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16. Abstract

The number of trucks on many highways in Texas and across the nation has increased to the point that special or unique roadway design treatments may be warranted. Increases in truck traffic have resulted from increases in time-sensitive freight (e.g., just-in-time deliveries), the North American Free Trade Agreement (NAFTA), and until recently a robust economy. As particular corridors have become increasingly dominated by truck traffic, or in locations where truck traffic might reasonably be segregated, questions have arisen regarding accommodations and treatments to address issues caused by truck traffic that may be appropriate for those corridors. This research investigated the sensitivity of current Texas design practice to the unique operating characteristics of large commercial vehicles and determined threshold conditions under which design should reflect these larger vehicles. Findings of this study indicate that serious consideration needs to be given trucks when the average annual daily truck traffic (AADTT) reaches 5000 trucks per day during the design period. When the design AADTT reaches 25,000 trucks per day, there may be justification for considering separated truck roadways with a minimum of two lanes in each direction. This research recommends that the Texas Department of Transportation (TxDOT) consider changes in the following design parameters in its *TxDOT Roadway Design Manual* (and/or other appropriate documents): stopping sight distance, intersection and channelization, lane width, shoulder width and composition, sideslopes and drainage features, traffic barriers, passive signs, and acceleration lanes.

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TRUCK ACCOMMODATION DESIGN GUIDANCE
FINAL REPORT

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EXECUTIVE SUMMARY

The number of trucks on many highways in Texas and across the nation has increased to the point that special or unique roadway design treatments may be warranted. Increases in truck traffic have resulted from increases in time-sensitive freight (e.g., just-in-time deliveries), the North American Free Trade Agreement (NAFTA), and until recently a robust economy. As particular corridors have become increasingly dominated by truck traffic, or in locations where truck traffic might reasonably be segregated, questions have arisen regarding accommodations and treatments to address issues caused by truck traffic that may be appropriate for those corridors.

Three prominent scenarios of truck treatment or accommodation that seem to depend largely on the volume of trucks on the roadway are: 1) allow trucks to operate in mixed flow with no special design treatment, 2) allow trucks to operate in mixed traffic with some restrictions on trucks and/or cars to improve safety and/or operations, and 3) provide separate truck roadways. For at least the second and third scenarios, there need to be special design considerations given to accommodate trucks and make the roadway as safe as feasible.

Concerns regarding geometric design issues voiced by stakeholders included: shoulders too narrow for trucks, insufficient truck parking, inadequate intersection design, entry/exit ramps too close together, sharp curves causing rollover, and acceleration lanes too short. TxDOT is already addressing some of these deficiencies by improving rest area parking for trucks and increasing the number of these facilities, providing warning systems for trucks on sharp freeway connector curves, and considering lane restrictions as a means of freeing at least one lane for other motorists.

In their evaluation of major truck corridors, researchers developed and used the following ranges of truck traffic (in terms of Average Annual Daily Truck Traffic [AADTT]): 0-480, 480-960, 960-2880, 2880-5760, 5760-11,520, 11,520-23,040, and 23,040+. In developing a summary of route-miles and truck-miles traveled (TMT) for all state (ST), interstate (IH), and U.S. routes in Texas, the Texas Transportation Institute concluded the following:

- Highways with high truck volumes (5760-11,520) account for 6 percent of the route miles and 31 percent of the annual TMT.

- Highways with very high truck volumes (11,520-23,040 +) account for 2 percent of the route miles and 18 percent of the annual TMT.

Also, by highway type, the following findings are useful:

- Interstate highways account for 11 percent of the route miles and 49 percent of the annual TMT.

- U.S. highways account for 40 percent of the route miles and 32 percent of the annual TMT.
- State highways account for 50 percent of the route miles and 20 percent of the annual TMT.

The various studies on truck accommodation define trucks in different ways. Some define a truck as Class 3+ whereas others define them as larger trucks such as Class 5+. In the Federal Highway Administration Scheme "F", Class 3 vehicles include four-tire vans, some pick-up trucks, and small trucks pulling one- or two-axle trailers. The FHWA Class 4 consists of two- and three-axle intercity buses, Class 5 includes two-axle single-unit vehicles with six tires, and Class 6 and above are heavy trucks with more than two axles. From a safety, capacity, and vehicle operations standpoint, Class 3 and above could be important, although Class 5 and above are much more important.

Past research evaluating the effects of truck lane restrictions on operations and safety indicates mixed findings. One 1989 study concluded that safety could be enhanced, while a study in 1990 found that capacity and safety were not improved. Public opinion was so favorable in a third study (pertaining to the Washington D.C. Capital Beltway) that lane restrictions were maintained even in the absence of positive findings related to safety and operations. General guidance suggests that lane restrictions should only be established on roadways with three or more lanes by direction, trucks should be restricted to the right two lanes or from the left lane(s), and lane restrictions should not make use of entry/exit ramps difficult.

Data from two truck roadways in the U.S. provide some useful information for other states that might consider building similar facilities. One facility is a 35-mile segment of the New Jersey Turnpike and the other is a short 2.4-mile segment of I-5 in California. It should be noted that these two controlled-access facilities do not prohibit smaller vehicles. However, they do facilitate side-by-side comparisons of mixed traffic (on the truck roadway) and cars only. Comparing crash rates between each of the two parallel roadways over the most recent three years indicates no significant difference in either injury or total crash rates. However, it should also be noted that crashes of cars with other cars should be less severe than trucks with other cars even if their total crash rates are similar. AADTT values on these two roadways range from 20,000 to 28,000 (Class 5+) trucks per day.

