Huntsville along I-45 between Houston and Dallas.

The growth of trade between the U.S and Mexico has resulted in the development of well-defined truck highway corridors with respect to major border regions. The three major border regions in Texas are the Lower Rio Grande Valley, Laredo, and El Paso. The major truck-traffic corridors in Texas, including potential enforcement sites, are addressed.

In an assessment of potential damage savings to the Texas highway system, particularly I-35 and I-10, an enforcement rate of as little as 10% using WIM stations produces an average of 5% reduction in the produced ESAL accumulations during a 20-year analysis period. The analysis also revealed that each additional 15% in the enforcement rate produces an average of 7 to 11% reduction in accumulated ESALs. This means that pavement life will be increased and substantial economic benefits can be realized. Whether harmonization talks result in the U.S. retaining its lower legal load limits, or in raising load limits, WIM systems should be considered for placement in the vicinity of each highway port-of-entry or along the designated “trade routes” described in this report to screen for overweight violators.

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CHAPTER ONE – INTRODUCTION

International trade between the United States and Mexico has increased significantly since the mid-1980's, and this trend is expected to continue due to the ratification of the North American Free Trade Agreement (NAFTA) in January of 1994. The associated increase in truck traffic is of great concern to the Texas Department of Transportation (TxDOT) and the Department of Public Safety (DPS), as the number of trucks traveling on Texas and U.S. highways and bridges will far exceed the number predicted in the original planning and design of these structures.

1.1 PROBLEM STATEMENT

The initial phase of NAFTA permitted trucks of U.S. origin to travel 12 miles (20 km) into Mexico and trucks of Mexican origin to travel 12 miles (20 km) into the U.S. This 24-mile (40-km) wide region between the U.S. and Mexico is called the commercial zone (Ref 4). The initial phase of NAFTA included provisions that within three years after agreement ratification, trucks with Mexican origin would be permitted to travel freely through each of the four bordering U.S. states and U.S. trucks would be able to travel freely through each of the six bordering Mexican states. Although this phase has not yet been implemented, the U.S. and Mexico will ultimately be opened up for unrestricted trade, which will undoubtedly add to the already growing number of commercial trucks on U.S. and Mexican roads. The increased free movement of commercial trucks poses a serious problem for truck weight enforcement on U.S. roads, as the number of trucks currently traveling on U.S. highways has already exceeded the design forecasts (Ref 22). Not only do the number of trucks cause concern, but also the excessive loads that are carried on these trucks, since the legal limits for axle loads in Mexico are 10 to 18 percent higher than those of the United States, and these limits are oftentimes not enforced. This situation is of particular concern to the State of Texas, as 66% of all truck traffic between the U.S. and Mexico travels through the state, and four of the seven major U.S.- Mexico border crossings are located in Texas.

Highway structures in the U.S. are designed to sustain specific legal loads and have a known, limited lifetime. The design life of U.S. road pavements is about 20 years and the life span of bridges is about 75 years, whereas the design life of Mexican pavements is 15 years (Ref 22). In the United States, truck size and weight enforcement is used to protect pavements and bridges from premature failure due to excessive, illegal loads. However, the more lenient regulations and enforcement practices in Mexico do considerably less to protect its roads and bridges from untimely failure. Not only are NAFTA trucks a concern to the deterioration of U.S.

roads, but also the large number of domestic trucks traveling within Texas as well as those passing through the state. Therefore, enforcement efforts need to be aimed not simply at NAFTA traffic, but at all truck movements on Texas roads.

Policymakers must make a decision concerning the enforcement of Texas and U.S. truck size and weight limits once truck-traffic-related provisions of NAFTA are implemented. A choice is mandated: to enforce, not enforce, or change the U.S. limits. This report will aid policymakers in their decision by presenting and evaluating truck weight enforcement methods and technology potentially applicable to NAFTA traffic in Texas. There are a number of technical and economic issues surrounding effective size and weight enforcement that must be considered when comparing traditional static weight enforcement techniques with a combination of weigh-in-motion (WIM) and static truck weighing methods. In order to enhance enforcement, Texas will need more personnel, more hours of operation, more equipment, or more effective equipment.

1.2 BACKGROUND INFORMATION

Studies by the American Association of State Highway Officials (AASHO) in the late 1950's show that a 5-axle truck carrying 100,000 pounds wears away a roadway three times as fast as a truck carrying the legal limit of 80,000 pounds. Pavement deterioration increases exponentially as the weight of trucks increases past the legal limit (Ref 4). In order to protect U.S. roads from excessive damage, thus allowing them to actually live out their design life, the maximum axle-load and gross-weight limits for trucks must be enforced. Weight enforcement is an enterprise that should be performed in the most cost-efficient and effective manner.

Truck weight enforcement in Texas is one of the responsibilities of the Department of Public Safety. In recent years, the DPS implemented a rigorous truck size and weight enforcement program throughout the State in order to improve its operations. Officers are utilizing all of their available resources to provide as much truck weight enforcement as they can. Currently, officers use several methods to regulate the loads carried on commercial vehicles. Until November 1997, officers had only static scales to weigh a truck; that is, the truck was required to come to a standstill on a scale before the weight was recorded. The DPS uses 3 types of static scales for weight enforcement – portable, semi-portable, and permanent; these will be described in more detail in Chapter 3. In November 1997, the first weigh station was opened in Texas which utilizes weigh-in-motion (WIM) technology to identify only suspected violators for static weighing; thus, making it possible to process vehicles through the station at a much faster rate. This technology is also being used regularly in several other states in order to enhance enforcement efficiency and effectiveness at ports-of-entry and on major highways.

WIM technology has been under development for the past four decades. As WIM is the process whereby the dynamic tire forces of a moving vehicle are measured and analyzed to estimate the corresponding tire load on the static vehicle, the estimated values are expected to be somewhat in error, when compared to those determined by static scales. Even with this recognized margin of error, WIM systems can be used effectively as screening tools to sort suspected overloaded trucks from a traffic stream so that only the suspected violators are stopped for weighing on static scales. Trucks that have crossed over the WIM sensors and are not suspected of being overloaded do not have to stop and can return to the main traffic stream.

While the initial cost of a WIM system, which has been reduced substantially over the past several years, has been a primary concern, there are a number of other advantages and disadvantages associated with the use of WIM systems. Nevertheless, the number of trucks weighed on WIM systems throughout the U.S. continues to rise dramatically, at a rate of over 250% from 1990 to 1995 (Ref 38). As the number of trucks driving on U.S. roads continues to increase, and the ensuing phases of NAFTA are implemented, effective weight enforcement will be a key issue in protecting roads and bridges from premature failure.

1.3 SPECIFIC OBJECTIVES

The content of this report addresses several issues concerning the implications of NAFTA truck traffic weight limit enforcement at the Texas-Mexico border using WIM technology. Chapter 2 gives a brief review of U.S. – Mexico trade, as well as the North American Free Trade Agreement and its potential impact on the growth of trade. This chapter also presents a summary comparison of the current size and weight limits between the U.S and Mexico and describes the current conditions at the Texas-Mexico border crossings and the transportation infrastructure in the State of Texas. The third chapter introduces the current methods of both static and in-motion weight enforcement. Chapter 4 includes a more in depth comparison of static weighing with in-motion weighing techniques, including advantages and disadvantages of each method as well as an evaluation of their capabilities, constraints, productivity, safety, accuracy, cost, and applicability. In Chapter 5, weight enforcement practices in both Texas and California are described, and potential enforcement sites in Texas are located. Chapter 6 presents an assessment of the potential reduction in pavement damage if WIM technology is implemented, using a concept developed from the American Association of State Highway Officials (AASHO) Road Test, whereby projected traffic loads are related to pavement damage in terms of equivalent 18-kip single axle loads (ESALs). Finally, Chapter 7 presents a summary of research findings, some conclusions drawn from this research, and recommendations for further study.

The feasible alternative technologies that should be considered by policymakers, engineers, and enforcement officers as they attempt to choose the optimal weight enforcement methods for protecting the existing and future infrastructure are presented in this report.

CHAPTER TWO – U.S. AND MEXICO TRADE AND WEIGHT ENFORCEMENT REGULATIONS

The difference between U.S. and Mexico weight regulations, as well as the difference in their application, is of great concern to the border states, as all truck travel between the countries travels on their highways. The continual growth in trade, and the impending truck-traffic-related provisions of NAFTA have raised the issue about the most effective methods of weight enforcement in order to help protect the U.S. and Texas infrastructure from premature failure. This chapter presents the background on U.S. – Mexico trade, including its growth to current conditions, and specifies the differences in size and weight regulations between the two countries.

2.1 U.S. – MEXICO TRADE

Growth in trade between the U.S. and Mexico has dramatically risen since the mid-1980's following Mexico's joining the General Agreement on Tariffs and Trade (GATT) in 1986, which is now called the World Trade Organization (WTO). Since that union, Mexico has decreased tariffs and has removed many of its trade permits that were necessary to import goods from other countries. As a result, trade between Mexico and other countries has soared, especially with the United States. The U.S. is currently Mexico's largest trading partner, and Mexico is the third largest export market for the U.S. By value, 90% of all U.S. Mexico trade is transported by surface transportation, of which 80% is carried by commercial trucks. In 1991, nearly 60% of U.S. exports to Mexico originated in or passed through Texas (Ref 22). There are currently 32 land ports-of-entry between the U.S. and Mexico, of which 18 are located in Texas. The three busiest ports-of-entry are, in order, the Laredo, El Paso (Texas), and Nogales (Arizona). In 1990, nearly 85% of truck traffic between the U.S. and Mexico passed through Laredo (Ref 11, 22).

Commercial traffic between the U.S. and Mexico consists of a wide variety of imported and exported goods, as well as trade brought about by the maquiladora industry. Maquiladora factories are usually located in Mexico near the border. The related cross-border trade consists mostly of raw goods and components transported by trucks into Mexico, where they are assembled at a low cost into a finished product, and then are transported by trucks back to the U.S. The number of maquiladora plants located south of the border has increased dramatically since 1966, when there were 57 plants employing 4257 people and by 1990, over 468,000 people worked in the 2,014 maquiladora plants located along the U.S.-Mexico border (Ref 11).

In January 1994, NAFTA was enacted, which reduced trade restrictions between the U.S., Canada, and Mexico. Even more trade was stimulated between the U.S. and Mexico, until the peso devaluation in December 1994, which caused a temporary decrease in U.S. exports to Mexico, although the imports from Mexico continued to increase (Ref 13). Currently, trucks are able to travel freely only within a 24-mile (40-km) wide “commercial zone” between the two countries. The second phase of NAFTA, when implemented, will permit trucks from Mexico to travel freely within the four bordering U.S. states while trucks of U.S. origin will be permitted to travel within the six bordering Mexican states. The third phase will allow trucks access to all U.S. and Mexican states. This causes serious concern about the welfare of U.S. highways and bridges, in these border states not only because the number of trucks has increased over time, but also because a substantial percentage of these trucks may be overloaded or operating under unsafe conditions.

2.2 INFRASTRUCTURE ASSESSMENT

Highway infrastructure plays a key role in ground transportation efficiency. The major trade highways in Texas include I-35, which is a major north-south corridor into Mexico is along I-35, and serves the northeast and central regions of the U.S. (e.g., New York and Chicago) as well as Canada, areas which are major providers of maquiladoras’ raw materials. I-10 is also an important east-west route for truck access to Mexico from the northwest and west regions, and for cargo coming from ports on the Pacific Coast (Los Angeles, Long Beach) and also from the southeast. This is the most convenient corridor for cargo moving from the Pacific to eastern Mexico, a route made difficult by the lack of infrastructure and by the mountain topography on the Mexican side.

The American Association of State Highway Officials (AASHO) Road Test (trafficked 1958 to 1960), was conducted to determine under controlled conditions the relationship between selected axle loads and the associated performance of different thicknesses of various flexible and rigid pavement structures and a few bridges. Interpretation of the results indicated that there was approximately a “fourth power” relationship between the number of passes of a standard (18,000 lb/8.2 Mg/80 kN) single (dual tire) axle that would cause equivalent pavement damage to that resulting from one pass of an axle load (single or tandem) of a given magnitude. For example, a single axle loaded to 22,000 lb (10 Mg or 98 kN) compared to a single axle loaded to 18,000 lb (8.2 Mg or 80 kN), which is a 22% difference, will cause $(98/80)^4$ or 2.23 times as much damage as the 18,000 lb axle. Likewise, an axle that is 10% overloaded will cause 46% more damage than one at the legal limit.

Although the performance of highway pavements is of great concern, the serviceability of bridges is an even greater concern due to the possibly more catastrophic results if a bridge fails. Not only is the gross weight of the vehicle important, but also the number of axles per vehicle and their load and spacing. To address this, AASHTO developed the “bridge formula” which specifies the maximum load allowed for a group of axles within a given overall spacing. This was intended to protect older, existing bridges that had been designed for lighter loads from premature damage. In a 1993 study, it was found that 6,800 of the 47,900 bridges in Texas were incapable of carrying the current design vehicle load, of which, less than 10% are located on major highways maintained by TxDOT. The study report also showed that 50% of the bridges in Texas were over 30 years old (Ref 22). Although they were originally built with large safety factors, the increase in the number and the weight of vehicles has probably caused a significant decrease in the original margin of safety.

Reliable highway pavements and bridges are necessary in order to sustain heavy truck traffic loading. In Mexico, generally only the toll roads are suitable for long-haul truck traffic. In 1992, only 1.5% (3,160 km or 1,960 miles) of the entire paved road system in Mexico was four-lane, high-type pavement able to sustain truck traffic. Of this, less than 0.5% of the entire system, only 832 km (515 miles) were non-toll facilities (Ref 4, 22). A combined public and private funding approach has been used since 1989 to construct or improve some selected highways in Mexico. This has led to the construction of a few high-quality highways that have very high tolls. As a result of the high cost of using these improved roads, truckers continue to use the lower-toll or non-toll facilities. Therefore, much of the money allocated to highway projects has gone into constructing newer, high-toll roads that are not widely used. Meanwhile, the roads that are heavily traveled are nearly neglected for maintenance and therefore deteriorate at an even faster rate than before. The typical design life of a Mexican pavement structure is 15 years, although increased traffic, lack of weight enforcement, and relatively higher allowable axle loads have led to unexpectedly rapid deterioration of roadways in Mexico (Ref 22).

Although the deterioration of U.S. roads has increased, especially in the border region where the amount of truck traffic has grown considerably, the average design life of U.S. highways is 20 years, and the average design life of bridges is 75 years (Ref 22).

According to a 1991 study conducted by The Texas Department of Transportation (TxDOT) for the U.S. General Accounting Office (Ref 33), the highways on the Texas border with Mexico could not accommodate current traffic at desired levels of service and safety. The cost of upgrading these highways to meet the desired levels of service and safety was estimated at almost $850 million. This same study estimated additional highway needs for meeting the traffic increases that would result from a free trade agreement with Mexico (Table 2.1). With the exception of a few cases in which added capacity was considered, the high cost estimate was linked to the need for pavement structures to support the expected increase in truck traffic volumes. A basic assumption in the study was that overloads from Mexico would not be allowed on Texas highways, which is a central concern given the flagrant abuse of load limits by many Mexican truckers. According to these estimates, a 100-percent increase in trade, within a 10-year timeframe, results in about a six percent rise in the cost of highway projects if compared with the costs necessary to accommodate current traffic at desirable levels of service and safety.

Table 2.1. Estimated border highway infrastructure needs (Ref 33)

Area	Number of Projects	Current Costs	Costs at four levels of trade increase (percent) within a 10=year frame (millions U.S. $)			
			10	**25**	**50**	**100**
El Paso	12	$513	$517	$522	$527	$538
Del Rio	1	9	9	9	9	9
Laredo	6	127	127	129	133	135
Rio Grande Valley	25	94	95	96	97	101
U.S. 281	9	106	107	108	110	113
Subtotal	53	848	855	864	876	897
Trunk System	26	1,180	1,192	1,207	1,224	1,256
Total	**79**	**$2,028**	**$2,047**	**$2,071**	**$2,100**	**$2,153**

2.3 U.S. AND MEXICO TRUCK SIZE AND WEIGHT REGULATIONS

Currently, there is considerable disparity between U.S. and Mexican truck size and weight regulations, which is of great concern to the Texas Department of Transportation, the Texas Department of Public Safety, and other government agencies that work to protect and maintain the welfare of U.S. roads. To complicate matters further, states within the U.S. are allowed to set their own standards for all highways other than Interstates, and may exceed Federally-mandated load limits on Interstates if these limits existed prior to 1956 (Ref 32). As the border is opening up for less-restricted trade with Mexico, this concern increases as more and more trucks (no matter their origin) will be traveling through the border states.

Because of the potential increase in U.S.-Mexico trade, and as part of an attempt to identify the effects of the different regulations on the existing transportation infrastructure, policymakers on both sides of the border have focused on, among other things, truck size and weight regulations. It is likely that if an agreement is reached about weight and size standards by both countries, the suspended NAFTA phase which calls for commercial vehicle travel in adjacent international states may be implemented. However, before the agreement is reached, both countries, but more so the U.S., are trying to balance the economic benefits of efficient freight transportation with the costs that large trucks can impose through road wear, accidents, geometric requirements for roads and bridges, and interference with the flow of other traffic.

2.3.1 U.S. Regulations

Although highway size and weight regulations have always been a state responsibility, in 1932 AASHO recommended nationwide axle weight limits of 16,000 lb (7.257 Mg) for single-axles, and a tandem-axle limit based on axle spacing. In 1946, these limits were increased to 18,000 lb (8.165 Mg) for a single-axle and 32,000 lb (14.515 Mg) for tandem-axles, and a gross-vehicle weight of 73,280 lb (33.239 Mg) for vehicles with a distance between extreme axles of at least 57 ft (17.32 m). In 1974 Congress adopted recommendations made by the U.S. Secretary of Commerce in 1964, following the AASHO Road Test that was conducted in the late 1950's. These weight limits, which the State of Texas still enforces, were applicable to all roads in the U.S. that received Federal Aid and are summarized below.

- 20,000 lb (9.072 Mg) for a single axle,
- 34,000 lb (15.422 Mg) for tandem axles
- 42,000 lb (19.057 Mg) for tridem axles (This value is not directly specified; however, it is generally used, as it is the result of a direct application of the bridge formula.)
- a maximum gross-vehicle weight of 80,000 lb (36.287 Mg), and
- a maximum weight limit for any group of consecutive axles in order to protect bridges from premature deterioration. This maximum value is determined by the "bridge formula" (also known as Formula B) (Ref 33, 35):

$$W = 500 \times \left(\frac{LN}{N-1} + 12N + 36 \right)$$

where:

W = overall gross weight in pounds on any group of two or more consecutive axles to the nearest 500 lb

L = distance in feet between the extreme of the group of axles, and

N = number of axles in the group under consideration.