Previous studies that established the need for truck roadways based on truck volumes used AADTT thresholds of 20,000 Class 5+ vehicles or 25,000 Class 3+ vehicles per day. Other important criteria that designers should consider besides truck volume include: volume of non-trucks, number of mixed-flow lanes available, level-of-service, the truck-involved fatal crash rate, and proximity to significant truck traffic generators. For example, other requirements that supplemented the 20,000 large trucks per day were an average annual daily traffic (AADT) of 120,000 vehicles per day, four travel lanes in each direction, and consistent traffic demand over a length of 10 miles or more. The authors suggest using these AADTT values as general guidelines, not as a final criterion. Based on data from the

Transportation Planning and Programming Division of TxDOT, highways with very high truck volumes (11,520-23,040 +) account for 2 percent of the route miles and 18 percent of the annual truck-miles traveled.

Separate truck roadways should not have less than two continuous lanes. Capacities of roadways with 100 percent trucks have been established by TTI in previous research which found that the capacity is 1600 trucks per lane per hour in flat terrain and 800 trucks per lane per hour in rolling terrain. (The authors recommend further review of these values in future research.) Based upon these level-of-service "E" values, observed peaking characteristics of truck flows, and growth rates in the 3 percent to 5 percent per year range, the peak hour truck flows in 20 years will be 2000 trucks per hour at 3 percent growth rate and 2500 trucks per hour at 5 percent growth rate. The result indicates that a truck roadway with two lanes (by direction) in flat terrain will have a capacity of 3200 trucks per hour and can accommodate a growth rate of 5 percent (or higher) over a 20-year design period. Considered another way, this finding suggests that a separated truck roadway with two lanes in flat terrain would not reach its capacity even during peak hours (assuming trucks only) at the end of 20 years even at a 5 percent growth rate. The perception of underutilization may become an issue, at least at first. In rolling terrain, the higher growth rate would require more than two lanes, given the values cited above.

The authors encourage TxDOT to adopt truck-friendly design to the extent feasible even at design year volumes of 1000 or more trucks per day. Beyond this design level, a reasonable criterion to begin considering special truck treatments is 5000 trucks per day (again, with about 6 percent of this daily value expected to occur in the peak period). The truck volume that would justify building future separate truck roadways would be about 25,000 trucks per day.

Table 1 summarizes both the design parameters identified early in this research and the recommendations of the TTI research team for change and the truck activity level at which the change should occur. Since the emphasis of the research moved to controlled-access facilities, some of these parameters originally selected did not apply. Much of TxDOT's current design practice already reflects the unique characteristics of large commercial vehicles, so the authors are recommending no change to several design parameters.

Table 1. Design Element Thresholds.

Design Element	Design Year AADTT		
	1000 to 5000	5001 to 25,000	Over 25,000
Sight Distance			
Stopping Sight Distance	NC [a]	NC [a]	NC [a]
Decision Sight Distance	NC	NC	NC
Passing Sight Distance	NA	NA	NA
RR-Hwy Sight Distance	NA	NA	NA
Intersection Sight Dist.	NC	NC	NC
Horizontal Alignment			
Curve Radius and Superelev.	NC	NC	NC
Intersection & Channelization	NC	*	*
Pavement Widening	NC [b]	NC [b]	NC [b]
Vertical Alignment			
Critical Length of Grade	NC	NC	NC
Downgrades	NC	NC	NC
Cross-Section Elements			
Lane Width	NC	NC	*
Shldr. Width & Composition	NC	*	*
Sideslopes & Drainage	NC [c]	NC [c]	NC [c]
Pavement X-Slope Breaks	NC	NC	NC
Vertical Clearance	NC	NC	NC
Traffic Barrier	NC	* [c]	* [c]
Passive Signs	NC	* [d]	* [d]
Curbs	NC	NC	NC
Acceleration Lanes	NC	*	*

* Change required from current TxDOT practice to design specifically for trucks.
NA: Not applicable to high-volume, controlled-access roadways for trucks.
NC: No change from current design practice.
[a] Needs a change in wording in the *TxDOT Roadway Design Manual*.
[b] For design speeds over 60 mph.
[c] Apply findings of National Cooperative Highway Research Program (NCHRP) 22-12 as appropriate to Texas roadways.
[d] For diamond interchanges use overhead signs instead of ground-mounted at ½ mi and 1 mi in urban areas and 1 mi and 2 mi in rural areas.

CHAPTER 1. BACKGROUND

1.1 INTRODUCTION

As particular corridors have become increasingly dominated by truck traffic, or in locations where truck traffic might reasonably be segregated, questions have arisen regarding the design characteristics that would be appropriate for those corridors. There are several scenarios of treatment that appear to be plausible at the outset of this research. Three prominent scenarios that seem to depend primarily on the volume of trucks on the roadway are:

- allow trucks to operate in mixed flow with no special design treatment,
- allow trucks to operate in mixed traffic with some restrictions on trucks and/or cars to improve safety and/or operations, and
- provide separate truck roadways.

For the second and third scenarios, there need to be special design considerations given to accommodate trucks and make the roadway as safe as feasible. Other issues that need to be evaluated besides design include: public and political sensitivities, motor carrier acceptance, cost and funding options, environmental issues, and enforcement. There needs to be guidance developed regarding circumstances that warrant special design features (e.g., special barriers designed for trucks) as well as what features should be included.

To satisfy concerns regarding truck traffic on Texas roadways, there must be attention given to design aspects of highways, and to various other programs to optimize safety and operations. The "design vehicle" is a key ingredient to the design process, and larger trucks will likely control design where their numbers are significant. The American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets (1)* commonly known as the *Green Book*, provides the basis of design policy throughout the U.S. supplemented in various states by other documents. TxDOT has its *Roadway Design Manual (2)* for use in day-to-day design. Every roadway and intersection is designed to accommodate a specific design vehicle, selected from among those presented in the *Green Book* or the *Roadway Design Manual.* The latter document does not provide firm guidelines governing the selection of the type of large vehicle to be used as a design vehicle, but it gives factors to assist the design engineer. These are as follows:

- the type and frequency of use by large vehicles,
- the consequences of encroachment into other lanes or the roadside, and
- the availability of right-of-way.

1.2 PROJECT OBJECTIVES

This project responds to the immediate need to more fully understand highway design features that are, or should be, influenced by trucks. The research addresses the topic for the state of Texas through a number of specific objectives. Overall project objectives are as follows:

- develop a profile of the truck fleet using, and expected to use, Texas roadways;
- evaluate geometric design criteria currently used and determine whether the criteria adequately reflect truck characteristics;
- identify design-related practices used elsewhere that could best improve Texas design practice;
- develop geometric guidelines for implementation; and
- develop two sets of training materials, one for mid-level designers and one for policy makers.

The objectives addressed in this report are the first three of the bullets above.

1.3 ORGANIZATION OF THE REPORT

Chapter 2 provides input from stakeholders, including TxDOT, motor carriers, enforcement, and other jurisdictions. Chapter 3 is an evaluation of the Texas truck fleet with emphasis on determining any vehicle factors that should be incorporated into geometric design practice in Texas. Chapter 4 is an evaluation of the major truck corridors in Texas to identify corridors that are anticipated to carry high truck volumes. Chapter 5 provides a discussion of methods used outside of Texas for accommodating trucks. Chapter 6 covers critical non-geometric design issues while Chapter 7 covers truck design thresholds. Chapter 8 provides design guidelines to be used for trucks.

CHAPTER 2. INPUT FROM STAKEHOLDERS

2.1 INTRODUCTION

The Texas Department of Transportation is experiencing increased truck traffic on most, if not all its facilities. TxDOT districts are facing tremendous challenges in attempting to keep roadways maintained at a desirable level under the constant growth and increased infrastructure damage by truck traffic.

2.2 METHODOLOGY

Information gathered in this project pertaining to TxDOT needs comes from three surveys, two that were conducted as part of Task 1 of this project and the third conducted by the Research and Technology Implementation (RTI) Office of TxDOT *(3)*. The first survey conducted as part of this project began by research staff developing a one-page list of questions (see Appendix A) to be sent to all 25 TxDOT districts. This survey involved a two-step process: 1) send out surveys to districts, and 2) select from the responses a few for office visits to supplement survey information. For the first step, the Texas Transportation Institute obtained email addresses of all 25 district engineers and sent the survey via email to them. District engineers forwarded the survey to the appropriate section for completion. A total of 17 districts responded within the allotted time of two weeks. A brief summary of the information provided by each district follows in the next section.

The districts selected for follow-up visits were Houston, Laredo, Pharr, and San Antonio. TTI talked first to district personnel then to motor carriers with operations in the district. TTI developed a list of desired motor carriers that included both line-haul operators and shorter-trip local carriers.

The RTI survey report *(3)* presents the compilation of responses to a questionnaire sent to all districts, divisions, and offices within TxDOT. Response to the RTI questionnaire was good. Out of 53 organizational units surveyed, 37 replied to the questionnaire, for an overall response rate of 70 percent. Perhaps more importantly, 24 of 25 districts replied, for a 96 percent district response rate. The questionnaire asked only two questions:

1. *Has your district/division/office implemented any specific actions or countermeasures due to increasing truck traffic volumes on the Texas highway system? If so, please describe briefly.*

2. *In your opinion, are there any processes or procedures that should be changed to better accommodate increasing truck traffic volumes on the Texas highway system?*

To supplement the information that resulted from the two surveys above, TTI also conducted a survey of Department of Public Safety (DPS) License and Weight personnel and Highway Patrol personnel. Appendix B contains the survey form. This activity began by sending the survey form to the Austin headquarters License and Weight office. This chapter also provides pertinent results of a truck driver survey that was conducted as part of a parallel research project. That survey asked open-ended questions that yielded some results that were not relevant to that project but addressed geometric design issues.

2.3 FINDINGS BASED ON STAKEHOLDER INPUT

Findings in this chapter come from interviews and surveys, with most of the interviews conducted as office interviews and a few by telephone. Findings are organized by the TTI, DPS, and RTI surveys first, followed by TxDOT district and division interview findings. Then, there are findings based on interviews with motor carrier representatives.

2.3.1 TxDOT Survey Findings

The TTI survey mail-out resulted in a total of 18 returned surveys from the 25 sent out. Districts responding were: Abilene, Atlanta, Austin, Bryan, Corpus Christi, Childress, Dallas, El Paso, Ft. Worth, Houston, Laredo, Lufkin, Pharr, San Angelo, San Antonio, Tyler, Wichita Falls, and Yoakum.

- The Abilene District does not have any designated truck corridors other than the statewide trunk system.

- The Atlanta District has U.S. 59, which is part of the designated I-69 corridor but other heavy truck routes are I-30 and I-20.