2.3.2 Texas Regulations

The State of Texas currently follows the U.S. federal regulations for truck weight. In addition, Texas has established size regulations, as shown in the 1995-1996 Texas Traffic Laws issued by the Texas Department of Public Safety (Ref 35). These size limitations include:

- The size shall not exceed 8.5 feet (2.6 m) in width and 13.5 feet (4.1 m) in height (including the width or height of any load on the vehicle).
- No motor vehicle (other than a truck-tractor) shall exceed 45 feet (13.7 m) in length.

- Any combination of three vehicle units to be coupled shall not exceed 65 feet (19.8 m).
- A semi-trailer may not exceed 59 feet (18 m) in length when operated in a truck-tractor and semi-trailer combination.
- A semi-trailer or trailer may not exceed a length of 28.5 feet (8.8 m) when operated in a truck-tractor, semi-trailer, and trailer combination.

Further regulations on trucks traveling through Texas are as follows (Ref 35):

- No vehicle shall have a greater weight than 600 pounds (0.272 Mg) per inch-width of tire upon any wheel using high-pressure tires, or 650 pounds (0.295 Mg) using low-pressure tires.
- No wheel shall carry a load that exceeds 8,000 pounds (3.629 Mg) on high-pressure tires, or 10,000 pounds (4.536 Mg) on low-pressure tires.
- No axle shall carry a load that exceeds 16,000 pounds (7.257 Mg) on high-pressure tires, or 20,000 pounds (9.072 Mg) on low-pressure tires.

2.3.3 Mexico Regulations

The size and weight regulations established by the Federal Government in Mexico are determined through the Dirección General de Autotransporte Federal (DGAF) under the Secretaría de Comunicaciones y Transportes (SCT). Prior to 1980, these regulations were somewhat similar to those of the U.S. However, in 1980, these limits were increased to the following (Ref 11):

- Maximum weight of a single axle with single tires – 5.5 ton (12,125 lb or 5.5 Mg)
- Maximum weight of a single axle with dual tires – 10 ton (22,050 lb or 10.0 Mg)
- Maximum weight of a tandem axle – 18 ton (40,000 lb or 18.143 Mg)
- Maximum weight of a tridem axle – 22.5 ton (49,600 lb or 22.5 Mg)
- Maximum gross vehicle weight of 77.5 ton (171,000 lb or 77.564 Mg)
- Maximum allowable length – 22.5 meters (72.2 feet)

The heavy vehicle regulations passed in 1980 included vehicle and road classifications that are used to further designate size and weight limits. Depending on the type of truck in operation, it may or may not be permitted to travel on specific roads.

The following three classifications describe the type of roadway and which types of vehicles may legally operate on the roadway (Ref 11, 22):

- Type A – “high type” pavements which are comparable to the U.S. highway system – all the classified vehicles are allowed to operate
- Type B – comparable to lesser (generally two-lane) rural highways – all buses, single-unit, and semi-trailer trucks are allowed to operate
- Type C – comparable to lesser (generally two-lane) rural highways – all buses and single-unit trucks are allowed to operate

Tables 2.2 and 2.3 show the axle-weight limits as well as the size and gross vehicle weight limits for each class of truck, and for each type of roadway.

Table 2.2. Truck axle weight limits in Mexico (Ref 11)

		ROAD TYPE					
		A		B		C	
Axle	Tires/ Axle	kg	lb	kg	lb	kg	lb
Single	2	5,500	12,125	5,000	11,023	4,000	8,818
Single	4	10,000	22,046	9,000	19,841	8,000	17,637
Dual	2	9,000	19,841	7,500	16,535	7,000	15,432
Dual	4	18,000	39,683	15,000	33,069	14,000	30,864
Triple	4	22,500	49,604	NA	NA	NA	NA

Table 2.3. Size and gross weight limits for vehicles in Mexico (Ref 11)									
				ROAD TYPE					
	OVERALL			A		B		C	
Truck Type	Height	Width	Length	kg	lb	kg	lb	kg	lb
C2	4.15 m or 13.62 ft	2.50 m or 8.20 ft	12.2 m (40.03 ft)	15,500	34,171	14,000	30,864	12,000	26,455
C3				23,500	51,808	20,000	44,092	18,000	39,683
C4				28,000	61,729	NA	NA	NA	NA
T2-S1			17.0 m (55.77 ft)	25,500	56,217	23,000	50,706		
T2-S2				33,500	73,854	29,000	63,933		
T2-S3				38,000	83,775	NA	NA		
T3-S2				41,500	91,491	35,000	77,161		
T3-S3				46,000	101,412				
C2-R2			19.0 m (62.34 ft)	35,500	78,263				
C3-R2				43,500	95,900				
C3-R3				51,500	113,537				
T2-S1-R2			22.0 m (72.18 ft)	45,500	100,309				
T2-S2-R2				61,500	135,583				
T3-S1-R2				53,500	117,946				
T3-S2-R2				61,500	135,583				
T3-S2-R3				69,500	153,220				
T3-S2-R4				77,500	170,857				

2.3.4 Comparison of Size and Weight Regulations

The differences in size regulations between the two countries are not large; U.S. truck limits are at nearly the same height, are 4 percent wider, and 10 percent shorter than Mexican trucks. Table 2.4 shows the difference between the size constraints for each country.

As may be seen in Table 2.5, the difference in weight regulations is of slightly more concern, as the Mexican limits are 10 to 18 percent higher than those of the U.S. However, the weight limit for a single-tire, single axle is 12,125 lb (5.5 Mg) in Mexico, whereas in the U.S. the single-axle limit is 20,000 lb (9.072 Mg), tacitly assuming dual tires.

Table 2.4. U.S. – Mexico truck size regulations (Ref 11)					
Dimension	U.S. feet	Mexico feet	U.S. meters	Mexico meters	% Difference
Width	8.50	8.20	2.60	2.50	+4
Height	13.5	13.62	4.11	4.15	-1
Maximum Length	65	72.18	19.81	22.00	-10

Table 2.5. U.S. – Mexico truck axle weight limits (Ref 11)			
Type of axle	U.S.* (lb)	Mexico** (lb)	% Difference
Single-axle	20,000	12,125	+39
Single-axle w/dual tires	20,000	22,050	-10
Tandem-axle	34,000	40,000	-17
Tridem-axle	42,000	50,000	-18

*Federal Regulations
**Regulations for road type A

Although the size and weight regulations do not differ significantly, the enforcement and its uniformity differs between the two countries. In Mexico, the federal government sets the standard applicable in all states. However, in the U.S., regulations are set at the state level and are, therefore, not uniform throughout the country (Ref 11). This may cause some trucking companies difficulty when trying to transport a load through a number of states with differing size and weight limits. It is important to note that although Mexico has size and weight regulations, they are not always enforced. This enables trucking companies to load trucks and trailers until they have reached the carrying capacity of the vehicle itself, not until they have reached the legal limitations of the federal government.

2.4 CURRENT CONDITIONS ALONG THE BORDER

A recent study along the Texas-Mexico border has produced quantitative data about the patterns of truck traffic: the number and type of vehicles, axle loading practices and patterns, as well as the gross-vehicle weight and the corresponding number of equivalent single axle loads (ESALs) for most northbound trucks entering the U.S. and southbound trucks entering Mexico at Laredo and El Paso.

2.4.1 1993-1995 Study Using Weigh-in-Motion Systems at Laredo and El Paso

Weigh-in-motion (WIM) data collection sites were located at the two most heavily trafficked ports-of-entry between Texas and Mexico; Laredo and El Paso. The freight through Laredo consists mostly of export and import traffic, while the freight at El Paso comprises mostly goods transferred to and from the maquiladora industry. The WIM sites were located in the U.S. near the north end of the Rio Grande bridges, and were used to gather data on all trucks traveling out of Mexico into Texas from 1993 to 1995. The classification of two of the primary trucks studied includes: 3S2, which is a 5-axle truck with 3 on the tractor (one steering axle, and a tandem drive axle), and 2 on the semi-trailer (a tandem axle). A 3S3 truck has 6 total axles; 3 on the tractor and 3 (tridem) on the semi-trailer.

The results of the data show that for the northbound direction in 1994, 23% of the observed tandem-axle loads on loaded 3S2's in Laredo were above the U.S. legal limit. In El Paso, 11% exceeded the limit. For 1995, results show that in Laredo, 35% exceeded the U.S. legal limit and in El Paso, 25% were above the limit. For 1995 at Laredo, 7.6% of the overloaded northbound trucks were 12 to 24 percent over the legal load, and in El Paso, 6% of overloaded northbound trucks were observed to be within this same range.

In the southbound direction, a larger proportion of trucks was overloaded. In 1994 at El Paso, 22% of the tractor-tandem and 13% of the trailer-tandem axles were overloaded by 12 to 23%. In 1995, the proportion of overloaded tandem-axle trucks was 36%, 24 percent of which were more than 12% overloaded. The authors state that the larger percentage of overloaded trucks in the southbound direction could be due to the fact that weight limits in Mexico are higher than those of the U.S., as well as the reputed lack of enforcement. Therefore drivers may risk overloading their trucks in the U.S. in order to maximize their load while traveling through Mexico.

The 3S2 comprised 67% of the total northbound truck traffic weighed at Laredo and 82% at El Paso. The average weekday count of 3S2's was 675 per day in El Paso and 925 per day in Laredo.

The percentage of overweight 3S3's is much higher than that of the 3S2's. For the northbound direction in Laredo, 87% of the tridem-axle loads on six-axle trucks surpassed the legal limit, and in El Paso, 80% of the tridem axles were overloaded. However, these trucks were a small percentage of total truck traffic, 3% and 2% in Laredo and El Paso, respectively. Although the actual number of trucks is small, loads on tridem-axles ranged up to 60% over the legal limit at both Laredo and El Paso. The average weekday count of 3S3's was 13 in El Paso and 43 in Laredo (Ref 14).

2.4.2 1991 Study of Weight Limit Compliance in Mexico

In 1991, the Instituto Mexicano del Transporte Secretaría de Comunicaciones y Transportes conducted a study of the compliance with Mexican weight regulations. Results of the study showed that there were routine violations of the regulations, and that nearly 30% of 5-axle trucks exceeded limits by an average of 18%. Although the number of 6-axle trucks is much smaller, over 40% of 6-axle trucks exceeded legal limits by an average of 28%. Considering that the Mexican weight limits are already 10-18% higher than those of the U.S., if 30 to 40 percent of Mexican trucks already exceed the legal Mexican limit, this should cause even more concern for U.S. bridges and highways (Ref 22).

2.5 SUMMARY

An overview of the history of trade growth between Texas and Mexico that has led to the current conditions is provided in this chapter. The growth in truck traffic is of special concern to the border states, as all border-crossing trucks pass over their highways. A research study from 1993 to 1995 at El Paso and Laredo on the Texas-Mexico border, using WIM sensors for data collection, revealed that 25% of the tandem axle loads on loaded northbound 5-axle, tractor semi-trailer trucks (these comprised 82% of the approximately 675 trucks weighed per weekday) at El Paso exceeded the U.S. legal limit. This truck type accounted for 67% of the approximately 925 trucks per weekday from Mexico weighed at Laredo, and about 35% of their tandem axles were overloaded by U.S. limits. The tridem axles on more than 80% of the semi-trailers towed by a three-axle tractor (13 trucks per weekday in El Paso and 43 per day in Laredo) exceeded the U.S. load limit; some were as much as 60% over the 42,000 lb (19 Mg) limit. This causes a great concern to decision makers especially when considering the results of a 1991 TxDOT study which indicated that the existing Texas-Mexico border transportation infrastructure is inadequate to accommodate the current traffic at the desired level of service and safety. Included in this chapter is a summary of the current size and weight regulations of the U.S., Texas, and Mexico.

CHAPTER THREE – CURRENT WEIGHING TECHNIQUES

In this chapter, the current methods of weight enforcement in Texas, as well as WIM systems potentially applicable in Texas' weight enforcement program are described and evaluated according to their productivity, cost, accuracy, and use. For several decades, the United States has been expanding inspections and enforcement programs nationwide to encourage safer U.S. trucks and truck operation on highways. Through the Motor Carrier Safety Assistance Program (MCSAP), the U.S. Department of Transportation (DOT) works in partnership with states to enforce federal truck regulations. As the states adopt federally-recommended safety and weight regulations, DOT provides financial assistance for enforcement. Although DOT maintains a presence in all states by requiring them to comply with minimum federal regulations and requirements related to truck safety and weight limits, it relies on the states to develop their own strategies for enforcement.

With about 66 percent of all truck traffic entering from Mexico (more than 2 million truck-crossings in fiscal year 1996) through four of the seven major U.S. border crossing locations, Texas continues to face the greatest enforcement burden. Texas's situation has been more complicated because three of its major locations have had two or three bridges each, where trucks cross the Rio Grande into the United States. However, in mid-1996 customs consolidated the truck traffic in McAllen by closing one of the two bridges to northbound trucks. Such consolidation might be possible for other major Texas locations. As of this date, Texas has no permanent truck inspection and weight enforcement facilities at any of its 11 border locations. In Laredo, for example, inspectors work in an uncovered parking area in extreme heat and humidity for much of the year. On the other hand, state and federal officials have announced plans to retrofit some existing buildings to establish a truck inspection facility at Texas's fourth busiest truck crossing location just outside McAllen, although they have not set a completion date for this project

This lack of permanent truck inspection and weight enforcement facilities at the border crossings, although, they may have little effect on intrastate routes since they only control international movements, is of considerable concern to state highway officials. Texas depends heavily on the Texas Department of Public Safety (DPS) to enforce safety and weight limits along Texas highways. One significant responsibility with which DPS is charged is regulating the operations of commercial vehicles in Texas, including the enforcement of the state's size and weight limitations in order to protect the highway infrastructure from premature destruction by overweight vehicles. This is done with the help of 362 commissioned officers in the Texas DPS's License and Weight Service using the available equipment and the State and Federal guidelines.

3.1 CURRENT STATIC WEIGHING TECHNIQUES

The Department of Public Safety currently uses three types of static weighing devices in their enforcement program, which they refer to as permanent scales (or fixed scales), semi-portable scales (or trailer scales), and portable scales (or hand scales). In the National Institute of Standards and Technology (NIST) Handbook 44 (1998), "Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices," these devices are called axle-load scales, portable axle-load weighers, and wheel-load weighers, respectively (Ref 26). The scales operate at different levels of efficiency, accuracy, cost, and function. This section includes a comparison of these scales to each other. Table 3.1 indicates some of the major differences between these scales.

Table 3.1. Comparison of static weighing techniques

	Wheel Load Weighers	Portable Axle-Load Weighers	Axle-load Scales
Tolerance	± 1% acceptance ± 2% maintenance	± 1% acceptance ± 2% maintenance	± 0.1% acceptance ± 0.2% maintenance
Units DPS owns	1,216	28	38
Cost estimates	$1200-$2000	$20,000-$30,000	$300,000
Malfunction rate	"not too often" 5-10% a month	"very often"	"very infrequently"
Time to weigh one truck	30-45 minutes with inspection; 10 minutes just weighing	5 minutes "once set up"	1-3 minutes
Trucks that can be weighed in one 8-hour period	10-12	35-45	160-240
Personnel used	1 trooper	3-4 troopers	2-10 troopers

3.1.1 Permanent Weigh Stations

DPS operates 38 weigh stations equipped with permanent scales throughout the State, of which half (19) are located along interstate highways. The permanent stations are operated from as little as 2 hours to as much as 3 days of continuous operation. The number of personnel used during each period of operation varies from two to ten officers (Ref 28). The setup and configuration of the permanent scales varies at different sites, depending on the right-of-way (ROW) obtainable and the amenities (electricity, water, telephone lines) available. The total cost of a fixed weigh station in Texas is estimated at $300,000 including the cost of ROW (Ref 28). Axle-load scales have the smallest tolerances among the scale types used by DPS, at ± 0.1% and ± 0.2% acceptance and maintenance tolerance, respectively (Ref 26). They are designed to measure the load on each axle-group and require a flat, level, stable surface. These fixed scales are durable and generally require little maintenance. One weigh station now in use by DPS is equipped with permanent scales, along with a WIM sorting system. This site, which opened in November 1997, is located on I-35 near Devine, Texas, and is the first station in Texas that utilizes in-motion weighing to sort suspected overloaded vehicles from the truck-traffic stream to be weighed on static scales. The operations at this station are described in more detail in Chapter 4.

3.1.2 Portable Scales

Weight enforcement officers use portable scales to weigh commercial trucks by the side of the road when they believe that the vehicle might be overloaded. Texas DPS uses PT300 wheel-load weighers manufactured by Intercomp, with dimensions of 20 x 10 x 3 ¼ in.(508 x 254 x 83 mm), as shown in Figure 3.1.

Figure 3.1. PT300 wheel-load weigher (portable scale)

An officer carries four of these scales in the trunk of his or her vehicle. The wheel load weighers cost about $1200-$2000, and weigh 40 to 50 pounds (18 to 23 kg) each, depending on the model. Axle loads measured with these scales are not as accurate as those from permanent scales, as they weigh each wheel on the axle individually, and the tire is lifted several inches as it is positioned on the scale. Their tolerance is ± 1% and ± 2% for acceptance and for maintenance, respectively (Ref 26). The scales indicate the load on each wheel in 50-pound (23 kg) increments and have a maximum capacity of 20,000 pounds (9000 kg). Each of the 319 License & Weight vehicles is equipped with four wheel-load weighers. DPS has a total of 1,216 devices, so the remaining scales are distributed to each sergeant district to be used as spares for broken or inoperable ones. These scales are known to break more often than permanent scales; in one district about 5-10 percent of the scales break each month (Ref 28).

Before weighing a truck, an officer considers the fact that they must have probable cause to pull the truck over, and they do not want to waste time and energy (especially in Texas heat) weighing and inspecting a truck that is possibly not overweight. Generally, troopers use previous experience and judgement to decide whether a truck is possibly overweight or unsafe and should be pulled to the side of the road for weighing and inspection. Certain hauling companies are notorious for unsafe or overweight driving conditions. Other visual clues are the length of the tire contact, the amount of smoke blowing out its exhaust, the type of load being carried, and unkempt-looking trucks, which may need a thorough inspection. When a possibly-overweight or unsafe-looking truck is identified, the trooper must signal to the driver to follow their car until a safe, level place is found to pull off to the side of the road. Once the truck is safely stopped beside the road, the officer places a wheel-loader weigher before each tire of the steering axle and the truck pulls onto the scale to indicate the load on the front axle. Subsequently, the trooper places a wheel-load weigher in front of the outside tire on each axle of an axle-group, then the truck pulls up and stops with the tires centered on the weighers. All indicated wheel loads are recorded before the next axle-group is weighed. Several photographs taken in Laredo Texas are shown in Figures 3.2 and 3.3; these show the steps a trooper takes in the process of measuring the axle loads of a truck. The gross-vehicle weight is the sum of all the wheel loads of a vehicle. Since the troopers generally carry four weighers in their vehicle, they need to repeat the process for each axle of a tridem-axle truck.