- The primary heavy truck route in the Austin District is I-35, but U.S. 183, U.S. 290, and S.H. 71 are also heavy truck routes. One proposed geometric design improvement suggested by the Austin District is wider pavement widths on interchange turn-arounds.

- The busiest truck routes in the Bryan District based on 1999 counts are: I-45 (8345 trucks per day [tpd]), S.H. 6 (3161 tpd), S.H. 36 (1653 tpd), and U.S. 79 (1770 tpd). Seasonal variations in truck flows average from 5 percent to 10 percent.

- The three heavy truck routes and their daily truck volumes in the Corpus Christi District are U.S. 77 (4295 tpd), U.S. 281 (2380 tpd), and I-37 (3242 tpd). U.S. 77, U.S. 281, and U.S. 59 all carry a substantial amount of NAFTA traffic.

- In the Childress District, I-40 serves an ADT of 12,000, 40 percent of which is trucks (4800 trucks per day). U.S. 287 has an ADT of 10,000 with 39 percent trucks (3900 tpd).

- In the Dallas District, I-35E has high truck volumes at 12,500 trucks per day. Other candidate truck corridors are I-20, I-635, and Loop 12. Seasonal variations are in the range of 5 percent to 10 percent. One suggestion by the Dallas District pertaining to trucks is to utilize frontage roads for diverting traffic around a hazardous spill on the truck routes noted above.

- The El Paso District's busiest truck routes are I-10 and Loop 375. NAFTA routes are these two plus S.H. 178 and Artcraft Boulevard.

- The Ft. Worth District reports I-35W as a NAFTA route across Tarrant and Johnson Counties. The main hazardous materials routes are I-20 and I-820 for through-transportation, and there are local arterials and collectors that are designated as truck routes. The district has built climbing lanes on U.S. 67, U.S. 180, U.S. 281, U.S. 377, U.S. 380, S.H. 114, S.H. 199, and S.H. 337. Daily truck volumes are in the range from 10,000 to 16,000 on I-20, I-30, I-35W, S.H. 121, and S.H. 183.

- The Houston District has corridors 18 and 20 of the I-69 corridor. Local restrictions in Houston include:
    - weight restrictions on some local city/county bridges,
    - through traffic restrictions,
    - specific routes for hazardous cargo,
    - city fire code restrictions, and
    - no trucks on city streets in residential areas.

- The Houston District has lane restrictions on I-10E from Waco Street to Uvalde where trucks are not allowed on the inside lane of the freeway from 6:00 a.m. to 8:00 p.m. Monday through Friday. There are exceptions to normal size/weight rules for the following routes serving the Port of Houston: S.H. 225, S.H. 146, and Beltway 8 in the Ship Channel area. The district's busiest truck routes are: I-45N (9700 tpd), I-10E (9000 tpd), U.S. 59S (9000 tpd), I-610E (8000 tpd), U.S. 59N (7400 tpd), and S.H. 146 (5600 tpd). Suggestions from the Houston District regarding planning for heavy truck volumes were: designated truck lanes for Interstate highways and some state and U.S. highways, and an independent facility for trucks in the corridor parallel to the existing highway.

- The Laredo District has the following NAFTA corridors: I-35 (Webb and La Salle counties), Loop 20, U.S. 59 (Webb and Duval counties), F.M. 1472, U.S. 83 (Webb and Dimmit counties), U.S. 277 (Maverick, Dimmit, and Val Verde counties), U.S. 57 (Maverick and Zavala counties), U.S. 90, S.H. 239, and F.M. 1021.

- The Lufkin District has one NAFTA route, U.S. 59. TxDOT is utilizing 12 "line segment consultants," who report to a general engineering consultant (GEC), who in turn reports to the Transportation Planning and Programming Office. The GEC is a consultant hired by TxDOT to be responsible for the "big picture" involving the other 12 consultants. Each district has a great deal of input on the pavement design through its area along with many other issues. The grand scheme for I-69 is to have an ultimate section of two inside dedicated truck lanes and four other lanes in each direction with a rail corridor in the median area. It should be emphasized that this is the ultimate scheme and will vary initially depending on current and 30 year needs. The Lufkin District, for example, will acquire the necessary corridor width to accommodate this cross-section, but might initially build only two or three all-purpose lanes in each direction (no dedicated truck lanes). However, it is anticipated that the initial design within high truck demand segments (e.g., in and near Houston) will incorporate dedicated truck lanes. As of early 2002, there were still many decisions remaining to be made.

- The Odessa District has the "Port to Plains" routes that are considered candidate truck corridors (more details provided in Chapter 4). The federal government has designated the Port to Plains Corridor from Colorado to Del Rio and on to Laredo as a truck/trade corridor. The majority of the route runs through the Amarillo, Lubbock, San Angelo, and Laredo districts. The Odessa District has a leg of the route (similar to the I-35 split) that follows S.H. 349 from Lamesa to Midland, and then east along S.H. 158 to Sterling City, where it connects with the route on U.S. 87. In addition to the Port to Plains routes, some cities in the Odessa District have designated truck routes. The busiest truck routes are I-10 and I-20 (no truck volumes provided).