Figure 3.2. Trooper weighs steering axle, then drive axle

Figure 3.3. Trooper places weighers and measures axle-group load

The officer reads the value on the digital display of each wheel-load weigher (as seen in Figure 3.4), sums them, and then compares them with the appropriate legal limits. The trooper may also use axle-group loads and axle-spacing to hand calculate possible bridge-formula violations.

Figure 3.4. Digital display of wheel-load weigher

It takes about 30 to 45 minutes to weigh a truck, perform an inspection, and write the citation, if necessary. It generally takes about 10 minutes to actually weigh a truck, and can take even longer if the truck driver is not cooperative. Weighing and inspecting a single truck using portable scales is a time consuming task, and is especially more intolerable if it is done in hot and humid weather.

One concern about this method of weighing is that all wheels of the truck are not on a level surface when a wheel load is being measured. Some load shift occurs when a wheel is raised on top of the weighing device while the wheels on other axles are on the surrounding, approximately-level pavement surface. The height of the wheel-load weigher is about 3 ¼ in. (83 mm), which causes a difference between the actual load and the measured load since the wheels are not on a level plane. Although the weigher itself measures the load that has been applied within specified tolerances, the portion of the gross-vehicle weight on the wheel has been shifted so that the applied load at the time of measurement is not the same as when all wheels are on a level, plane surface.

Semi-Portable Scales

The Texas Department of Public Safety has a set of semi-portable scales for each of the 28 sergeant-districts that it operates. The semi-portable scale, also called a portable axle-load weigher, is a transportable platform scale about 4 in. (100 mm) high and 30 in. (760 mm) wide, with a ramp at each end, designed to weigh a single, tandem, or tridem axle group. This scale is usually transported on a special trailer behind a pickup truck or van. It can be used on the road surface in a roving operation or set in pits at a permanent site. Once these scales are set up, trucks can be weighed faster than they can by the portable scales. The enforcement officer is provided with a digital readout of the weight, and the equipment can be powered from the 12-volt battery of any vehicle. The scales are usually available in 7 and 12-ft (2.1 and 3.7-m) lengths. Several scales can be connected to provide for a longer weighing platform. Figure 3.5 shows a set of semi-portable scales.

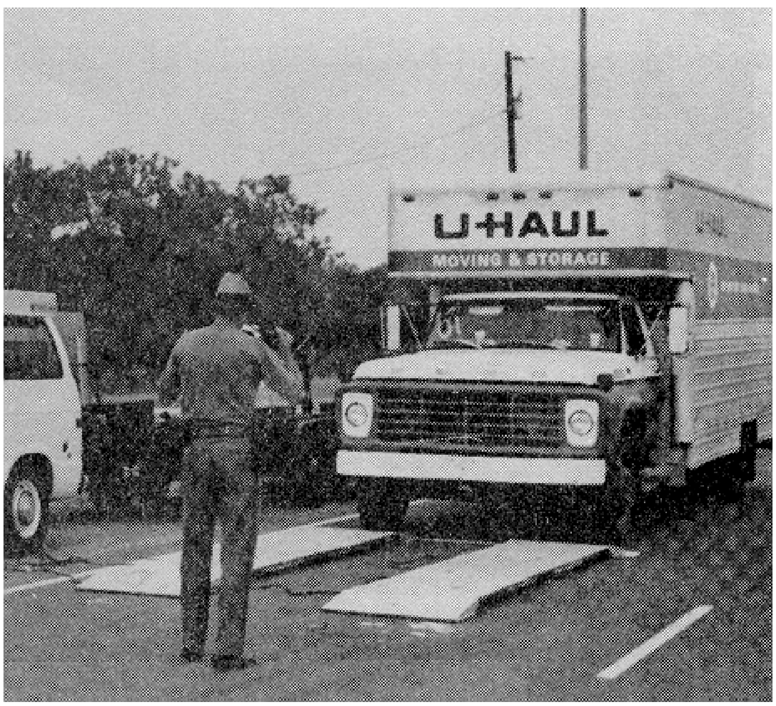


Figure 3.5. Portable axle-load weigher (semi-portable scale) (Ref 21)

The semi-portable scales are used to complement permanent and portable scales. . They are generally used at DPS-selected weigh sites that are suitable for operation at most effective times chosen by the DPS officers. The sites generally are paved, level weigh areas constructed by TxDOT which are not equipped with permanent scales. They are sometimes used on the improved shoulders of highways and by-pass routes. The cost of a semi-portable scale is about $20,000 to $30,000, and they frequently require maintenance (Ref 28). The tolerance of semi-portable scales is the same as that of the portable scales; at ± 1% for acceptance and ± 2% for maintenance (Ref 26). DPS usually operates semi-portable scales for a minimum of two hours at a time with at least three troopers (Ref 28). It generally takes about 10 to 30 minutes to set up the scale and prepare for weighing operation after arriving at a site. Once the scale is set up, it generally takes an average of about 5 to 10 minutes to weigh a truck.

The inaccuracy of using portable axle-load weighers is similar to that of wheel-load weighers, as all axles on the truck are not on a flat, level surface while they are being weighed. Although the semi-portable scales require less time for weighing each vehicle, some DPS troopers say that it is their least favored among the different scales available, as they require frequent maintenance and are more cumbersome and difficult to work with (Ref 10).

3.1.3 Types of Inspections

NAFTA's three member nations have accepted the truck inspection standards established by the Commercial Vehicle Safety Alliance (CVSA). For the most part, there are two types of inspections conducted according to the trilaterally-accepted truck inspection guidelines- "Level 1" and "Level 2" inspections. The Level 1 is the most rigorous and includes a full inspection of both the driver and the vehicle. The driver inspection includes ensuring that the driver has a valid driver's license, is medically qualified, and has an updated logbook showing the hours of service. The vehicle inspection includes a visual inspection of the tires and of the brake air pressure, and an undercarriage inspection that covers the brakes, frame, and suspension. The Level 2 inspection is a "walk-around inspection," and includes a driver inspection and a visual inspection of the vehicle. It does not include the careful undercarriage inspection. Trucks that fail these inspections for serious safety violations are usually placed out of service until the needed repairs are made.

Level-1 and Level-2 inspections constitute about 80 percent of the inspections nationwide. Level 3 inspections, which accounts for about 18 percent of all inspections, focus on the driver's records rather than the vehicle's condition. Level-4 and Level-5 inspections, which constitute fewer than 2 percent of all inspections, are special purpose inspections (Ref 39).

3.2 WEIGH-IN-MOTION TECHNOLOGY

The concept of in-motion weighing is that wheel, axle, or axle-group load, and gross-vehicle weight can be estimated from instantaneous measurements of the vertical component of the dynamic (continually changing) force that is applied to the road surface by the tires of a moving vehicle (Ref 21). A weigh-in-motion system performs two basic functions; (1) it detects the presence of a vehicle, then measures and records the vertical component of the dynamic force from each wheel, axle, or group of axles crossing the sensors, and (2) it translates these dynamic forces into equivalent static loads. The WIM system can also calculate and perform several other functions such as detecting bridge-formula violations.

Weigh-in motion (WIM) technology has been used extensively for data collection throughout the United States, Canada, and in several South American and European countries. A number of WIM systems have been placed in the main lanes of traffic to capture data on every vehicle that crosses its sensors. As a result, these systems obtain a near 100 percent sample of vehicle speed, axle spacing, axle and axle-group load, as well as gross-vehicle weight data. Since the early 1950's, WIM systems have evolved and improved in many areas; in accuracy, cost, ease of installation, efficiency, reliability, durability, communications capability, and data storage ability.

A number of in-motion weighing technologies are commercially available today. Some examples of the WIM sensors now in use include hydraulic single load cell, bending plate, low-profile, and piezo-electric systems. In addition, new WIM sensors using piezo-quartz crystal and fiber optic technology, are being developed and tested.

3.2.1 ASTM Standard

ASTM E 1318-94 describes four types of WIM systems; Types I and II to be used in data collection and Types III and IV for enforcement applications. For purposes of this report, only Types III and IV will be discussed. The WIM system classification depends on the tolerances and the data items measured/calculated by the system. Type III systems are designed for installation in one or two lanes, to function at vehicle speeds of 15 to 50 mph (16 to 113 km/h), and Type IV systems are designed for speeds of 0 to 10 mph (0 to 16 km/h). The standards state that for Type III systems, automatic traffic-control devices can be used to direct trucks to bypass the static scales without stopping or to proceed to a static scale for weight verification. Type III and IV systems are specified to produce the data items shown in Table 3.2. They will subsequently calculate and detect any wheel, axle, axle-group, gross-weight, bridge formula violations, speed, and axle-spacing within the tolerances stated in Table 3.3.

Table 3.2. Data Items Produced by WIM System Types III and IV (Ref 2)	
1	Wheel Load
2	Axle Load
3	Axle-Group Load
4	Gross-Vehicle Weight
5	Speed
6	Center-to-Center Spacing Between Axles
7	Site Identification Code
8	Lane and Direction of Travel*
9	Date and Time of Passage
10	Sequential Vehicle Record Number
11	Violation Code

*Not applicable to Type IV

Table 3.3. Functional Performance Requirements for WIM Systems (Ref 2)

Tolerance for 95% Probability of Conformity					
Function	Type I	Type II	Type III	Type IV	
				Value ≥ lb (kg)	± lb (kg)
Wheel Load	± 25 %		± 20 %	5000 (2300)	250 (100)
Axle Load	± 20 %	± 30 %	± 15 %	12000 (5400)	500 (200)
Axle-Group Load	± 15 %	± 20 %	± 10 %	25000 (11300)	1200 (500)
Gross-Vehicle Weight	± 10 %	± 15 %	± 6 %	60000 (27200)	2500 (1100)
Speed	± 1 mph (2 km/h)				
Axle-Spacing	± 0.5 ft (150 mm)				

Although there are a number of WIM systems available today, the focus of this report will be on the bending plate sensor and the hydraulic single load cell sensor, as they are the most common and are capable of meeting ASTM standards for enforcement screening. In order for a broader comparison several other types of systems will be discussed briefly: piezo-electric systems, low-profile strain gage, and piezo-quartz sensors.

3.2.2 Hydraulic Single Load Cell Sensor

The single load cell tire-force sensor is the largest in the WIM market; it comprises two rectangular weighing platforms that are 6' 0" wide by 1'9" long by 9" deep. (1.8 m x 530 mm x 230 mm). Since the sensor is so large, construction costs are relatively high due to the need for a large, approximately 3-ft (0.9-m) deep steel-reinforced Portland Cement Concrete (PCC) pit to support it, mechanical hoists to handle it, and provision for adequate drainage (Ref 8). The PCC needs a long cure time (which takes up to 28 days), and is therefore not normally practicable for mainlane installations. In consideration of the required traffic control, this sensor is better suited for weigh stations off the mainlanes so that no traffic is disrupted while the PCC pit and approach slab are curing. Load cell sensors are applicable in the Type III category.

In addition to the two platforms at a site (one in each wheel path), an axle sensor is placed several feet downstream from the weighpads to measure time between axles, which is used in bridge-formula and other calculations. Two inductive loops are placed in the pavement before and after the sensor platforms to determine the presence of a vehicle and to measure its speed.

As this system is large and durable, there are usually minimal maintenance costs. The load cell itself is only one small component located in the top, middle of the platform. If the load cell fails, it is easily accessible from the surface for repair or replacement without having to remove the entire platform from the pavement. The single load cell sensor, which was introduced about 1968, has proven to be quite robust; some systems installed in the 1970's are still operating today (Ref 9).

3.2.3 Bending Plate Sensor

The bending plate tire-force sensor consists of a rectangular steel plate that is 6'0" wide by 1'8" long by 0.9" deep (1.8 m x 510 mm x 23 mm). Strain gages placed in strategic locations measure bending strain in the plate under applied tire loads. The entire sensor is encased in a vulcanized synthetic rubber in order to protect the gages from the environment. This sensor can measure wheel loads up to 40,000 lb (18.143 Mg) (Ref 8).

Since the bending plate weighpad frame is only about 2 in. (50 mm) deep installation usually requires only a shallow cut-out section of pavement. It can be installed in the mainlanes of travel in a few hours. If the weighpads are to be installed in an existing rigid pavement, the surface may only need to be ground smooth before cutting the shallow pit. The system can also be installed in flexible pavement; however, rigid pavement usually remains smooth for a longer period of time. If existing flexible pavement on the mainlanes is replaced by rigid pavement for 200-300 ft (60-90 m), installation costs will increase due to the cost of materials, construction, lane closures, and traffic control. These sensors are suitable for Type III systems. Many bending plate sensors have functioned for 12 years or more under heavy traffic (Ref 9).

3.2.4 Other Sensors

A piezo-electric tire-force sensor generates an electrical charge (voltage) when an imposed tire load mechanically deforms (deflects) the sensitive ceramic material that is usually shaped into the hollow-cylinder form of a cable and contained between coaxial metal conductors. The cable is typically encased in an elastomer surround and installed in a shallow groove sawn into the pavement with the surface of the elastomer flush with, or slightly above, the adjacent pavement surface to receive the tire pressure from the wheels of a moving vehicle. The charge is amplified, integrated, and then used as a basis for estimating the static wheel load, using certain calibration factors (Ref 23). Piezo-electric sensors are simple and relatively inexpensive to install due to their small size. However, the accuracy suffers because the full tire-contact area is not on the force sensor simultaneously, and there is a bridging effect of the tire that transfers force to the adjacent pavement surface, and temperature affects the stiffness of the elastomer that transfers tire force to the piezo material and springs it back after the load has been removed. They are not considered accurate enough to be used for enforcement sorting (ASTM Type III); and are therefore better suited for data collection (ASTM Type II) (Ref 9).

A newly-designed piezo-quartz tire-force sensor entered the WIM market in 1996. It utilizes a series of piezo-quartz wafers arranged in a hollow cavity in the vertical web of an “I”-shaped metal strip to sense the compressive deformation in the wafers caused by a tire load on the top flange and generate an electric charge (voltage) that is proportional to only the vertical component of the applied tire force. The bottom flange is supported by epoxy in the bottom of a 3 in x 3 in (76 mm x 76 mm) groove cut transversely in the paved traffic lane. Foamed plastic material fills the area between the flanges on each side of the web and isolates the wafers from sensing any horizontal deformation of the surrounding pavement (Ref 7). Although this type sensor has not yet been evaluated extensively in practice, it is expected to have a low initial installation cost as it is similar in size and shape to the familiar piezo-electric strips. It will probably be more accurate and more durable than piezo-electric sensors (Ref 9).

The low-profile tire-force sensor was introduced into the WIM market several years ago. This sensor is similar in size to the bending plate sensor and in some literature, is described as a bending plate sensor. It is important to distinguish between the two, however. The original bending-plate sensor (circa 1968) has gages uniquely arranged on a single steel plate to sense bending strain in the plate at selected locations. The low-profile sensor comprises multiple strain-gaged elements attached to a steel plate, which in fact bends under imposed tire loads, but shear strain – not bending strain – is measured by the gages to indicate applied tire force. Experience in several states has shown that the low-profile sensor is not nearly as durable as the bending plate, and some sensors have failed, and even dislodged from the pavement, after only a few months in service (Ref 18).

3.2.5 Further Comparison of the Sensors

Bending plate sensors have been installed in more than 1500 lanes worldwide, and single load cell sensors have been installed in about 100 lanes. Low-profile sensors have been placed in over 1,000 lanes and approximately 2,000 lanes have been equipped with piezo-electric sensors. Piezo-quartz sensors have only recently come into the market (1996), and are still being evaluated. Fiber optic systems are not yet fully developed and are still under investigation (Ref 9).

Table 3.4 shows a qualitative comparison of the cost, maintenance, and accuracy of these sensors, as reported in "Traffic Technology International."

Table 3.4. Qualitative Comparison of WIM Sensors (Ref 9)

Sensor Type	Level of Usage	Cost	Upkeep cost	Accuracy
Load cell	Restricted	High	Low	High
Bending plate	Common	Moderate	Moderate	Moderate
Piezo-electric	Common	Low	High	Low
Quartz crystal	Growing	Low-mod	Moderate	Moderate

3.3 SUMMARY

The Department of Public Safety currently uses three types of devices to weigh trucks statically for enforcement: wheel-load weighers (1,216 units), portable axle-load weighers (28 units), and axle scales (38 stations). In 1997 the first WIM-sorter-equipped weigh station in Texas became operational on I-35 near Devine, Texas. This chapter contains a description of each device, how they are used, and their capabilities and constraints. In addition, the concept of weigh-in-motion (WIM) technology and the current ASTM Standard for WIM systems are presented. Several WIM tire-force sensors are described briefly and compared to each other according to cost, accuracy, and durability.

CHAPTER FOUR – EVALUATION AND COMPARISON OF STATIC AND WIM TECHNIQUES

There are a number of significant differences between static and in-motion truck weighing methods. Thus, there is continual concern about which method is most appropriate for use in achieving the results needed by an enforcement officer or a weight-enforcement agency. Undoubtedly, more truck size and weight enforcement activity in Texas will decrease the potential number of ESALs and overloaded or unsafe trucks on our highways for two principle reasons:

(1) a larger number of overloaded or unsafe vehicles can be intercepted at enforcement sites and
(2) truck drivers and trucking companies will be less likely to overload their vehicles when it is well known throughout the trucking industry that Texas has extensive and effective enforcement.

The question is, how can weight enforcement be increased in the most effective, and cost-effective, manner? Two options can be considered:

- Continue using solely static weighing methods – increase personnel and increase the amount of equipment to provide greater coverage
- Use in-motion methods in conjunction with static methods – construct strategically-located WIM sites and utilize existing personnel and static equipment

The differences between these two options, including advantages and disadvantages of WIM vs. traditional static methods are enumerated and discussed in this chapter. Estimated initial and operational costs of weigh station components are illustrated and used as a basis for evaluating the potential cost-effectiveness of different types of enforcement weighing. These differences should be evaluated carefully before deciding which method is most appropriate for achieving the results an enforcement officer or weight-enforcement agency desires.

4.1 ADVANTAGES OF WIM

4.1.1 Vehicle Processing Rate

The vehicle processing rate is one of the major advantages of WIM over static weighing. More trucks can be weighed in a shorter period of time by WIM, thus providing more efficient operations. Currently, three speed levels of WIM systems have been developed; low-speed (LSWIM) which measures at speeds up to 10 mph, intermediate-speed (ISWIM), which weighs at speeds of 10-30 mph, and high-speed (HSWIM) systems which weigh at speeds of about 55 mph (Ref 21). The rate of vehicle processing therefore depends on the speed capability of the WIM system used. The time required for a truck to travel across the sensor can range from merely a fraction of a second to several seconds per vehicle, depending on the speed.

It takes an officer at least 10 minutes to weigh a truck using portable scales, and once the scales are set up, it takes about 5 minutes to weigh a truck using semi-portable scales. At permanent stations, productivity increases and an officer can weigh a truck in 1 to 3 minutes. At a station where WIM is used as a sorting device, it only takes a few seconds for the truck to pass over the weighpads at intermediate speeds. The number of trucks that need to be weighed statically after WIM sorting is only a small percentage of all trucks that pass over the WIM sensors. This fast processing rate by WIM allows for a number of other advantages; larger and less-biased samples, safer weighing operations, and fewer personnel needed per truck weighed.

4.1.2 Larger Sampling and Less Bias

Since in-motion scales measure every truck that crosses the sensors in the roadway, they are able to obtain a larger and more representative sample of the truck population than is feasible with current static scale methods of truck weighing. Presently, officers using portable or semi-portable scales stop and weigh trucks that appear to be overweight. They look for certain conditions that indicate that a truck is likely to be overloaded or unsafe, such as tires that are significantly flattened, excessive smoke blowing out the exhaust, or a questionable condition of the truck. In addition, some trucking companies are more notorious for driving with unsafe or overloaded equipment than others. A weight enforcement officer uses these indications before stopping a truck in order to optimize the use of their time and resources.

Once a permanent scale is opened, it generally remains open until an excessive queue forms back to the highway mainlanes. In some locations, such as was observed outside Laredo, Texas, this may take only a few minutes. The queue of trucks shown in Figure 4.1, formed at the permanent station along I-35 near Laredo, TX merely five minutes after the weigh station was opened. The queue built up quickly and officers had to close the station temporarily to allow subsequently-arriving trucks to pass by in order to provide safer conditions along the highway. As a result, a number of trucks were allowed to bypass the station without being weighed.

Figure 4.1. Queue of trucks at a fixed-scale station in Laredo, TX

Using a WIM sorting device can enable all trucks not suspected of being overweight to bypass the static scales. Every vehicle is weighed over the WIM scales, but only the suspected violators (a much smaller percentage) stop to be checked on the static scales. As a result, the length of the queue of trucks to be weighed on the static scales is much shorter, the queue *rarely* backs up to the highway, and it is *rarely* necessary to bypass trucks without weighing them.

4.1.3 Safety

The use of weigh-in-motion systems is safer than using permanent, semi-portable, or portable scales. In the case of permanent scales, when a queue backs up on the exit ramp to the weigh station and possibly back to the highway, trucks traveling in the right-hand highway lane are decelerating to enter the weigh station, while passenger cars and other vehicles are traveling at highway speeds; this invites rear-end collisions. However, if trucks are advised to exit at a properly-designed WIM sorter station, they are able to enter the ramp at or near highway design speed, decelerate comfortably on the ramp to the posted ramp speed, and maintain that speed over the WIM sensors. Non-violators do not stop in the weigh station; they are directed back to the mainlanes. Only suspected violators, a small percent of all trucks, are required to stop for static weighing and queues seldom form.

Portable and semi-portable scales are used either on the shoulder beside the road or in improved areas near the mainlanes. These locations are unsafe for both the truck and driver and the officer weighing the truck, as they are located just off the traveled way where high-speed traffic is passing by.

4.1.4 Continuous operation

The permanent weigh stations in Texas generally run for several hours at a time (Ref 28). Also, when a permanent scale opens, word is out over the truckers' radios that the scales are open, and truckers who know they are overweight will either "wait-it-out" or bypass the scales on an alternate route. If a WIM station were operated for only several hours at a time, it could also be waited-out or bypassed. However, since WIM has a much greater capacity for trucks, while requiring minimum personnel, it can feasibly operate continuously over long periods of time. Although permanent and portable scales could also be operated continuously, it would take a significantly larger number of personnel to weigh as many trucks as a station using WIM as a sorting device.

4.1.5 Number of Personnel Required/Number of Trucks Weighed per Person

As described in Section 4.1.1, the processing rate of a WIM screening system is much greater than any type of static weighing device. A WIM sorting station can conceivably be run by one individual; however, more inspections can be accomplished if one officer focuses on monitoring WIM data and static weighing, while the other focuses on inspection and citations. With two people at a WIM-equipped weigh station, the number of trucks weighed per trooper is substantially larger than the number that can feasibly be weighed using static scales. During peak truck-traffic hours when 3 or 4 people man the station, they can each weigh many more trucks per person than via any static method in the same time period.

4.1.6 Automated Data Processing and Calculations

Another advantage of using in-motion sorting is that the computer system can automatically determine wheel loads, axle loads, axle-spacing, gross-vehicle weight and instantly compute bridge-formula limits for axle groups. Texas' law sets a 10,000 lb (4.536 Mg) wheel-load limit which is seldom, if ever, enforced. The WIM sorting system can easily be programmed to check for this violation; however, it is not feasible to verify such a violation on a static axle-load scale. Wheel-load weighers are required. Using static weighing methods, the axle spacing must be measured manually, and the gross-vehicle weight and bridge-formula calculations must be made by hand. Sometimes the information observed for a truck is manually recorded on paper and then entered into a hand-held calculator. All information obtained from in-motion weighing is stored automatically in digital format for immediate and future use.

4.1.7 Greater Coverage Area

A weigh-in-motion system at a strategic location can capture data about a very large number of trucks on a major truck route, such as an interstate or state highway; in fact, every truck can be weighed by WIM. This makes it practicable for some troopers to manage the WIM site while others focus on enforcing possible bypass routes with portable scales. Without WIM, it is not feasible for troopers to cover both the main truck-route and all probable bypass routes as effectively unless vastly more resources are committed to the area. Using WIM on principal truck routes and portable scales on bypass routes simultaneously allows for substantially better coverage on the key truck-traffic routes while still providing effective coverage on possible/probable bypass routes.

4.2 DISADVANTAGES OF WIM

4.2.1 Accuracy

Although the accuracy of WIM systems has improved over time, it is still not recognized as accurate enough to be used as a legal basis for writing a weight-violation ticket. Although some WIM sites operate at much higher accuracy than others, no system has yet been proven to consistently yield load and weight values that are within legally-acceptable tolerances. WIM inaccuracy comprises three components: (1) actual static vs. dynamic force differences, (2) dynamic tire-force measurement error, and (3) static tire-force measurement error. These errors tend to be compounded together to form what is usually called “WIM inaccuracy,” although a component of this inaccuracy certainly is due to static tire-force measurement error (Ref 16). Current static weight enforcement devices are expected to perform within tolerances of ±1% acceptance and ±2% maintenance for portable and semi-portable scales, and tolerances of ±0.1% acceptance and ±0.2% maintenance for permanent scales when tested under field standard test weights (Ref 26). When used for weighing trucks in enforcement practice, with the brakes locked and all wheels sometimes not in a level plane, indicated wheel loads may be outside these tolerances in many cases. In recognition of this probable error, troopers routinely, by unwritten policy, allow an agreed-upon tolerance over the legal limit before writing a ticket.

As a result of the perceived legally-acceptable weighing tolerances discussed above, WIM cannot be currently used alone for weight enforcement. However, it can be used effectively as a sorting device in conjunction with static scales to sort only suspected violators from the traffic stream. Once a truck’s weight is verified by the static scales, an officer is able to legally write a citation. Other than the accuracy of the sensors and instrument system itself, the accuracy of

WIM estimates of static load and weight depends on a number of factors, which are shown in Table 4.1 and are classified under three categories: roadway, vehicular, and environmental factors.

Table 4.1. Factors that Affect WIM accuracy (Ref 8, 20)		
Roadway Factors	Vehicular Factors	Environmental Factors
Smoothness of pavement	Speed	Wind
Longitudinal profile	Acceleration	Water
Transverse profile	Tire condition and air pressure	Temperature
	Load, load shift	
	Axle configuration	
	Body type	
	Suspension system	
	Center of gravity	
	Aerodynamic characteristics	

In reference to the difference between static and in-motion measurements of gross-vehicle weight, Dr. Lee states that "accurate in-motion weighing of highway vehicles is possible only when the vertical acceleration of all vehicle components is zero. The sum of the vertical component of tire forces exerted on a smooth, level surface by the perfectly round and dynamically-balanced, rolling wheels of a vehicle moving at constant speed in a vacuum is exactly equal to the gross weight of the vehicle" (Ref 21). In reality, however, no truck wheel and tire is perfectly round, no pavement is perfectly straight, smooth, and level, vehicle components transfer forces to each other, and there will always be air resistance to the truck's motion, which may not be at constant speed. These factors can all, to varying degrees, affect the accuracy of WIM measurements (Ref 21). Some of the more critical elements are the smoothness of the pavement, the speed of approach, the roundness of the tires, and inclement weather. In practice, it is difficult to minimize all of these factors; however, certain conditions can be controlled.

The smoothness of the pavement on the approach to the WIM sensors can be controlled, and it is essential to accurate tire-force measurements, because a smooth pavement surface minimizes the vertical motion of tires as they travel over the sensors. ASTM E 1318-94 specifies that "the surface of the paved roadway 150 ft (45 m) in advance of and beyond the WIM sensors shall be maintained in a condition such that a 6 in. (150 mm) diameter circular plate 0.125 in. (3 mm) in thickness cannot be passed beneath a 20 ft. (6 m) long straightedge" when the straightedge is maneuvered in a specified pattern over the pavement (Ref 2). Generally, a rigid pavement (PCC) approach is used in order to provide maximum strength, durability, and smoothness. Flexible pavements (asphalt concrete) can rut and distort under heavy loads. Grinding the pavement surface smooth before installing WIM sensors is feasible with modern machines, and it is being done routinely where high-quality, long-term pavement performance is expected from high-speed WIM systems.

The speed and acceleration of the vehicles being weighed can also be somewhat controlled by using proper signage. This is especially effective at weight enforcement sites. WIM-system computation algorithms provide features for adjusting the measured dynamic tire force to compensate for speed effects of local site conditions on estimated static loads.

Other factors that can be controlled at a WIM site are the longitudinal and transverse road profiles. These profiles are an important consideration, as they can affect the magnitude and direction of gravity forces acting on a vehicle. The vehicle being weighed should travel a straight and level path, or even on a *slight* downgrade to reduce the effects of drive-train torque that occurs on an upslope (Ref 20).

The most critical of the uncontrollable vehicle factors is the tire condition and air pressure, as poorly kept tires can create large variations in the vertical component of force on the tire-force sensors. Although the tire-condition variable cannot be controlled in in-motion weighing, observation and experience indicate that the tires on most long-haul trucks are maintained in reasonably-good condition (Ref 21).

Other uncontrollable factors that affect WIM estimates of tire load to varying degrees include weather and vehicle characteristics such as the gross load, load shift and distribution, axle configuration, body type, suspension system, and the aerodynamic characteristics of the vehicle (Ref 8, 20).

4.2.2 Initial Cost

The initial capital cost of a WIM-system equipped weigh station can be rather high, depending upon the system used and the layout of the station. There are a number of components involved in the construction and installation of a WIM system. A general description of the costs that go into a WIM system and weigh station is presented in the following sections.

Although the capital costs for installing a WIM system are higher than those needed for static weighing, several states have found WIM to be highly cost-effective due to its several advantages over static methods of weighing trucks. A WIM system significantly reduces the manpower necessary per truck weighed. As a result, a government agency does not need to add more personnel in order to provide a higher rate of enforcement. Rather, an enforcement agency can substantially increase the number of trucks weighed by using currently-employed personnel and more efficient equipment. They can maximize productivity while significantly decreasing the amount of physical labor and the number of personnel necessary to weigh each truck.

4.2.3 Susceptibility to Electrical and Electromagnetic Disturbances

There is considerable electrical and electronic equipment involved in an in-motion weighing system, thus a large number of sensitive components must be protected and properly maintained in order to keep the system running smoothly. WIM systems use solid-state electronic devices, which are sensitive to electromagnetic and electrical disturbances, such as lightning strikes near the system, power surges, and power failures. As a result, the equipment needs to have state-of-the-art protection from these disturbances by: (1) installing adequate grounding systems, (2) shielding against radiated electromagnetic energy, and/or (3) using protective devices at the input terminals to the equipment (Ref 8). Consideration must also be given to uninterruptable power supplies and air conditioning the instrument operating environment.

4.2.4 Portability

One disadvantage of a WIM system is that it cannot be moved to various locations along the highway and operated on a short-term basis to aid enforcement weighing activities. Portable WIM systems utilizing a rubber and steel sandwich nailed to the road surface to form a capacitance-change mat tire-force sensor have been developed and used for collecting statistical data, but the durability and accuracy of WIM systems based upon these sensors is not adequate to be considered as a suitable enforcement sorting device.

4.3 OTHER CONCERNS

Enforcement personnel have voiced several other concerns regarding the operation and ability of weigh-in-motion systems. For example, some believe that in-motion sorting will shift the entire focus of truck regulation towards the weight issue, thus encouraging officers to neglect safety and other necessary inspections. However, experience at the first WIM station in Texas, as well as experiences in other states, particularly California, safety and other inspections continue to be an integral part of enforcement activity at a WIM-equipped weigh station. For example at the Devine WIM-equipped weight and inspection station, every truck exits the highway mainlanes, reduces speed, and passes over the WIM sensors. Officers located upstream in the scale house can see each truck approaching the sensors. The officer can at any time manually override the WIM-system-activated traffic signals to direct the truck to the static scale to verify any potential overloading, and can subsequently direct it to the safety inspection area. If the truck is not suspected of being overweight, it does not need to stop on the static scales; rather it can proceed directly to the inspection area. At the Antelope weigh station on I-80 near Sacramento, California, every truck that enters the weigh station passes directly in front of the scale house at speeds of 3-5 mph (5-8 km/h), allowing the officers to view at close range the condition of almost every truck.

In addition to pulling out suspected unsafe vehicles from the truck traffic stream, officers are also able to take random samples of the truck population for inspection. If the troopers want to inspect every truck that passes over the scales, they are still able to do so, but the storage area may quickly fill, long queues may form, and the station would perform the same as a permanent scale operating while inspecting every truck.

4.4 COST ESTIMATES

Many difficult factors affect the cost of a WIM system, as there is a wide variation in the types of systems (load cell, bending plate, piezo-electric), their location (mainlanes, separate sorting station), and the market where they are sold (whether there is competition among vendors in the area). There are a number of references in the literature that contain estimates of the cost of a WIM system, its additional equipment, and installation; however, much of the information is not directly comparable as each situation is unique. Information from these sources will be summarized here to provide a basis for cost comparison of the various WIM system components and installation.

4.4.1 Components of Cost

The following list shows a distribution of cost items for a WIM station.

- weighpads
- installation of weighpads
- electronics – from WIM to cabinet, within the cabinet, and from the cabinet to scale house
- computers, hardware, software
- traffic control signals
- signage, lane markings, guardrails
- inductance loops
- rigid pavement slab

- grinding of rigid pavement
- flexible concrete pavement throughout station
- scale house
- cost to bring any amenities (water, power, phone lines) to station
- drainage
- right-of-way
- landscaping
- overall construction costs

The following list shows a distribution of operating costs for a WIM station.

- maintenance of – WIM system
electronics
computer, hardware
pavement
surrounding land
lighting
traffic control devices
- utilities – electric
water
phone
- office costs
- cleaning
- personnel

4.4.2 Other Studies and State Experience

B. Taylor and A. Bergan present a comparison of three WIM systems. Table 4.2 shows their estimates on the initial cost and the average cost per lane (including maintenance and assuming a 12-year life span) (Ref 23). These figures are based on mainlane highway installation. Although they are a good indication of the relative cost and accuracy for each system, the source did not specify the confidence level (or performance level) of the measures of accuracy. They only include accuracy measures for the gross-vehicle weight and not for axle or axle-group load. In addition, the study report mentions that "several vendors" provide bending plate systems, and subsequently do not mention the "low-profile" system. One might conclude that they are classifying the low-profile system as a bending plate, although they are not necessarily comparable. In addition, the table includes a "double bending plate" system in which two bending plate weighpads are used in an attempt to obtain average measurements to possibly improve the accuracy of the static load estimates (Ref 23).

Table 4.2. Cost comparison of WIM systems (Dec 1997) (Ref 23)			
WIM system	Performance (% error on gross vehicle weight at highway speeds)	Estimated initial cost per lane (equipment and installation)	Estimated average cost per lane (12-year life span including maintenance)
Piezoelectric sensor	± 10%	$ 9,500	$ 4,224
Bending Plate Scale	± 5%	$ 18,900	$ 4,990
Double Bending Plate Scale	± 3 – 5%	$ 35,700	$ 7,709
Deep Pit Load Cell	± 3%	$ 52,500	$ 7,296

The total cost for the WIM site in Devine, Texas (described in Chapter 5) was $3.1 million for the two stations, one on each side of I-35, which comes to just over $1.5 million for each station. A total of $1.3 million was spent on the single load cell platforms, electronics, traffic control devices, computer equipment, software, static scales, and rigid pavement for the two sites, which comes to about $650,000 for each station. The remaining $1.8 million covered the construction costs, the scale houses, and the cost to initially provide utilities at the sites, which comes to $900,000 for each station (Ref 29).

The resources available in California, as well as the competition among vendors, and the large quantity of WIM purchases (85 sites) from these vendors reduces the cost of a WIM station significantly. The cost of a typical WIM system in California is estimated to be $300,000 using 2 bending plates and 2 piezo sensors in the mainlanes of travel before a station, as well as 4 additional piezo sensors in the mainlanes adjacent to the station. In some cases, the rigid pavement does not need rehabilitation, and the WIM sensors can be placed in the existing pavement. The pavement is always ground smooth before installing the sensors to produce minimal vertical movement of the moving truck (Ref 30).

The 1997 Comprehensive Truck Size and Weight Study, by the U.S. Department of Transportation (USDOT) and Federal Highway Administration (FHWA) states that the total cost of the St. Croix, Minnesota facility on I-94 was $1.7 million in 1987, and the total cost of the Woodburn, Oregon facility on I-5 was $2.4 million in 1986. These are both elaborate inspection facilities that are located at a state's port-of-entry (Ref 38).

A study by John Wyman estimated the cost of bending plate systems to be $35,000/lane installed in 1987, whereas the single load cell system in 1985 cost $113,000 for 2 lanes installed, including scales, electronics, software, computer, modem, and printer. In addition, the construction costs for a 4-lane highway installation including signing crews was $100,000 (Ref 41). Oregon DOT constructed a weigh station north of Roseburg in 1992 using single load cell sensors installed in asphalt concrete, which cost about $180,000 (Ref 16).

There is a large variation in the initial cost of a weigh station depending on the WIM system, the materials, land area, and the comprehensiveness of the station layout. Although the cost of a WIM system is rather high, when compared to a fixed scale station at a cost of $300,000, the cost to implement WIM in some locations may be 4 or 5 times the cost of a fixed scale, but will result in an even greater multiple of trucks weighed, thus the potential for more fines collected. In other locations, such as California, the cost to implement a weigh station is not much higher than the cost of a fixed station and is therefore very cost efficient to process a substantially greater number of trucks.

The operational costs of a WIM station include maintenance, utilities, office costs, cleaning, and personnel. All of these costs would also be necessary for a fixed station that had a scale house with amenities, except the maintenance would be for less equipment. As an example of the operational costs at a WIM station, the cost for utilities at Devine are $300/month, office costs total nearly $100/month, cleaning is $675/month, and about $250/month covers computer costs and phone. This totals about $1350/month for the expenses at the scale house. There have only been some minor expenses necessary for maintenance of the WIM system, and some of its equipment, as the system is only one year old (Ref 29).