- The Pharr District has several NAFTA corridors such as various routes leading to the Ports-of-Entry to Mexico. Examples of NAFTA corridors are: U.S. 281 (9788 tpd), U.S. 83, U.S. 77/83, F.M. 755, F.M. 1015, F.M. 1016, S.H. 336, S.P. 241, U.S. 281 Military Road, F.M. 509, LP 499, F.M. 511, S.H. 48, and S.H. 4. The district has one "overweight corridor," which is S.H. 48; it allows combination vehicles hauling selected commodities that are heavier than 80,000 lb. Permit fees collected from these abnormally heavy vehicles provide revenue for replacing the existing asphalt pavement with concrete pavement, although the replacement rate lags behind the deterioration. The highest seasonal variations (over 15 percent) occur due to grain harvest, such as on F.M. 1015.

- The San Angelo District's NAFTA corridors consist of the Texas Trunk System Phase I: S.H. 158 in Glasscock/Sterling counties and U.S. 83 in Concho, Menard, and Kimble counties. The district's busiest truck routes are: U.S. 83 (1800 trucks per day), U.S. 67 (1800 trucks per day), U.S. 87 (2800 trucks per day), and LP 306 (2800 trucks per day).

- The San Antonio District has I-35 as its primary NAFTA route. The district recently designated hazardous materials routes.

- The Tyler District only has I-20 as a NAFTA corridor or truck corridor. Inside city limits in this district, loops such as LP 281, LP 323, and LP 317 (Athens) are designated as truck routes. The district identified a need for an economical solution to remedy deteriorated subgrade material without resolving to full reconstruction. Presently, the district is adding a hot-mix asphalt cement (HMAC) surface course for strength due to limited reconstruction funding.

- The Wichita Falls District considers the following corridors as candidate truck corridors: I-35, U.S. 287, I-44, and U.S. 277. There are local truck restrictions in the city of Wichita Falls, Wichita county roads, and several F.M. roadways, which are load posted for weight restrictions. The district's busiest truck routes are: I-35 (7700 tpd), U.S. 287 (4600 tpd), I-44 (2300 tpd), and U.S. 277 (1300 tpd). Seasonal fluctuations in these volumes are in the 11 to 15 percent range. The district has constructed two truck parking facilities at abandoned rest areas on U.S. 287 to assist drivers who need to rest.

- The Yoakum District has two future I-69 corridors along U.S. 59 that it anticipates will carry significant amounts of NAFTA freight: Corridor 18 from Ft. Bend county to Goliad County and Corridor 20 from the Ft. Bend County line to Victoria and south to Refugio County. The district's busiest truck routes are I-10 (10,374 tpd) and U.S. 59 (4756 tpd). These truck volumes vary seasonally by 11 to 15 percent. One specific geometric challenge is movement of prestressed concrete beams in and around Victoria (Texas Concrete Company plant location).

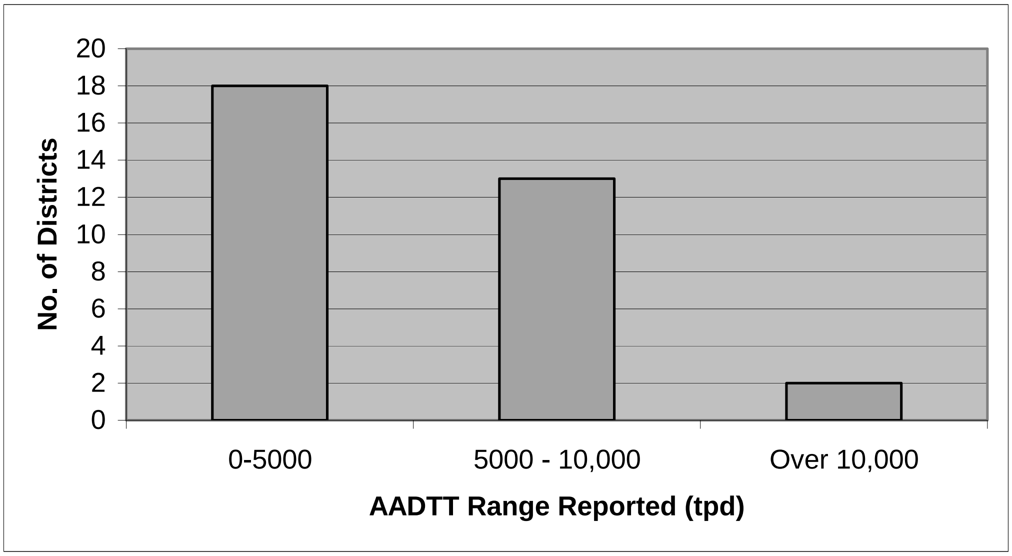
In summary, the NAFTA routes mentioned in the returned surveys totaled 42, although two districts considered the Texas Trunk System as a NAFTA route and multiple districts used the I-69 corridor. Local restrictions for trucks were mostly hazardous materials routes or city restrictions forbidding trucks from using certain streets. In addition, there were weight restrictions on routes or bridges, restrictions against through trucks, and restrictions due to low overhead clearance. For designated truck lanes or separate truck facilities, the Ft. Worth district noted climbing lanes for trucks on eight specific route numbers and the Houston district cited its truck lane restriction on I-10E from Waco Street to Uvalde Street from 6:00 a.m. to 8:00 p.m. Monday through Friday. There were two examples cited of route-specific exceptions to the normal size/weight rules. One was in the Houston District in the area of the Houston Ship Channel for S.H. 225, S.H. 146, and Beltway 8; the other was an overweight corridor in the Pharr district using S.H. 48 from the Mexico border to the Port of Brownsville.