Troopers generally spend about 25% of their time at either weigh station, which allows the two to operate about 40-45 hours per week. A station is manned usually by two or three people, and the average salary of a trooper is $30,000 to $40,000 per year (Ref 28, 29). The cost of personnel to run the station 40-45 hours a week with two people is about $5,000 to $6,670 per month. The cost of personnel to run the station with three people is about $7,500 to $10,000 per month. It is important to note that the cost for 40-45 hours/week of work is the same regardless of the method of enforcement used. However, using WIM results in thousands more trucks weighed each month. The cost of maintenance and operations, not including personnel, is somewhat comparable between fixed and WIM-sorter stations. However, WIM stations have the additional cost of the maintenance of the WIM system and its electronics, and of the rigid pavement. As an example, the cost of the replacement of a bending plate sensor is about $3,500 and the cost for rehabilitation of rigid pavement is about $30,000 (Ref 23). However, bending plates are known to last about 12 years, and rigid pavement is expected to last about 30 years.

Assuming two or three people work at the station each day, the cost for personnel may be about $7000 per month for 40-45 hours of operation each week. In addition to the $1350 per month cost of maintenance, this comes to $8350/month operating expenses not including maintenance of the system itself. Within a month, the WIM system can weigh thousands of trucks using only 25% of each officer's time.

Both the initial and the operating costs of the WIM systems must be taken into account when assessing the cost difference between static and in-motion weighing methods. In addition, the potential number of trucks weighed per cost is a critical factor to consider.

4.5 FURTHER COMPARISON OF STATIC METHODS AND IN- MOTION METHODS

The 1997 Comprehensive Truck Size and Weight Study contains an evaluation of various aspects of truck travel in the United States, including the past and current practices of weight enforcement. This study states that nationwide, truck size and weight enforcement has substantially increased over the past 10 years. Under the Motor Carrier Safety Assistance Program (MCSAP) of 1982, states were instructed to increase their truck safety inspections. This would potentially reduce the number of trucks weighed, as safety inspections take more time. However, the study states that the initial and increasing use of WIM for enforcement has significantly increased the number of trucks weighed while at the same time, placing emphasis on inspections due to the MCSAP. In 1985, 105.2 million trucks were weighed nationwide on all types of scales: portable, semi-portable, permanent, and WIM. 7.9 million of these were weighed using WIM in only four states. In 1995, the total number of trucks weighed on all types of scales was 169.6 million (57.9 million with WIM in 28 states). As the number of trucks weighed increased by 14.3 million in the 10-year period, the number of overweight citations decreased slightly from 664,000 to 655,000. However, the violation rate has remained relatively steady from 1986 to 1995 (Ref 38). The nationwide numbers of trucks weighed, with and without WIM, as well as the number of citations issued, and the subsequent action taken, are shown in Table 4.3. Table 4.4 shows the nationwide distribution in the number of trucks weighed by each type of scale.

Table 4.3. Nationwide Weight Enforcement FY85-FY95 (Ref 38)						
Year	Weighed (including WIM) 1000's	Weighed (excluding WIM) 1000's	Weight Citations	Violation Rate	Off-loaded	Load Shift Required
1985	105,234	97,330	664,033	0.007	106,618	371,104
1986	113,269	102,504	650,728	0.006	81,716	395,184
1987	117,900	104,452	671,259	0.006	85,949	432,598
1988	130,188	111,532	700,928	0.006	89,033	453,841
1989	146,950	124,687	692,673	0.006	79,309	438,584
1990	149,187	126,076	667,463	0.006	76,769	425,298
1991	150,428	116,759	663,204	0.006	85,935	396,913
1992	160,536	113,563	677,976	0.006	60,142	380,249
1993	162,615	111,889	653,492	0.006	76,611	451,643
1994	161,066	108,124	642,616	0.006	82,491	447,396
1995	169,568	111,620	654,903	0.006	105,948	472,614

Table 4.4. Trucks Weighed by Scale Type, FY85-FY95 (1000's). (Ref 38)					
Year	Fixed	Semi-portable	Portable	WIM	Total
1985	94,685	1,152	1,494	7,903	105,234
1986	100,010	1,238	4,257	10,764	113,269
1987	101,801	1,444	1,206	13,449	117,900
1988	108,881	1,439	1,212	18,656	130,188
1989	122,188	1,312	1,187	22,263	146,950
1990	123,748	1,175	1,153	23,111	149,187
1991	114,271	1,233	1,255	33,669	150,428
1992	111,016	1,229	1,318	46,973	160,536
1993	109,347	1,238	1,304	50,726	162,615
1994	105,679	1,183	1,262	52,942	161,066
1995	109,275	1,107	1,237	57,948	169,568

It is apparent that the use of WIM has had a significant impact on the number of trucks weighed throughout the U.S. As seen in the tables above, the number of trucks weighed using static scales has steadily decreased since 1990 (except it rose slightly in 1995), while the number of trucks weighed by WIM has increased by 250 percent. In addition, the violation rate has remained nearly constant nationwide at about 0.6 percent. Therefore, even as the number of trucks being weighed has significantly increased, the percentage of trucks that are found overloaded still remains relatively constant, so the number of violators found also increases proportional to the number of trucks weighed.

4.6 SUMMARY

This chapter contains a more in-depth look at the capabilities and constraints of weigh-in-motion systems to aid enforcement compared to those of static methods of weight limit enforcement. The advantages of using WIM include a faster vehicle processing rate, the ability to obtain a near-100-percent sample of truck traffic data, less bias of the truck data taken, safer conditions, continuous operation, less personnel required per truck weighed, automated data processing, and greater coverage area. The disadvantages of using WIM are concerns about its accuracy, higher initial cost than conventional static methods, susceptibility to electromagnetic disturbances, and its lack of portability. Representative figures for the initial capital cost of a WIM system as well as the operating costs are included in this chapter.

The 1997 Comprehensive Truck Size and Weight Study (Ref 38) analyzed the number of trucks weighed nationwide with each type of scale: permanent, semi-portable, portable, and with WIM. The figures show a substantial increase in the number of trucks weighed with WIM, while the number of trucks weighed by other techniques decreased up to 1995. This is another good indication that WIM sorting can be an effective tool for weight enforcement, and it is being used more widely throughout the U.S.

CHAPTER FIVE – TRUCK WEIGHT ENFORCEMENT IN TEXAS AND CALIFORNIA

This chapter details the use of WIM in Texas and contains information regarding potential future WIM enforcement sites in the State of Texas. In addition, it includes a brief description of weight enforcement practices utilizing WIM in California.

5.1 TEXAS' EXPERIENCE WITH WIM AS AN ENFORCEMENT TOOL

The feedback received from the first WIM-equipped weight enforcement site in Texas has been very positive. Sgt. Riley, who heads the License and Weight Service program of the Texas DPS in Devine, gave useful insight into the operations, capabilities, and constraints of the weigh stations during recent site visits. There are two nearly-identical WIM sorting stations located near Devine that opened in November 1997, one off the northbound lanes of I-35, and one off the southbound lanes. Each station consists of an exit ramp from the freeway mainlanes on which truck drivers are directed to maintain a speed limit of 20 mph (32 km/h). Trucks pass over side-by-side single load cell sensors and an axle sensor. Inductance loops are located before and after the WIM tire-force sensors in order to determine the truck's presence and speed. Figure 5.1 shows the force sensors and axle sensor at the station.

Figure 5.1. Single load cell tire-force sensors and axle sensor

Once the truck has passed over the WIM-system sensors, axle load, axle-group load, gross-vehicle weight, speed, and axle-spacing data are relayed instantly to the computer in the scale house. Appropriate calculations are made for detecting permissible axle-group loads according to the bridge-formula. If any WIM system value of the truck's load or weight is found to exceed its respective legal limit, after appropriate tolerances have been allowed, an overhead green-arrow traffic control signal directs the truck into a lane where it will stop each axle successively on a certified axle-load scale for legal determination of each axle load. If all WIM-system values are found to be within the preset limits, an overhead green-arrow traffic control signal indication directs the truck to a lane that returns it to the interstate without stopping, as shown in Figure 5.2. A red "X" traffic control signal indication is displayed simultaneously with each green arrow over the other lane.

Figure 5.2. Traffic control signals after WIM sensors

The officer in the scale house can at any time override the WIM-system-controlled traffic signals to direct a selected truck into one of the two lanes. If a truck's wheels miss the WIM sensors by running off the road, or if the system did not obtain a load value for an axle, the system is programmed to flash an error message on the computer screen in the scale house, and automatically direct the truck towards the static scale lane.

At the static axle-load scale, a changeable message sign displays instructions to the driver, as seen in Figure 5.3.

Figure 5.3. Changeable message sign displays instructions to drivers

The bottom line of the changeable message sign displays the indicated load value as each axle is stopped on the scale. After the last truck axle moves off the static axle-load scale, the gross-vehicle weight is displayed. The available messages include:

- Proceed onto scale
- Slowly
- Stop
- Backup
- Move forward to next axle
- Return to interstate
- Proceed to inspection area
- Report to office
- Proceed to parking

Most of the troopers contacted during site visits, including Sgt. Riley, are pleased with the overall operation and even seem somewhat surprised at the excellent efficiency of the WIM sorter. The troopers generally operate one station at a time, depending on the predominant direction of truck travel during different times of day. However, there is not a set pattern as to when they operate so that they can achieve some element of surprise to the truckers as to when a station will be open. The stations are routinely scheduled to operate for at least 40 hours per week, but have been operated up to 78 hours per week. On average, they are operated 40-45 hours per week (total for the two stations). Sgt. Riley stated that although the stations are scheduled to operate about 40 hours/week, some officers choose to operate them during non-scheduled hours in order to weigh more trucks on their shift. Generally, 2 or 3 people man the station during a typical shift, whereas during periods of heavy truck-traffic 6 or 7 troopers may work at the site. It only takes one officer to operate the computer and the static scale, and the other officer(s) to be in charge of inspecting trucks, checking logbooks, and writing citations. The stations provide more than weight enforcement; the officers regularly inspect safety features of trucks and the drivers' logbooks (Ref 29).

Sgt. Riley estimates that about 2% of trucks that pass through the station are cited for a weight, safety, logbook, or other type of violation. In a typical month, one trooper can weigh 1000 to over 2000 trucks, using only 25 percent of his or her time at the WIM station. In the first 10 months of operation, about $900,000 in fines were collected. Most citations are issued for tandem-axle load violations. There are a few possible bypass routes around the WIM site about 15-20 miles out of the way, and these routes are generally covered by troopers using portable scales. If a violator is found using one of the bypass routes to avoid the WIM station, the driver is given a more substantial fine. The fine structure for weight violations in Medina County, Texas in 1998 is shown in Table 5.1 (Ref 29).

Table 5.1. Fine Structure for weight violations in Medina County, TX (1998). (Ref 29)

Over Allowable Gross Weight Violations:	Fine ($)
Up thru 4,999 lbs (2250 kg) over gross weight	196.00
5,000 thru 7,499 lbs (2250 to 3375 kg) over gross weight	347.00
7,500 thru 9,999 lbs (3375 to 4500 kg) over gross weight	546.00
10,000 thru 14,999 lbs (4500 to 6750 kg) over gross weight	817.00
15,000 lbs (6750 kg) and over	1,066.00
Over Weight – Axle Limit & Overweight Group of Axles	
Up thru 4,999 lbs (2250 kg) over axle limit	147.00
5,000 thru 7,499 lbs (2250 to 3375 kg) over axle limit	172.00
7,500 lbs (3375 kg) and over	196.00

The station layout is unique, in that it is located on the narrow highway right-of-way between the mainlanes of I-35 and a frontage road. The station has a linear design, which does not provide a large amount of storage for trucks to be inspected. The contractors included a number of important design principles in the construction of the site, but also omitted some elements that should have been included. The WIM sensors and system itself were installed into a 300 ft (90.9 m) length of rigid pavement which was ground smooth to produce minimal vertical movement of the truck. Seventy-five feet of the pavement extends past the tire-force sensors. The intended pavement type was continuously reinforced concrete pavement (CRCP) but the existing slab at the site has a formed joint every 40 feet (12 m) and two transverse cracks have already opened between each joint. Despite these cracks, the pavement is currently smooth enough to meet ASTM E 1318-94 standards and it has been well maintained. The static scale is performing well but drivers have difficulty in seeing the 12 ft (3.6 m) scale platform as its concrete deck looks exactly like the concrete scale aprons before and after it. Drivers need to be able to see the scale platform clearly so that they can stop their wheels directly on the platform without wasting time backing up or pulling forward trying to position their wheels on the scale. This problem can be solved simply by painting the platform a contrasting color.

The computer has pre-designated commands, listed above, to display on the changeable message sign so that an officer only has to click on the appropriate command to display it to the driver. However, these commands do not include “release brakes” which can have significant influence on the static loads obtained at the scales. When a truck stops by applying its brakes, load is transferred slightly towards the forward axle as the center of vehicle mass is above the road surface, where the retarding friction forces are applied. The message “Release Brakes” should be programmed and used routinely whenever an axle is weighed on the static scale. When the truck has stopped and the brakes have been released, the gross-vehicle weight is redistributed among the axles (except for friction in the suspension system) and more accurate axle-load measurements are obtained. Troopers have also suggested a loudspeaker system so that they can talk to the drivers instead of, or in addition to, using the changeable message sign.

The scale house is quite functional; it is elevated above the ground so that troopers are on the same level with truck drivers. It has all needed amenities and has an excellent view of the approaching trucks. However at night, the window that faces the approaching trucks reflects light sources inside the scale house and causes glare. If the window were tilted outward at the top, the glare from the inside lights would be reduced.

There have been only a few minor constraints to the operation of the system and the station as a whole. Some of these problems include; a lightning strike which caused a WIM sensor load cell to fail, which was replaced; and a small bump in the flexible pavement located at the transition point to the rigid pavement slab approaching the WIM sensor – this has since been remedied by patching with asphalt mix. There have been no major system maintenance problems. The sensor signal-processing electronics are kept in an air-conditioned cabinet at the side of the road near the sensors. This keeps the instrument system and its circuitry from overheating during hot weather.

One major concern is that the byass lane that directs trucks back to the interstate is not wide enough (about 13-14 ft, or 4 m) to accommodate wide loads. When a wide load approaches the station, it must be directed by an officer to stay on the highway or to enter the weigh station and cross over the static scales. Another major problem was the premature failure of some of the flexible pavement on the ramps and bypass lane that received repeated, channelized truck loading. Due to the trucks traveling on the pavement, it had to be rehabilitated after a short time with a higher-strength design. The rigid pavement slab around the WIM sensor has not yet had any problems.

The first WIM site in Texas has proven to be a valuable learning experience for both the Department of Public Safety and TxDOT. It has enabled officers to see how in-motion weighing allows them to weigh, inspect, and possibly ticket a greater number of trucks. Although the stations were rather expensive, they have enabled DPS to weigh a much larger number of trucks with minimal personnel. In addition, they have already collected a significant amount of money in fines as a result of weighing more trucks. The success of the weigh stations in Devine has prompted the construction of a second WIM site near Huntsville along I-45 between Houston and Dallas.

5.2 NAFTA TRUCK CORRIDORS IN TEXAS

Highway trade corridors are established as trade flows between major population and manufacturing centers through specific land ports on the U.S.-Mexico border. The pattern of flow creates the location of the highway corridor; the density of truck traffic, measured in numbers of trucks per year, determines the significance of the corridor. Because the interstate highway system in Texas connects major population and manufacturing centers in the U.S. with its major land ports along the U.S.-Mexico border, and because it has three of the seven major border crossings in the U.S., the Texas Interstate highway system is an important player in trade movement by trucks. Although most dominant highway trade corridors are located along U.S. interstate highways, not all of the interstate highways can be considered trade corridors either in terms of the total volume of traffic or of the percent of highway truck traffic which is trade truck traffic.

In order to identify NAFTA trade corridors, it is important to recognize the location and concentration of population and manufacturing in Mexico and the U.S. In the U.S., these concentrations are located in the northeastern and southeastern regions and in Texas and California. More than three-fourths of the trade movements between Mexico and the U.S. are to or from Texas and the northeastern U.S. (i.e., the upper midwest and mid-Atlantic regions). In Mexico, the principal origin and destination for trade movements is the central portion of the country, which contains approximately two-thirds of the population and most of the manufacturing employment. The secondary origin and destination in Mexico is the maquiladora factories located along the Mexican side of the U.S.-Mexico border. Therefore, the primary trade flow between the U.S. and Mexico is from Texas and the northeastern U.S. into the heart of Mexico. This causes I-35 between Laredo and Dallas to be the major U.S.-Mexico trade corridor in the U.S., with over 1 million trucks per year carrying products to and from Mexico.

To locate other major trade corridors in Texas, a recent study by McCray (Ref 24) developed a database using international trade statistics from the U.S. Department of Commerce, the Transborder data from the Bureau of Transportation Statistics, and data from U.S. Customs. This same study also determined specific links using maps provided in the National Transportation Atlas, TransCad (a transportation analysis software product), and the database to create NAFTA trade flow maps for 1996, which are shown and discussed below. Since this project focuses on highway corridors in Texas, only three border regions are discussed: the Brownsville, Laredo, and El Paso border regions.

5.2.1 The Brownsville Border Region

As shown in Figure 5.4, the pattern of U.S.-Mexico trade truck traffic to and from Brownsville is radial. The dominant trade corridors to and from Brownsville are to the north and east of a line from Brownsville through San Antonio and Dallas. There are no trade highway corridors to the valley with 20,000 or more trade trucks per year north of Dallas or west of a line from Dallas to San Antonio.

Figure 5.4. 1996 Estimated trucks carrying U.S.-Mexico trade on U.S. highway corridors to and from the Lower Rio Grande Valley Region (Ref 24)

As shown in Figure 5.4, the major highway corridor that transports trade between Brownsville and major U.S. manufacturing and population centers is along U.S. 77 and U.S. 281. This corridor, which runs from Brownsville to its intersection with I-37 in the vicinity of Corpus Christi, Texas, transported 500,000 to 1,000,000 trade trucks in 1996. The two next most important trade highways are I-37 from Corpus Christi to San Antonio and I-35 between San Antonio and Dallas. Both these highways carry 250,000 to 500,000 trade trucks per year. Between Corpus Christi and Houston, U.S. 77 and 59 carry 100,000 to 250,000 trade trucks. Trade highway corridors, which have 50,000 to 100,000 trade trucks per year, include I-10 between Houston and New Orleans and I-30 between Dallas and Memphis. Highway corridors to and from Brownsville with 20,000 to 50,000 trucks per year include I-65 and I-85 from New Orleans to Atlanta; I-59 and I-81 between New Orleans and Philadelphia; I-40, I-65, I-71, and I-75 between Memphis and Detroit; and I-55, I-57, and I-70 between Memphis and Indianapolis. All other trade highways to and from Brownsville had less than 20,000 trade trucks in 1996 (Ref 24).