For summarizing the district's heaviest truck routes, the analysis used three categories of average annual daily truck traffic: zero to 5000 trucks per day, over 5000 but not more than 10,000, and over 10,000 trucks per day. As Figure 1 indicates, districts that responded cited 18 roadways with truck volumes in the lowest range, 13 in the middle range, and two in the high range. Few districts had truck volumes that varied significantly by season, but of the seven that reported seasonal variations, one was less than 5 percent, four were between 5 percent and 10 percent and two exceeded 15 percent.

Table 2 summarizes district responses pertaining to elements of design where special consideration is given to trucks. The percentages are simply total cell entries divided by the total number of districts responding, which was 18.

2.3.2 DPS Office Meeting and Survey

A representative of the Texas Motor Transport Association (TMTA) mentioned in an earlier office visit that rest areas across the state were being converted to truck enforcement sites, so researchers asked DPS officers about that plan. The response was that this action was being taken to help truck drivers comply with federal hours of service (HOS) requirements. There was to be $100 million available to TxDOT to upgrade rest areas to what they were calling



Data Source: TxDOT.

Figure 1. TxDOT Survey Responses.

Table 2. Summary of District Survey Responses.

Design Element	Percent	Design Element	Percent
Pavement issues	72	Stopping sight distance	28
Intersection design	61	Acceleration (intersection)	22
Minimum design for sharpest turn	56	Passing sight distance	22
Climbing lanes	50	Operating characteristics on grades	22
Bridge issues	44	Weaving distances	22
Capacity considerations	44	Braking characteristics	17
Left-turn lanes	44	Roadside hardware (e.g., signs, barrier)	17
Off-tracking characteristics	39	Decision sight distance	11
Acceleration (grades)	33	Driver eye height	11
Deceleration on grades	33	Intelligent Transportation Systems (ITS) (e.g., active warning on curves)	11
Ramp design	33	Lighting	11
Alignment (horizontal)	28	Side slopes	11
Alignment (vertical)	28	Signing (passive)	6

Data Source: TxDOT.

“super rest areas” to serve three needs: 1) truck drivers that need to stop for HOS reasons, 2) all other motorist parking, and 3) enforcement activities. One of the on-site buildings would be one for DPS personnel to use while weighing and inspecting trucks. However, DPS anticipated problems in maintaining a building adjacent to a motorist rest area. DPS is still receptive if these facilities are made as truck-only facilities.

A DPS officer with the rank of major, who serves on an International Association of Chiefs of Police (IACP) task force, is evaluating actions such as lane restrictions to minimize the impacts of trucks. This task force has recommended that all states evaluate lane restrictions. Trucks traveling side-by-side in all lanes add to frustration of other drivers because these other drivers cannot pass. On freeways with two lanes in each direction, it is not uncommon to see a truck in the left lane overtaking a slower vehicle in the right lane. This maneuver often takes considerable distance to complete, so motorists queuing behind these vehicles must reduce speed. These motorists then tend to drive much faster once they are past the trucks, perhaps to make up lost time and perhaps due to the added frustration.

Enforcing separate truck roadways could use technology such as weigh-in-motion near entry points followed by an enforcement officer downstream to check static weights or safety-related items. Speed enforcement might rely on technology as well. TTI has evaluated technology in work zones where space is limited for pulling vehicles out of the traffic stream. This procedure would measure speeds at a point in the work zone and send all or some speed measurements downstream to an enforcement vehicle at a location that provided more room for apprehension. Therefore, there is precedent for using technology along with the more traditional methods. DPS encounters significant challenges on congested high-speed urban freeways, but has found that the effect of their enforcement “presence” near urban areas carries over into urban areas where there is little or no room to stop motorists.

Anytime a DPS officer cites an offender, say for speeding, the officer must prove at least two things: 1) that the motorist was on a public road, and 2) must prove the actual speed of the motorist. Along with these two items, the officer must prove that the offender was this particular driver and vehicle. Of course, these items are still required on a truck roadway.

One example of a geometric problem for trucks was near Weatherford on I-20 where an adverse crown caused trucks to roll over. A countermeasure suggested first by a DPS patrol sergeant in Ft. Stockton was rumble strips along shoulders. The effect of this treatment is to wake up drowsy drivers, especially in undeveloped areas.

Measurement of semitrailers in Texas is from the nose of the trailer to the rearmost load-bearing part of the trailer. There is no requirement in Texas for kingpin to rear axle or other measurement from front of trailer to rear axles. Therefore, offtracking of longer vehicles could be problematic.

TTI sent out a survey through the Austin headquarters of the Department of Public Safety’s License and Weight Service. Headquarters forwarded the survey to all six DPS regions for completion by both Highway Patrol and License and Weight troopers who were familiar with roadways in their area. Appendix B shows a copy of the survey form; it included questions pertaining to adequacy of truck parking, general and specific questions on roadway geometrics, and the prevalence of semitrailers over 53 ft in length. Survey results indicate that some areas have greater needs than others pertaining to geometric design issues and that there are only a limited number of long semitrailers being used throughout the state.

2.3.2.1 DPS Survey Results

Table 3 indicates the results of the 84 surveys returned for evaluation. There were four general questions and four specific questions about geometric design problems, followed by questions about vehicle trends. The column entitled "Percent of Surveys" reflects the percent of the 84 responses that identified problems in that category. In most cases, there was more than one example of the problem, so the table does not necessarily reflect the total extent of each problem. According to these results the major problems related to geometric design for commercial vehicles pertains to shoulders too narrow for emergency parking, insufficient parking space, and inadequate intersection design for trucks.