5.2.2 The Laredo Border Region

Figure 5.5 shows that the pattern of U.S-Mexico trade truck traffic to and from Laredo is also radial, but highways that run between Laredo and the industrial midwest and northeast are the dominant highway trade corridors. These trade corridors link Laredo to the northeast through

San Antonio, Dallas, Memphis, Nashville, and Detroit and link Laredo to the southeast through Houston. Although the dominant highways are to the northeast, Laredo has a significant number of trade trucks traveling between San Antonio and Los Angeles.

Figure 5.5. 1996 Estimated trucks carrying U.S.-Mexico trade on U.S. highway corridors to and from the Laredo Region (Ref 24)

The major highway which transports trade between Laredo and important manufacturing and population centers in the U.S. is I-35 between Laredo and San Antonio. This densely-traveled truck highway corridor carried over 1,000,000 trade trucks in 1996. Another important highway, with 500,000 to 1,000,000 trade trucks per year, is I-35 between San Antonio and Dallas. The two next most important trade highways, with 250,000 to 500,000 U.S-Mexico trade trucks per year, are I-10 from San Antonio to Houston and I-30 and I-40 between Dallas, Memphis and Nashville. Trade truck corridors which have 100,000 to 250,000 trade trucks per year include I-10, I-65, and I-85 between Houston and Atlanta; I-65, I-71, and I-75 between Nashville and Detroit; and I-40 and I-81 between Nashville and New England. Trade truck corridors which have 50,000 to 1,000,000 trade truck per year include U.S. 69 and 75, I-44, and I-55 from Dallas to Chicago and I-10 from San Antonio to Los Angeles. Highways with 20,000 to 50,000 trade trucks in 1996 include I-5 between Los Angeles and San Francisco and I-35 between Dallas and Wichita. All other trade highways to and from Laredo served less than 20,000 trade trucks in 1996 (Ref 24).

5.2.3 The El Paso Border Region

As shown in Figure 5.6, the major highway which transports trade between El Paso and the manufacturing and population centers in the U.S. is along I-10 between El Paso and the intersection of I-10 and I-20 southwest of Pecos, Texas. This trade corridor carried 500,000 to 1,000,000 trade trucks in 1996. The second most dominant highway, with 250,000 to 500,000 trade trucks per year, is I-20 between its intersection with I-10 and Dallas. The three next most important trade highways, with 100,000 to 250,000 U.S.-Mexico trade trucks per year, are I-10 from its intersection with I-20 to San Antonio and Houston; I-25, I-40, I-44, I-70, and I-75 between El Paso, Oklahoma City, St. Louis, Indianapolis, and Detroit; and I-30, I-40, I-44, I-70, and I-75 between Dallas, Memphis, Nashville, Lexington, and Pittsburgh. All other Texas trade highways to and from El Paso had less than 20,000 trade trucks in 1996 (Ref 24).

Figure 5.6 1996 Estimated trucks carrying U.S.-Mexico trade on U.S. highway corridors to and from the El Paso Region (Ref 24)

5.3 SELECTING POTENTIAL NAFTA-TRAFFIC ENFORCEMENT SITES

The location of enforcement sites is probably the single most important factor in an effective weight enforcement program. Several issues should be evaluated when selecting a potential site for weight enforcement. The following criteria should be considered during this process:

- As a first step, corridors with high volumes of truck traffic must be identified and important highway segments should be determined. This can be done by analyzing historical and forecasted truck count data and listing high priority routes in terms of truck traffic flow. When determining high priority routes, truck traffic, as opposed to all traffic, should be emphasized.

- Once candidate segments are identified, the bypassing issue should be examined. An effective enforcement site must be located in a highway segment that is not easily bypassed. Sites on many interstate and principal arterial roads in the United States can be bypassed using state or county roads. Thus, a selected site should be located in an area where nearly all the truck traffic can be intercepted. An example could be at an intersection of the candidate highway and other state or county roads. Another location that can be considered is adjacent to a natural obstacle, such as a large river, where the enforcement station cannot be easily bypassed.
- The next criterion in WIM site selection should be geometric features. Grades on the main highway should be gentle or slightly rising. Enforcement personnel at the weigh station should have good visibility along both the main lanes and the access ramps. Distance between the weigh station and interchange ramps should be sufficient to prevent traffic conflict. Signing and visibility should allow the driver sufficient reaction time to maneuver the truck onto the weigh station ramps. The ramps should meet AASHTO design guidelines for deceleration, acceleration, and roadway widths (Ref 10). Sufficient width should be provided for wide loads to pass through the station in the bypass lane as well as the enforcement scale lane. On high-volume truck routes the storage provided on the ramps must be sufficient to prevent trucks from queuing onto the main highway. Smooth traffic flow within the station is necessary. Each truck must be guided to the bypass lane, to parking areas, to the scales, and to reentry ramps. Finally, sufficient space should be provided for trucks to unload or shift loads from one axle to another in case of a violation. Figure 5.7 shows a typical geometric layout of a WIM station.
- Another criterion in selecting a site is the availability of utilities. Access to electricity, telephone lines, water, and sewage is necessary for the operation of a WIM station. This is particularly important when two WIM stations are not located directly opposite each other along the highway.

When considering potential NAFTA-traffic enforcement sites in Texas, the criteria discussed above should be taken in consideration. Major NAFTA truck corridors in Texas are discussed in the previous sections and potential highway segments where enforcement sites can probably be most effective are listed in Table 5.2. These potential sites have been prioritized according to annual NAFTA trade traffic volume. First consideration should be given to locations as near as feasible to the actual border-crossing points on the Rio Grande. Such sites can be very effective in protecting the Rio Grande bridges from overloads by intercepting overloaded trucks before the bridges. WIM screening in both directions will require cooperation with Mexican authorities. These sites will also help avoid traffic congestion on the bridges and reduce the number of overloaded trucks -both U.S. and Mexican- using the bridges.

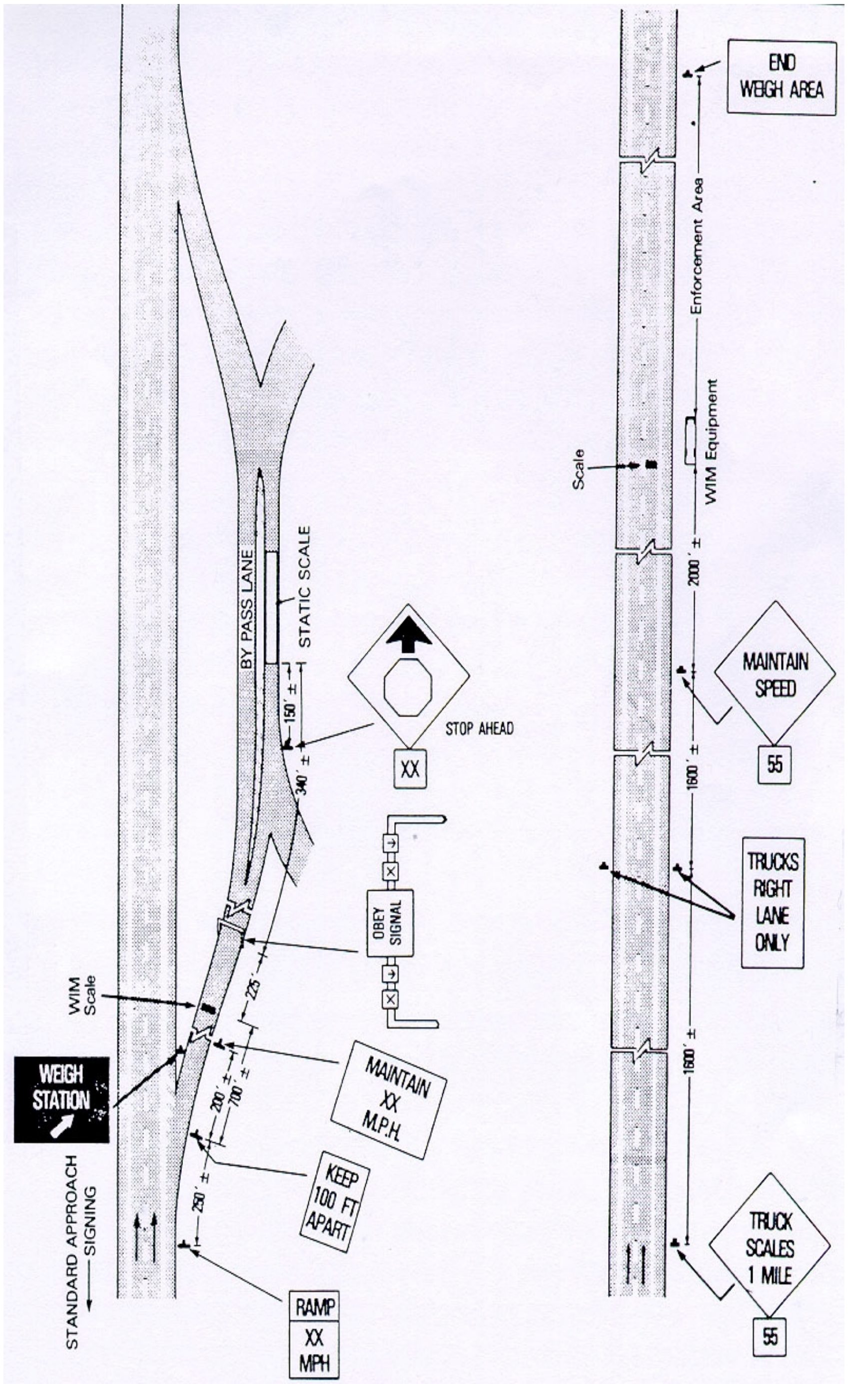


Figure 5.7 Typical geometric layout for WIM stations (Ref 10)

Table 5.2. Potential sites for enforcement based on border region in Texas			
Border Region	**Highway**	**Segment**	**Annual Truck Traffic**
Brownsville	U.S. 77 or U.S.281	From Brownsville to intersection with I-37	500,000 to 1,000,000
	I-37	From Corpus Christi to San Antonio	250,000 to 500,000
	I-35	From San Antonio to Dallas	250,000 to 500,000
	U.S. 59 or U.S 77	From Corpus Christi to Houston	100,000 to 250,000
Laredo	I-35	From Laredo to San Antonio	>1,000,000
	I-35	From San Antonio to Dallas	500,000 to 1,000,000
	I-10	From San Antonio to Houston	250,000 to 500,000
El Paso	I-10	From El Paso and Intersection with I-20	500,000 to 1,000,000
	I-20	From Intersection with I-10 to Dallas	250,000 to 500,000
	I-10	From Intersection with I-20 to San Antonio and Houston	100,000 to 250,000

5.4 BRIEF LOOK INTO CALIFORNIA'S EXPERIENCE

The application of weigh-in-motion technology in California is extensive; there are 85 operational WIM sites in the state. The state currently uses bending plate, single load cell, and piezo-electric sensors as part of their weight enforcement program. In California, the setup of most weight enforcement sites is rather different than the one in Devine, Texas. A typical example is the Antelope station located on I-80 near Sacramento. Bending plates are located on the highway in the right two lanes of travel, with piezo strips in the left two lanes before the station. Since most trucks use the right two lanes, CalTrans weighs most trucks with the more-accurate instruments. Since piezo sensors are not as accurate, but are easier and cheaper to install, they are placed in the lanes of travel that are not used by as many trucks. This enables CalTrans to capture the weight of every truck that passes the station. Since many trucks use the same routes repeatedly, they may have electronic tags and participate in the Heavy Vehicle Electronic License Plate (HELP) program, which enables drivers to use the PrePass system. If a truck has an electronic tag, its coded data is read by electronic tag-reader antennas, shown in Figure 5.8, that are set up on overhead mast arms above the bending plate WIM sensors (Ref 30).

Figure 5.8. Overhead PrePass tag-reader antennas

The truck's identification is read from the tag; its axle load, axle-group load, and gross-vehicle weight are read and recorded by the WIM system, and all the data are relayed to the computer inside the scale house. If the truck axle loads are within the tolerances set on the WIM system computer, a signal is sent to the tag on the vehicle to advise the driver that it is not necessary to enter and stop at the weigh station. This significantly decreases travel time for tag-equipped trucks that are not overloaded. If the truck with an electronic tag is overweight by the WIM measurements, the driver is signaled by an in-cab device (a red light) to enter the weigh station. Piezo-electric tire-force sensors, located in all four lanes downstream of the entrance to the weigh station, verify that all tag-equipped trucks have followed instructions as to whether to enter the station or not. Since piezo-electric force sensors are relatively inexpensive to install, and are not as reliable as other more-accurate sensors, two piezo strips are used in each lane to obtain an average measurement of axle loads. This may *slightly* increase the accuracy of the WIM load and weight estimates (Ref 30). A chase car may be dispatched to stop the tag-equipped trucks that fail to exit as instructed.

If a truck does not have a tag, it must exit at the weigh station. The initial weight information obtained from the bending-plate sensors is conveyed to the computer in the scale house and a video camera allows officers inside to see every truck that passes over the weighpads and approaches the station. Once the trucks approach the station, they are directed by signs to split into either of two lanes; one for empty vehicles and one for loaded vehicles so that trucks not carrying a load do not have to wait in a queue simply to be weighed as an empty truck. Those that are laden travel at slow speeds, 3 mph (5 km/h), across an axle-load scale directly in front of the scale house so that officers obtain a second axle-load measurement and so they can easily see whether the truck should be pulled over for a closer inspection. If an axle load or the gross-vehicle weight estimated by the WIM system indicates that the truck is possibly overweight, officers track the truck on the video monitor until it reaches the axle-load scale and check the WIM values against those shown by the axle-load scale. If the verification slow-roll-over weighing on the axle-load scale indicates a significant overload, that the driver might need to shift the load among axles, that the truck should be re-weighed with each axle stopped on the scale, or that a citation should be written, the officer uses a green arrow signal indication to direct the driver into the inspection/parking area behind the scale house for further examination. If no violation is indicated, the officer uses a circular green traffic signal indication to direct the driver to return to the highway mainlanes (see Figure 5.9).

Figure 5.9. Traffic control signals after axle-load scale at Antelope weigh station

In the “EMPTY” lane, trucks are directed to travel at 5 mph (8.3 km/h) and pass over piezo-electric sensors to verify that they are actually unloaded. Directly across from the scale house, they pass over a bump in the road so that they slow down even further for officers to get a look at the truck and so that they can see how the truck bounces off the bump (to tell whether the truck is, in fact, unloaded). California’s weight enforcement program is extensive throughout the state, which ranks them as leaders in the field of weight enforcement applications. The use of WIM is a key component of their program, and its usage continues to expand as new stations are opening throughout the state. As the market for WIM systems in California is considerably large (85 WIM sites), there is healthy competition among vendors for contracts, thus allowing the state to procure WIM systems at a lower cost. The cost of a typical weigh station in California, as well as cost estimates for other existing WIM sites throughout the U.S., is described in Section 4.4.

5.5 SUMMARY

Using WIM as a tool for sorting suspected violators from a truck traffic stream has proven to be a learning experience in Texas in several ways; in that the design of the facility is crucial to proficient operation, and that using WIM enables DPS officers to weigh a substantially larger number of trucks. States such as California and Georgia have been utilizing WIM to aid enforcement since the early 1970's and, therefore, have a more extensive network of facilities. Other states' success with weigh-in-motion sorting is an indication that it can be an effective tool to aid in weight enforcement. This chapter contained information on the major truck corridors through the State of Texas. In addition, the considerations for selecting a specific weight enforcement sites were detailed, which allows for optimal truck-weight-enforcement-site selection.

CHAPTER SIX – WEIGH-IN-MOTION ENFORCEMENT IMPLICATIONS

The 1993-1995 study using WIM systems at Laredo and El Paso described in Section 2.4.1 has indicated that 25% and 35% of the observed tandem-axle loads on loaded north-bound trucks from Mexico exceeded the U.S. limit (15.4 Mg) at the Laredo and El Paso ports of entry, respectively (Ref 15, 34). This occurrence of overloads raises great concerns over infrastructure needs, especially once NAFTA interborder transport restrictions are repealed. Once the NAFTA restrictions are lifted, the current cargo transfer procedures will gradually be eliminated, and Mexican carriers will be allowed access to virtually the entire Texas highway system. Although the harmonization talks addressing commercial carrier size and weight regulations have been going for quite a while, the outcome remains to be seen. An assessment of the potential benefits of using WIM technology to aid weight limit enforcement might assist decision makers as they decide whether to increase U.S. weight limits or enforce the current limits.

The concept of in-motion weighing as well as the practices used in WIM stations are discussed in Chapters 3 and 5, respectively. By using axle-loading information from a WIM system installed in the weigh-in-motion entrance ramp, suspected over-loaded vehicles can be identified and routed via computer-controlled traffic signals to a certified scale for enforcement weighing to document the infraction. Given its inherent variability, WIM technology is currently not acceptable in a court of law as a direct weight enforcement tool. Nonetheless, this technology can aid in the enforcement process as it allows continuous screening of suspected overweight vehicles. Studies have shown that only 1% of the trucks weighed at an open static weighing station are overloaded, while as many as 30% of the population of trucks not being statistically weighed are overloaded (Ref 27). An important aspect of WIM technology is the ease of identifying potential axle loading violations. Although a vehicle may be under the maximum allowable gross-vehicle weight, it might include one or more axle groups that exceed the allowable loads. On interstate highways, axle-load limits are 20 kips on a single axle, 34 kips on a tandem axle and, by applying the bridge formula, 42 kips for a tridem axle. All axle-loads are the primary concern in pavement design and performance, but gross-vehicle weight is a major concern in bridge design.

Relative pavement damage caused by various axle loads can be estimated by applying an equivalent single axle load (ESAL) factor. An equivalent single axle load ESAL factor is defined as the number of passes of a standard (usually 18-kip single) axle needed to equal the damage to a particular pavement structure caused by one pass of a given axle type (e.g., single, tandem, tridem, or steering) when it applies its observed (or assumed) load to the pavement. An average (weighted) ESAL factor can be developed for a vehicle type (or axle arrangement) by summing the ESALs for all axles on a representative sample of all observed vehicles of that type and dividing by the number of observed vehicles. Then, by assuming no change in the pattern of loading on any vehicle type, the cumulative ESALs on a selected pavement structure during an analysis period can be obtained by summing the product of the projected cumulative number of trucks of each type and their respective ESAL factors.

6.1 METHODOLOGY FOR ASSESSING WEIGHT ENFORCEMENT EFFECTIVENESS

In order to assess the potential effectiveness of WIM-aided weight enforcement in preserving pavement condition during a certain future time period, this study focuses on two high-priority NAFTA corridors. These corridors are I-35 from Laredo to San Antonio and I-10 from El Paso to San Antonio. As discussed in the previous chapter, these highways carry a significant percentage of truck traffic crossing from Mexico into the U.S. through the Laredo and El Paso ports of entry. Furthermore, these two corridors were selected due to the availability of truck count and axle-load data that were collected during a previous CTR research project (Ref 15, 34).