Table 3. DPS Survey Results Summary.

Survey Question	No. of Comments
Shoulders Too Narrow for Trucks	60
Insufficient Parking for Trucks	46
Inadequate Intersection Design for Trucks	39
Two-Lane Roadways Need Climbing Lanes	27
Short Dist. between Entry/Exit Ramps	20
Sharp Turns or Curves Causing Rollover	19
Accel/Decel Lane Lengths Too Short	18
Specific Parking Problem Locations	14
Other Trends Affecting Opr. Characteristics	8
Trend in Longer Semitrailers	7
Trend in Different Vehicle Types	4

Data Source: DPS.

2.3.3 TxDOT Research and Technology Implementation (RTI) Survey Findings

The RTI survey report *(3)* is divided by: 1) actions currently being taken to mitigate the impacts of increasing truck traffic levels on the Texas highway system, and 2) actions suggested by survey respondents to mitigate truck impacts. It is further subdivided into the following categories: geometric design, pavement design and construction, pavement maintenance, bridges and structures, work zone safety, traffic control devices, traffic management, and truck parking facilities. While the primary emphasis for Research Project 0-4364 is geometric design, several of the other categories are also important and are included below.

2.3.3.1 Geometric Design

Nine districts indicated various geometric improvement efforts to better accommodate increasing levels of truck traffic. At least three districts are considering adopting the "Texas Super 2" geometric design guidelines. The "2" in the "Super 2" refers to a two-lane roadway, with one lane in each direction. TxDOT sponsored research that developed these guidelines for intermittent passing lanes to provide improved capacity and traffic safety on two-lane routes that do not carry enough traffic to warrant upgrading to a four-lane facility. The Childress District implemented Super 2 guidelines along U.S. 83 and U.S. 82, and the Paris District is using them for design of S.H. 121 improvements. The Tyler District is currently considering Super 2 guidelines for proposed shoulder widening and rehabilitation projects.

Other actions that districts are taking include:

- lane and shoulder widening projects (not necessarily Super 2),
- increasing sight distance and using larger turning radii at intersections,
- constructing additional acceleration/deceleration and turning lanes at intersections, and
- providing passing and climbing lanes.

Districts recommended actions to mitigate the effects of increasing numbers of trucks. Several district responses suggest a review of existing design standards to determine if they are still appropriate for current and projected future truck traffic volumes. Specific recommendations made by districts include:

- reduce design criteria for maximum percent grade to result in a speed reduction of only 5 mph, rather than the 10 mph reduction allowed under present standards;
- adopt the Texas Super 2 guidelines as the standard for primary two-lane roads with high truck traffic volumes; and
- consider different design standards for rehabilitation projects. Right-of-way restrictions, particularly in cities, make major changes difficult. If standards are increased too much, rehabilitation of existing facilities might not be possible. Bypasses around towns might be the only alternative; however, they are expensive, require a large amount of right-of-way, are unpopular in many areas, and take a long time to develop and construct.

2.3.3.2 Traffic Operations

One third of all responses indicated a need for managed lanes along freeways, especially through urban and metropolitan areas. Responses were divided as to the best way to separate truck traffic from smaller vehicles. Suggestions include "preferred truck lanes," "designated truck lanes," "truck only lanes," and "truck-excluded lanes." The Waco District indicated interest in conducting a pilot project along I-35. Passenger cars and light trucks would have at least one lane free of heavy trucks but would be allowed to use the “truck preferred” lanes as necessary. A project such as this would offer a good opportunity for assessing the effects of designated truck lanes on traffic operations and pavement performance.

Other specific suggestions for mitigating the effects of heavy trucks on traffic operations include:

- Find ways to install rural ITS in less time.
- Educate local governments on what they can legally do to restrict truck traffic on state facilities.
- Consider restricted hours of operation and/or lane-use fees for trucks along certain sections of roadway.
- Place special emphasis on the operational impact of the truck/car traffic mix regarding safety and congestion. The special needs (width, sight and stopping distance, merges, etc.) of truck traffic, especially within restricted construction zones, should be highlighted.
- Consider providing separate turning lanes at intersections and special signing along high volume truck traffic routes.
- Traffic management centers need to emphasize truck traffic operations, including truck-oriented dynamic message sign displays.
- Provide wider shoulders along controlled access facilities to assist in traffic control during maintenance operations and incident events.

2.3.3.3 Pavements

Eleven of twenty-four districts reported increased use of reinforced concrete pavement for main lanes due to increased numbers of trucks. There is also increased use of concrete pavement at intersections and for rest stop parking areas. Pavement type selection includes life cycle cost analysis in at least three of these districts. However, lack of resources for funding the higher initial costs of superior-performing products continues to be the final determining factor in most cases.

Perhaps one of the most significant actions taking place in response to increasing truck traffic is the ongoing development of Heavy-Duty Hot Mix Asphalt Pavement (“perpetual pavements”) Specifications. Designed to give stone-on-stone contact, these heavy-duty mixes may achieve modulus values some 50 percent higher than conventional mix designs at a cost increase of 25 to 30 percent. The heavy-duty specifications are intended for use on roadways carrying an average of 5000 trucks per day. Pilot testing has recently concluded on five projects, and full-depth projects are now planned in the Waco, Laredo, and Fort Worth Districts. Expected life of roads constructed with heavy-duty mixes is indefinite, with minor rehabilitation expected after 15 to 20 years.