These data were obtained by installing WIM devices near the north end of the international bridges that cross the Rio Grande at Laredo (1993) and El Paso (1994). The WIM devices recorded data such as axle loads, number of axles per vehicle, axle spacing, gross-vehicle weight, and other characteristics for individual trucks that crossed the bridges. Since it is likely that after NAFTA implementation, a considerable portion of this truck traffic will go beyond the existing commercial zones and travel along I-35 and I-10, a sample from the observed data was used to characterize loading patterns of various truck types. The observed axle-load data were used to obtain average ESAL factors for different truck types. Although the sample data collected at these ports of entry is representative of the truck traffic that now stays in the commercial zones, it is reasonable to assume that trucks with similar load characteristics will travel along the selected corridors.

Other data used in this study include weekday of loaded trucks observed at Laredo and El Paso ports of entry in 1994 through 1996. The data were used to estimate growth rate factors for different truck types. Finally, the truck counts were used to calculate ESAL accumulations on I-35 and I-10 during a selected analysis period for NAFTA trucks only.

6.2 ESAL FACTOR CALCULATIONS

Since the observed data at the Laredo and El Paso ports of entry indicated little change of truck loading patterns during the three-year study mentioned above, a sample of six months from 1996 (Feb. through July) was used to represent truck loading characteristics for future NAFTA trucks going northbound from Mexico along I-10 and I-35. The sample included only weekday traffic since weekend traffic comprised only a small fraction of the observed total flow at the bridges.

The sample data analyzed for this study includes the loads measured for various axle types; these were: 1) single axle, 2) tandem axle, and 3) tridem axle. The steering axle (front axle) of these trucks is not included, as the damage due to the steering axle is already included in the AASHTO ESAL factors of the other axles on each truck. Thus, for a two-axle truck, load data for only the second axle are included. The single axle-load of a 2S1 (two-axle tractor with a single-axle semi-trailer) unit is not included, since this axle arrangement comprises less than 10 percent of the three-axle truck population. Vehicle types 3S1 and 2S2 are discussed in the four-axle truck category. The single (dual-tire) axles of two four-axle vehicle types are included: the single-drive (2S2) and the single-trailer (3S1) axle. Trailer-tandem (2S2) and tractor-drive-tandem (3S2) include tractor-tandem and trailer-tandem and trailer-tandem axles. Likewise, six-axle trucks (3S3) have a tractor-tandem and a trailer-tridem axle. The different types of trucks and axle configurations observed at the Texas south border crossings are shown graphically in Figure 6.1. These truck types comprised about 80% of the observed trucks and are the focus for the following analysis.

A method that can be used to characterize truck-loading patterns involves the calculation of Weighted Average Equivalency Factors (WAEF) for each vehicle type. WAEF for different vehicle types can be obtained by multiplying each weight in the axle load frequency distribution for each axle on each vehicle type by their respective factor. The equivalency factors for different dual-tire axle types were obtained from the AASHTO Guide (Ref 1) assuming a flexible pavement with a terminal serviceability of 2.5 and a structural number of 6. These pavement characteristics are typical for these pavements designed for high traffic volumes. To facilitate this analysis, ESAL factors for violating and non-violating trucks were computed separately. Observed axle loads were sorted into violating and non-violating categories within each axle configuration.

Violating axles included axle loads that exceeded, 20, 34, and 42 kips for single, tandem, and tridem axles, respectively. Axle-load frequency distributions were calculated for the two categories, and WAEFs were determined for each vehicle type. An example of WAEFs for four-axle loaded trucks observed at Laredo is shown in Table 6.1.

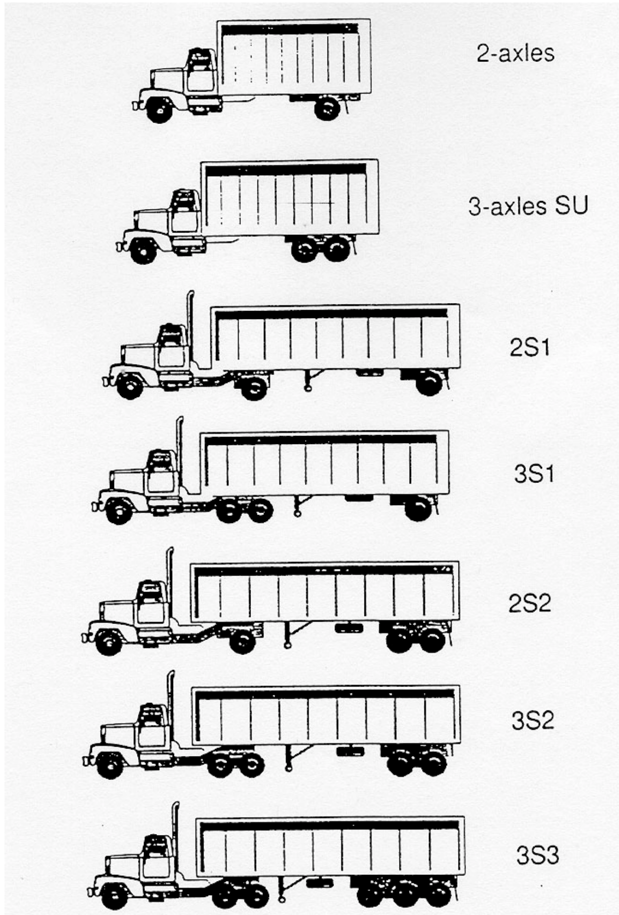


Figure 6.1 Trucks observed at Texas south border crossings (Ref 15)

Table 6.1. Calculated ESALs for observed 4-axle trucks at Laredo (Feb to July 1996)											
				3S1				**2S2**			
Single Axle		**Tandem Axle**		**Trailer Single Axle (1616)**		**Tractor Tandem Axle (1476)**		**Drive Single Axle (4665)**		**Trailer Tandem Axle (4525)**	
Weight Range	**Equiv. Factor**	**Weight Range**	**Equiv. Factor**	**Weight Dist.**	**ESALs**	**Weight Dist.**	**ESALs**	**Weight Dist.**	**ESALs**	**Weight Dist.**	**ESALs**
0_6	0.002	0_10	0.003	0.10%	0.0000	0.02%	0.0000	0.13%	0.0000	0.10%	0.0000
6_8	0.031	10_14	0.13	17.34%	0.0054	3.18%	0.0041	3.41%	0.0011	8.61%	0.0112
8_10	0.08	14_18	0.043	25.95%	0.0208	18.63%	0.0080	2.65%	0.0021	25.25%	0.0109
10_12	0.176	18_22	0.11	25.86%	0.0455	41.16%	0.0453	20.25%	0.0356	30.48%	0.0335
12_14	0.342	22_26	0.242	15.83%	0.0541	25.63%	0.0620	16.42%	0.0561	21.50%	0.0520
14_16	0.606	26_30	0.47	6.27%	0.0380	9.41%	0.0442	19.06%	0.1155	10.34%	0.0486
16_18	1	30_34	0.834	5.49%	0.0549	1.99%	0.0166	23.80%	0.2380	3.72%	0.0310
18_20	1.55	34_38	1.38	3.17%	0.0492	73.80%	1.0184	14.28%	0.2214	41.93%	0.5786
20_22	2.3	38_42	2.14	98.43%	2.2639	7.38%	0.1579	38.75%	0.8912	53.97%	1.1549
22_24	3.27	42_46	3.16	0.73%	0.0240	0.00%	0.0000	23.42%	0.7659	4.15%	0.1312
24_26	4.48	46_50	4.49	0.00%	0.0000	0.00%	0.0000	11.59%	0.5193	0.00%	0.0000
26_28	5.98	50_54	6.17	0.00%	0.0000	0.00%	0.0000	13.31%	0.7962	0.00%	0.0000
28_30	7.8	54_58	8.2	0.00%	0.0000	0.00%	0.0000	5.75%	0.4483	0.00%	0.0000
30_32	10	58_62	10.7	0.00%	0.0000	0.00%	0.0000	6.23%	0.6226	0.00%	0.0000
32_34	12.5	62_66	13.7	0.00%	0.0000	0.00%	0.0000	0.96%	0.1197	0.00%	0.0000
Weighted Average ESALs per Axle											
Non-Violators					0.2679		0.1803		0.6698		0.1872
Violators					2.2879		1.1764		4.1632		1.8647
Total ESALs per Truck											
Non-Violators					0.4482				0.8570		
Violators					3.4643				6.0279		

6.3 PROJECTED NAFTA TRUCK ESALS

The method which was used to estimate the potential effects of WIM-aided enforcement was based upon a comparison of the percent change in projected ESAL accumulations over a 20-year time period under various scenarios, including different violation and growth rates. A model was developed to calculate the projected ESALs along the two selected corridors (I-35 and I-10) in Texas for a 20-year analysis period. A schematic of the analysis procedure is presented in Figure 6.2.

$$ESALS = [R\,\Sigma_{type}(V_i * EF_{nvio} * G_i)] + [(1-R)\Sigma_{type}(V_i * EF_{nvio} * G_i) * (1-F_i)] + [(1-R)\,\Sigma_{type}(V_i * EF_{vio} * G_i) * F_i]$$

Where V_i = Average Daily Volume for Truck Type i, Trucks per day

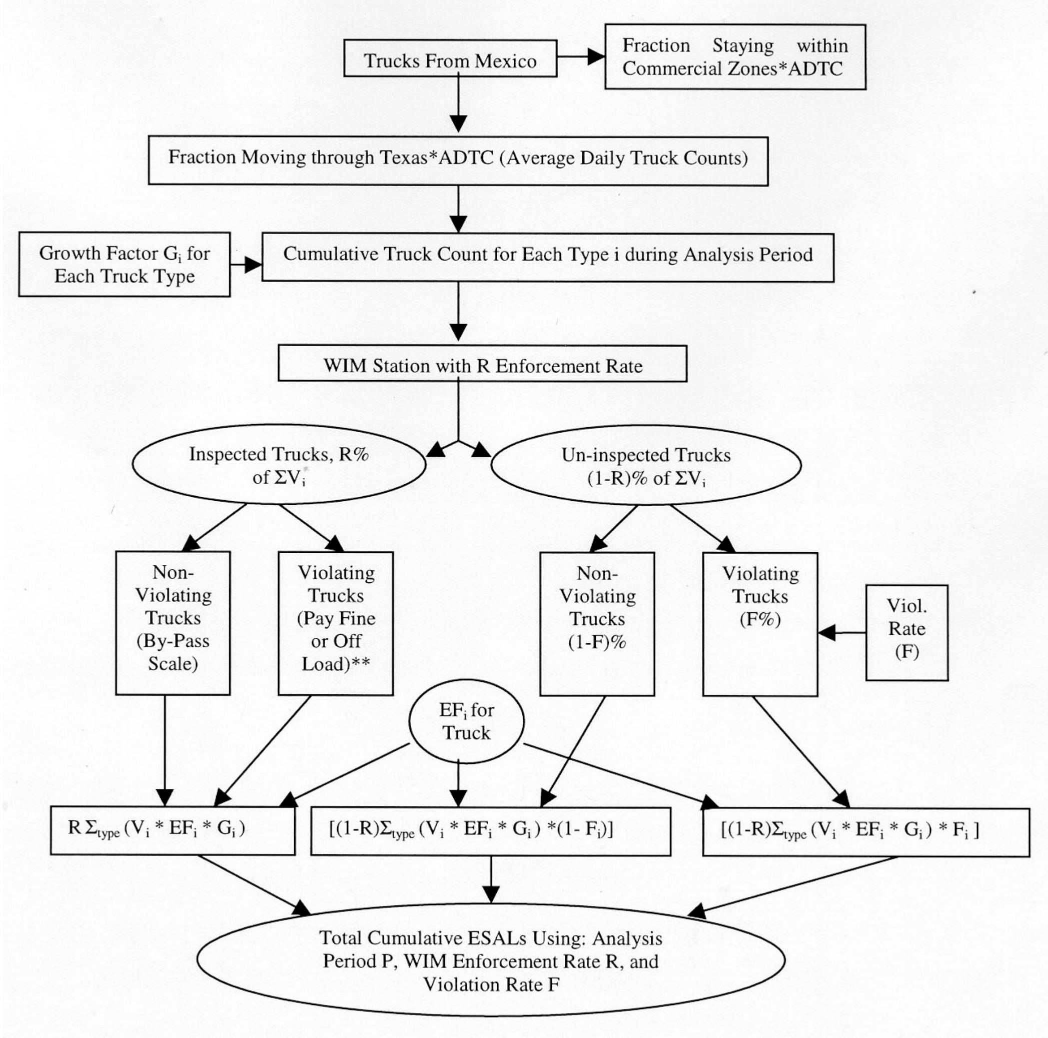
G_i = Growth Rate for Truck Type i, % (% per year, compounded annually)

R = Enforcement Rate, %

F_i = Violation Rate, %

EF_{nvio} = ESAL Factor for Non-Violating Trucks

EF_{vio} = ESAL Factor for Violating Trucks



**Trucks in this category are converted to non-violating trucks by off-loading

Figure 6.2. A Schematic for ESAL projection analysis along I-35 and I-10

As provided in Figure 6.2, once NAFTA restrictions are lifted, a certain percentage of truck traffic will remain within the commercial zones, whereas other traffic will probably travel north along major highways. Most of the truck traffic entering the U.S. at Laredo will tend to use I-35 heading north through San Antonio, while truck traffic entering at El Paso will probably use I-10 heading east through San Antonio and to Houston.

For a comparative analysis of various enforcement scenarios, NAFTA truck traffic on these routes was characterized using a fraction of the northbound weekday loaded truck counts observed by CTR (Ref 15, 34) for different truck types, the corresponding growth rates, 365 days in the year, and an analysis period of 20 years. A cumulative truck volume for each truck type was derived. Once these volumes are calculated, they were broken into two categories according to enforcement rate. The enforcement rate is a percentage value that describes the fraction of the total truck traffic stream that will be inspected at the WIM-aided enforcement site; it is a function of the percent of time that the station is in operation. This means that trucks are sorted into two categories: inspected and un-inspected.

Within the inspected truck category, it is assumed that if trucks are in violation, they are required to unload or shift the load to a different axle, which makes them legal. Because in most cases trucks in this category are inspected and are legally loaded, a non-violating ESAL factor (from previous section) is multiplied by the cumulative truck volume for each corresponding truck type. In the un-inspected category a violation rate is used to sort trucks in this category into violating and non-violating trucks. Based on this rate, cumulative truck volumes for each type are determined for each case and are multiplied by a violating or non-violating ESAL factor, depending upon whether the volumes represent the violating or non-violating trucks. Finally, the cumulative number of ESALs is determined by adding across the truck types the total ESALs contributed by each of the three truck categories. An example of the projected ESALs calculated for I-35 using the Laredo load data is shown in Table 6.2.

In this investigation, several combinations of violation rates (25%, 35%), enforcement rates (2%, 10%, 25%, 40%), and NAFTA-traffic growth rate (10%, 15%, 20%) have been used to compare the cumulative design ESALs against those produced by the base case (2% enforcement rate). The 2% enforcement rate is assumed as a logical rate for traffic being inspected using static scales. One other parameter that has been included in this analysis is the number of years before NAFTA restrictions are lifted (2 and 5 years). This is an important factor since traffic may be growing at a steady rate but as soon as the NAFTA restrictions are lifted a big jump may be witnessed in truck traffic traveling along these two corridors during the implementation year. Figure 6.3 shows an example of the assumed growth pattern in this analysis for 2-axle trucks. Thus, this analysis is using different NAFTA growth rates (10%, 15%, and 20%) to account for the sudden growth of truck traffic during the implementation year. The annual growth rates used after the implementation year are similar to the rates used before implementation. The results of the projected cumulative design ESALs are summarized in the next two sections for both I-35 and I-10.

Table 6.2. Example of projected ESALs for NAFTA traffic on I-35 (Northbound)

No. Of Axles	Truck Type	Current Daily Truck Vol.	Annual Growth Rate	Proj. Daily Truck Ver NAFTA Impl. Year	Cum. Traffic V_{cum}	Non-Violators ESAL Factor (/veh)	Violators ESAL Factor (/veh)	Inspected Traffic		Uninspected Traffic				Total ESALs in 20 years
										Non-Violating Traffic		Violating Traffic		
								V_{cum} * R	ESALs	V_{cum} * (1- R) * F	ESALs	Vcum * (1- R) * (1- F)	ESALs	
2-axles	SU	86	3%	100	857713	0.2085	3.6631	17154	**3577**	210140	**43814**	630419	**2309289**	**2356680**
3-axles	SUt	36	3%	42	359043	0.1566	3.3074	7181	**1125**	87965	**13775**	263896	**872811**	**887711**
4-axles	3S1	25	3%	29	249335	0.3272	4.1328	4987	**1632**	61087	**19988**	183261	**757383**	**779002**
	2S2	24	3%	28	239362	1.0261	9.9845	4787	**4912**	58644	**60174**	175931	**1756583**	**1821669**
5-axles	3S2	764	7%	962	11940239	0.6689	5.7243	238805	**159737**	2925359	**1956772**	8776076	**50236890**	**52353399**
6-axles	3S3	23	3%	27	229388	0.5410	6.0628	4588	**2482**	56200	**30404**	168601	**1022191**	**1055077**
													Total	**59253538**

Note: Years before NAFTA Implementation: 2
Violations Rate: 25%
Year of Implementation Growth Rate: 10%
Enforcement Rate: 2%

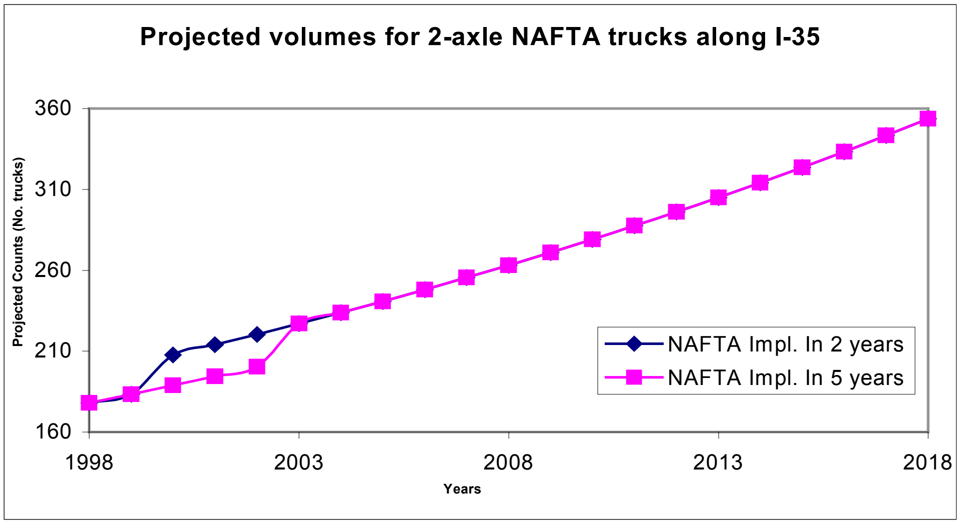


Figure 6.3. Projected volumes for 2-axle NAFTA trucks along I-35

6.3.1 Projected NAFTA Truck ESALs for I-35

Following the method described above, daily truck counts for different NAFTA truck types along I-35 (northbound), and the set of ESAL factors (violating and non-violating) from Laredo were used to calculate projected cumulative ESALs on I-35 for a 20-year analysis period. Several combinations of violation rates, enforcement rates, NAFTA growth rates were included to calculate the percent reductions in the produced ESALs for different scenarios compared to the base condition (2% enforcement rate). The results are summarized in Tables 6.3 and 6.4 for 2 and 5 years before NAFTA implementation, respectively.

From Table 6.3, a 4% decrease in ESALs is realized over a 20-year analysis period with an enforcement rate of only 10% and an additional reduction of 7% for each additional 15% in enforcement rate when the violation rate is 25%. When the violation rate is 35%, a reduction in projected ESALs of 4.7% is realized with only 10% enforcement rate and an additional reduction of 8% on average for each additional 15% enforcement rate. Furthermore, the Growth in ESALs due the NAFTA growth rates can also be appreciated by comparing the adjacent columns in Table 6.3. Similarly, Table 6.4 shows the projected ESALs for I-35 if the NAFTA restrictions are not lifted until 5 years from now. It can be seen that under this situation, about 4% reduction in the produced ESALs is realized with only 10% enforcement rate and an additional reduction of 7% on average for each 15% increase in enforcement rate when the violation rate is 25%. When the violation rate is 35%, about 4.7% reduction in ESALs is realized with only 10% enforcement rate and an additional 9% reduction on average for every 15% increase in enforcement rate.

Table 6.3. Projected ESALs (millions) for I-35 if NAFTA is implemented in 2 years					
Enforcement Rate	**Violation Rate**	**NAFTA Growth Rate** 10%	15%	20%	**% less than current ESALs**
2%	**25%**	29.8	31.1	32.3	----
	35%	35.6	37.2	38.7	----
10%	**25%**	28.6	29.8	31.0	4.0%
	35%	34.0	35.4	36.9	4.7%
25%	**25%**	26.3	27.5	28.6	11.4%
	35%	30.8	26.3	33.5	18.6%
40%	**25%**	24.1	25.1	26.2	17.2%
	35%	27.7	28.9	30.1	22.2%

20-year analysis period

Table 6.4. Projected ESALs (millions) for I-35 if NAFTA is implemented in 5 years					
Enforcement Rate	**Violation Rate**	**NAFTA Growth Rate** 10%	15%	20%	**% less than current ESALs**
2%	**25%**	29.5	30.7	31.8	----
	35%	35.3	36.7	38.1	----
10%	**25%**	28.3	29.4	30.5	4.0%
	35%	33.7	35.0	36.3	4.7%
25%	**25%**	26.1	27.1	28.1	11.4%
	35%	30.6	31.8	32.9	13.4%
40%	**25%**	23.9	24.8	25.7	18.9%
	35%	27.4	28.5	29.6	22.2%

20-year analysis period

6.3.2 Projected NAFTA Truck ESALs for I-10

A similar analysis was performed for I-10. The average daily truck counts for different truck types along this highway, and the calculated set of ESAL factors (violating and non-violating) from the El Paso data were used to calculate the projected I-10 cumulative design ESALs for a 20-year analysis period. The same combinations of violation rates, enforcement rates, NAFTA growth rates were also included for this analysis to calculate the percent reductions in the produced ESALs under different scenarios and to compare them against the base condition. The results are summarized below in Tables 6.5 and 6.6 for 2 and 5 years before NAFTA implementation, respectively.

From Table 6.5, a 5.4% decrease in ESALs is realized over a 20-year analysis period with an enforcement rate of only 10% and an additional reduction of 10% for each additional 15% increase in enforcement rate when the violation rate is 25%. When the violation rate is 35%, a reduction in projected ESALs of 6% is realized with an enforcement rate of 10% and an additional reduction of 11% on average for each additional 15% enforcement rate. Similarly, Table 6.6 shows the projected ESALs for I-10 when it is assumed that NAFTA restrictions will be lifted in 5 years from now. When the violation rate is assumed to be 25%, a 5.4% reduction in the produced ESALs is realized with an enforcement rate of 10% and an additional reduction of 10% on average for each 15% increase in enforcement rate. When the violation rate is assumed to be 35%, it can be noted that about 6% reduction in ESALs is realized with only a 10% enforcement rate and an additional reduction of 11% on average for each 15% increase in enforcement rate. These trends confirm the concept that the higher the enforcement rate, the lower the number of produced ESALs.

Table 6.5 Projected ESALs (millions) for I-10 if NAFTA is implemented in 2 years

Enforcement Rate	Violation Rate	NAFTA Growth Rate 10%	15%	20%	% less than current ESALs
2%	**25%**	26.8	28.0	29.2	----
	35%	33.9	35.4	36.9	----
10%	**25%**	25.4	26.5	27.6	5.4%
	35%	31.9	33.3	34.7	6.0%
25%	**25%**	22.7	23.7	24.6	15.5%
	35%	28.1	22.7	30.5	23.4%
40%	**25%**	20.0	20.8	21.7	24.0%
	35%	24.3	25.4	26.4	28.4%

20-year analysis period

Table 6.6 Projected ESALs (millions) for I-10 if NAFTA is implemented in 5 years

Enforcement Rate	Violation Rate	NAFTA Growth Rate 10%	15%	20%	% less than current ESALs
2%	**25%**	26.6	27.7	28.7	----
	35%	33.6	35.0	36.3	----
10%	**25%**	25.2	26.2	27.2	5.4%
	35%	31.6	32.9	34.1	6.0%
25%	**25%**	22.5	23.4	24.3	15.5%
	35%	27.9	29.0	30.1	17.2%
40%	**25%**	19.8	20.6	21.4	25.6%
	35%	24.1	25.0	26.0	28.3%

20-year analysis period

6.4 ENFORCEMENT IMPLICATIONS ON PAVEMENT LIFE

Premature highway wear-out that occurs when high volumes of heavy trucks, not anticipated during design stages, are operated over the system will require early expenditure of resources to maintain a desired level of serviceability and safety that can be much greater than the cost of building and operating a WIM-aided weight enforcement station.

For pavements, a rough estimate of the reduction in service life can be made by comparing the design ESALs for the original design loads against those projected to accumulate under increased axle loads or traffic growth rates. For example, the process used above might be performed on a hypothetical base traffic stream mix resulting in 20 million ESALs as the design load over a 20-year analysis period. A subsequent traffic mix projection might entail the accumulation of 22 million ESALs over the same period. Since the road was originally designed to withstand only 20 million ESALs, a reduction in life is expected. The original estimate of ESAL accumulation is 9.1% lower; a corresponding reduction in the AASHTO growth factor is required to make the projected traffic "fit" the original design. The AASHTO growth factor equation is

Growth Factor (G_F) = $[(1 + g)^n - 1]/g$,where

g = [growth rate/ 100] for non-zero growth rates, and n = the analysis period.

By solving for n, a new analysis period, n' corresponding to the reduced growth factor, G'_F , is established.

$$n' = \ln[g(G'_F) + 1]/\ln(1 + g),$$

where the growth rate can be varied to correspond to the new traffic stream mix. Here, n' may be viewed as the analysis period corresponding to the shortened pavement life caused by increasing traffic volume and loading or lack of enforcement. To illustrate the benefits of WIM-aided enforcement in terms of pavement life, consider data for 25% violation rate from Table 6.4. If the existing traffic mix on I-35 is used with an assumed 10% NAFTA growth rate in the implementation year that is 2 years from now, and a 2% enforcement rate as a base case (G_F=34.9), 56.1 million ESALs will accumulate during the 20-year analysis period. If a 10% enforcement rate is used and holding the other parameters constant, 52.7 million ESALs will accumulate. To accumulate the same number of overall ESALs as the base case, a 6.4% increase in the original growth rate must be applied to the new condition. The new growth factor, G'_F is equal to 37.0. Solving the above equation for n' and the projected 5% overall growth rate after the implementation year gives an analysis period of 21.5 years, reflecting the increased pavement life under the current traffic and enforcement condition. Table 6.7 shows a sampling of n' corresponding to design ESALs in Table 6.4, as compared against the base case of existing traffic and enforcement conditions with an assumed 5% growth rate over a 20-year analysis period. It is apparent that higher enforcement rates increase the pavement life.

Table 6.7. Years of pavement life resulting from increase in enforcement rate

Enforcement Rate	**NAFTA-Traffic Growth Rate 10%**	**15%**	**20%**
2%	20.0*	20.1	19.5
10%	21.5	20.9	20.4
25%	22.9	22.4	22.0
40%	24.1	23.8	23.4

*Basis of Comparison, Violation Rate: 25%

6.5 SUMMARY

Whether decision-makers choose to increase the truck weight limits or enforce the current ones, an assessment of potential benefits of truck weight limit enforcement using WIM technology in terms of pavement damage is very helpful. This chapter provided an analysis of the projected ESALs for two high-priority corridors, I-35 and I-10, under different traffic and enforcement scenarios. The analysis revealed that an enforcement rate of as little as 10% using WIM stations - it is not feasible to enforce at this rate when weighing static vehicles - produces an average 5% reduction in the produced ESAL accumulations of NAFTA trucks during a 20-year analysis period. The analysis also revealed that each additional 15% in the enforcement rate produces an average of 7 to 11% reduction in accumulated ESALs. This means that pavement life will be increased and substantial economic benefits can be realized by the traveling public.

CHAPTER SEVEN – SUMMARY, CONCLUSION AND RECOMMENDATIONS

Due to the continually increasing volume of trucks on U.S. and Texas roads, as well as the impending truck-traffic related provisions of NAFTA, the enforcement of size and weight regulations has become a critical matter. Weight enforcement is necessary in order to protect the infrastructure from premature deterioration due to repeated loading of overweight trucks. The focus of this report has been the evaluation and comparison of current weight enforcement techniques that can be applied in order to increase enforcement of truck size and weight limits on Texas highways. This includes a state-of-the-practice description and a qualitative comparison of the static and in-motion methods of weight enforcement. In addition this report includes the implications of NAFTA truck traffic weight limit enforcement using WIM technology. An analysis of the projected ESAL accumulations that might be produced by NAFTA trucks in the next 20 years was performed for different scenarios of violation and enforcement rates in order to study the potential effects of WIM-aided enforcement on pavement life. The findings indicate that once the NAFTA restrictions are lifted, WIM technology has great potential for increasing the effectiveness (percent of trucks weighed) and the efficiency (personnel time per truck weighed and no unnecessary delay to truckers) of the truck weight enforcement program needed to address NAFTA traffic and thereby help protect Texas highways from premature wear-out.

7.1 SUMMARY

The growth of trade between the U.S. and Mexico has been increasing rapidly since the liberalization of Mexican economic policies in the mid-1980's. As a consequence, the volume of interborder commercial motor carrier activity has also dramatically increased. While the increased volume in truck-born freight might be a positive indicator of welcomed economic growth, it is not without its negative consequences. When the second phase of NAFTA is implemented, Mexican truckers will be allowed unrestricted access to all territory in the four bordering states and U.S. truckers will be allowed reciprocal access to the six Mexican border states. A major concern about this provision is the effect of overweight Mexican trucks on the Texas highway infrastructure. At present, Mexican legal axle load limits exceed corresponding U.S. limits, generally by about 10-18%. In addition, no cap on GVW is imposed by Mexican federal law and most importantly; Mexican regulations are perhaps not as well enforced as U.S. regulations. Mexican-origin commercial trucks are currently allowed to operate within U.S. commercial zones, which extend slightly beyond border municipality limits, without weight verification checks.

In Texas, truck size and weight enforcement is one of the responsibilities of the Department of Public Safety. Currently, the three static scales used to measure the axle, axle-group, and gross-vehicle weight of suspected overloaded vehicles are; the wheel-load weigher (portable scale), axle-load weigher (semi-portable scale), and the axle-scale (permanent or fixed scale). These devices vary in their size, setup, ease of use, cost, accuracy, and maintenance requirements. The currently used static methods of WIM systems in other states vary in their ease of installation, cost, accuracy, and durability. Texas has recently begun operation of its first weigh station utilizing in-motion techniques to sort suspected violators from a truck traffic stream so that only those suspect of being overweight are stopped on the static scales, while those that are not suspect are directed back towards the highway. This technology, along with its many capabilities, has some disadvantages that cause concern to the DPS and other officials. Both static and in-motion methods are compared to each other with respect to the vehicle processing rate, the sample size of trucks, safety issues, ability for continuous operation, personnel requirements, coverage area, accuracy, cost, susceptibility to electromagnetic disturbances, and portability. Examples of WIM station initial and operating costs provide representative values of cost for comparison with static scale costs.

Using WIM as a tool for sorting suspected violators from a truck traffic stream has been a learning experience for the DPS and TxDOT. The DPS has found that using WIM enables a facility to weigh a substantially higher number of trucks with the same amount of personnel. In addition, they have learned that specific design factors are critical in order to provide effective and efficient operation of the facility, and other elements are useful hints that work to even further enhance the operation of a weigh station. The strongly supported use of WIM in other states, as well as the now-growing interest in Texas, is a good indication as to its capabilities that compensate for its limitations.

Highway engineers have known for more than 70 years that heavy truck loads, delivered through individual axles and wheels, rapidly consume pavements. With damage relationships developed as a result of the AASHO Road Test in the late 1950’s, it is possible to quantify, relative to the loading on a standardized axle (equivalent single axle load, or ESAL), the relative damage caused by the passage of trucks. Such damage escalates exponentially, approximately to the fourth power of the ratio of loading on similar axle-group configurations.

Using current static methods of enforcement, state troopers inspect an estimated average of 2 percent of the truck traffic on Texas highways. This low enforcement rate has negative implication concerning accelerated damage of the Texas highway infrastructure, especially, when the second phase of NAFTA is implemented.

7.2 CONCLUSION AND RECOMMENDATIONS

International trade between the U.S. and Mexico is continually growing due to fewer restrictions on trade between the countries. As a result, economic growth occurs within each country; however the infrastructure suffers due to the increase in truck travel between them. As nearly two-thirds of the U.S. truck traffic travels through Texas, the protection of Texas highways has become a forefront issue. Utilizing current static methods of weight enforcement cannot increase the amount of enforcement without a substantial increase in personnel. Weigh-in-motion techniques, even with their recognized limitations, have proven to be effective in a number of other states. The State of Texas has invested in a WIM station to attempt to protect one of the nation's most critical trade links from premature deterioration. This experience has spurred the construction of a second facility on another primary trade route/truck corridor.

Although one of the major concerns with using WIM is the higher initial cost compared to static methods, the investment in a WIM system allows for a number of benefits, including a higher vehicle processing rate, thus providing for a near 100 percent sample of truck traffic on major roadways. The more extensive sample reduces the bias that occurs when choosing a truck to be weighed with static methods. A WIM station is safer than all static methods, and since it needs minimal personnel to operate the station, it can easily be operated continuously. Using WIM on a major truck corridor allows other enforcement officers with portable scales to focus only on possible bypass routes, thus providing a greater coverage area. However, the accuracy of WIM systems is not enough to provide enforcement alone. Instead, if WIM is used to sort suspected violators from truck traffic, a static scale must be used in order to legally write a citation. Other disadvantages of WIM are its inability to be moved to different locations, and its susceptibility to lightning strikes or other electromagnetic disturbances.

The initial cost of a WIM station can range from about $300,000 up to about $1.5 or $2.5 million for a comprehensive facility. Again, the location of the station makes a large difference in its cost. However, if a station is located on a critical truck route, the number of trucks weighed can exceed a couple thousand in one 24-hour day. Although the initial cost can be four or five times the amount of a permanent station, the number of vehicles that can be weighed increases even more dramatically. The same amount of manpower can weigh thousands more trucks per week using WIM than they can using conventional static methods.

U.S.-Mexico trade-related commercial truck traffic volumes are likely to continue their sizable growth rates. With the implementation of the second phase of NAFTA, these growth rates are expected to triple especially during the implementation year. The growth of trade between the U.S and Mexico has resulted in the development of well-defined truck highway corridors with respect to major border regions. These highway corridors are created by trucks carrying products between ports along the U.S.-Mexico border and major concentrations of population and manufacturing in the U.S. The three major border regions in Texas -Lower Rio Grande Valley, Laredo, and El Paso- have distinctly different corridor patterns. The Lower Rio Grande Valley has a radial pattern with dominant corridors in Texas and to the northeast of Texas. Laredo has a radial pattern with dominant corridors to the northeast and southeast of the U.S. El Paso has a pattern with linkages primarily to Texas and the industrial northeast (Ref 24). When all truck movements are combined and highways carrying less than 40,000 trade trucks per year are eliminated, dominant highway corridors are shown to run between the northeastern U.S. and Texas border regions. In 1996, I-35 from Laredo to San Antonio was the dominant truck trade corridor, with over 1,000,000 trucks. To and from El Paso, the dominant corridors are to the east and they run east-west, linking El Paso to Houston (I-10).

In an assessment of potential damage savings to the Texas highway system, particularly I-35 and I-10, an enforcement rate of as little as 10% using WIM stations produces an average of 5% reduction in the produced ESAL accumulations during a 20-year analysis period. The analysis also revealed that each additional 15% in the enforcement rate produces an average of 7 to 11% reduction in accumulated ESALs. This means that pavement life will be increased and substantial economic benefits can be realized. An accurate forecast of the commercial motor carrier growth rate is essential in allowing highway planners to develop meaningful damage projections. While increases in average axle loads are an important consideration for pavement damage, miscalculating traffic growth rates will have a far greater relative impact on pavement life. A WIM system can keep a record of every truck weighed, by type and axle configuration. This is valuable statistical data for traffic forecasting. The magnitude of heavier vehicle loads, and their configurations are particularly salient considerations in determining bridge overstress, where understanding the impact of single “critical load” vehicles, or a multiple presence incident, are essential to ensuring that resulting moments do not exceed a bridge’s operating stress. Whether harmonization talks result in the U.S. retaining its lower legal load limits, or in raising load limits, WIM systems should be considered for placement in the vicinity of each highway port-of-entry or along the designated “trade routes” described in this report to screen for overweight violators. WIM systems could also be used at major interchanges to screen traffic for violators traveling unauthorized routes or bypassing permanent stations. WIM-system data should be recorded and analyzed continuously to establish trends in traffic loading at every site. In addition, weight enforcement policies should become stricter, with penalties based on sound cost-recovery principles such as assessing damage attributable by equivalent fatigue weight (Ref 22) for bridge cost recovery and ESAL-miles (1.61 km = 1 mile) for pavement cost-recovery.

In order to provide more enforcement, a weight enforcement agency can continue using static methods, and must purchase additional equipment and hire more personnel. Or the agency can invest in a WIM system and substantially increase their productivity while maintaining the original amount of personnel in the department. Therefore, the initial expense of a WIM station can provide a savings in annual operating costs for personnel, while providing a greater amount of enforcement producing more citations, more fines collected, and greater protection of our pavements from premature failure.

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