Other actions being taken by the districts include:

- use of the Hamburg Wheel Test during pavement mix design,
- increased use of high-end binders (PG 76 -22 and above),
- construction of thicker asphalt pavement layers,
- increased use of hot mix asphalt as base material,
- increased use of lime as an anti-stripping agent,
- increased use of modified-binder HMAC as base material and surface course, and
- implementation of density profile and longitudinal joint specifications to obtain longer pavement life.

Districts also reported several activities pertaining to pavement maintenance. Six districts reported shoulder retrofitting and widening in response to increasing pavement edge damage attributed to truck traffic. One district reported a marked increase in pavement edge damage along entrance ramps due to truck parking just prior to highway merge zones.

2.3.3.4 Bridges and Structures

- The bridge design load for new construction and rehabilitation projects has been increased from HS-20 to HS-25 for many structures along major routes throughout the state. The Bridge Division is currently evaluating changes needed to incorporate the heavier design load into current standards.
- The Bridge Division is requiring more rugged sealed expansion joints (SEJ-Ps) at locations where truck traffic is expected to be heavy.
- The Bridge Division recently coordinated the development of a web-based map that provides location information and restriction requirements for on-system and off-system load-restricted bridges throughout the state. Truckers can use the map as a planning tool to avoid routes with load-restricted or closed bridges.

Several districts provided additional information including:

- Provide increased vertical clearance at grade separation structures and remove abandoned railroad structures.

- Install overheight vehicle warning systems.

- The Houston District has installed the heavy truck (HT) bridge rail at selected major interchanges to contain errant commercial vehicles. However, the Bridge Division notes that standard TxDOT bridge rails are adequate for most locations and advises prudence in the use of the HT rail.

2.3.3.5 Other Improvements for Trucks

In several truck forums held in Texas, one of the complaints from the trucking industry is the lack of truck parking at rest areas. According to many of the truck drivers, the rest areas are filled to capacity, forcing drivers to use the shoulder of the highway to stop and rest. This becomes a safety hazard to both the traveling public and truck drivers. To help meet this need, construction of additional rest stops and truck parking areas has resumed after a period of inactivity. The Corpus Christi District is incorporating increased median widths into the design of new facilities to accommodate additional truck parking needs. The Yoakum District is using concrete pavement for truck parking at rest areas and is attempting to provide adequate capacity for truck parking off the roadway to discourage parking on shoulders and ramps.

Accommodating greater numbers of trucks leads to a need for increased funding as well as different allocation methods for available funds. There is attention being given current funding allocation methods among districts. Suggestions include allocation of funds based on the remaining life of pavements (instead of distress only), using the Pavement Management Information System as a baseline, load rating existing pavements, and making allocations based on current or future truck traffic volumes. Expansion of the trade fair concept currently used by TxDOT to allow the transfer of funds from one category to another could conceivably provide the needed additional flexibility for this and similar situations. Survey respondents perceived that commercial vehicles do not pay their fair share of road taxes in relation to the amount of damage they cause. Suggested changes included adjusting the diesel fuel tax and the 2060 Overweight Permit fee structure to address this issue.

2.3.4 TxDOT Office Interviews

2.3.4.1 Houston District

The Houston District has a truck lane restriction on an eight-mile section of I-10 East in Houston between Waco Street and Uvalde Street. The Texas law that allows cities to adopt lane restrictions for trucks requires that the cross-section of the freeway have a minimum of six lanes (three lanes in each direction), and that the restriction be applied only on weekdays during peak traffic. The demonstration roadway met the cross-section requirement, and the time period for applying the truck restriction began at 6:00 a.m. and ended at 8:00 p.m. Monday through Friday. The proposed ordinance restricts trucks to the right two lanes and does allow trucks to use the left lane for passing other traffic.

TTI's Houston office performed an evaluation of this restriction over a 36-week period to determine its effectiveness from the standpoint of compliance, crash rates, freeway operations, and public perception. To determine compliance with the restriction, TTI conducted vehicle classification studies by lane at several locations within the limits of the restriction in a before-after scenario. To determine the effect of the restriction on crash rates, TTI analyzed crash records for the I-10 East Freeway. Determining the effect of the restriction on freeway operations required monitoring the test section to identify any significant impacts due to the truck restriction. Project staff determined the general public reaction to the restriction through a handout survey and an Internet survey.

In brief, results indicate that the demonstration project was successful. Compliance rates increased to a range of 70 to 90 percent, but the high level of enforcement undoubtedly had an impact on the compliance rate. Only 20 percent of violators were local drivers, so unfamiliar non-local drivers might have missed the regulatory signs posted along the roadway. Several factors could have contributed to the 68 percent reduction in crashes during the 36-week study, but two likely candidates are increased enforcement and the lane restriction. The traffic studies determined that the lane restrictions had no significant impact on freeway operations. The utilization of the left lane by automobiles did not increase as much as expected, but this use might change after a longer time period. The lane restriction produced no appreciable impact upon travel times and freeway speeds. Traffic studies also determined that there was no significant impact on the frequency of lane changing or traffic patterns as a result of the lane restriction.

Based on survey results, about 90 percent of motorists were aware of the lane restriction and around 90 percent of automobile users favored the project. Although the majority of truck drivers felt that the restriction did not significantly impact their travel, they did raise several issues of concern which may require further investigation prior to additional implementation elsewhere. TTI recommended that the demonstration project be continued on I-10 to allow for additional monitoring and long-term evaluation. Also, the I-45 North Freeway and the S.H. 225 La Porte Freeway have sufficient truck volume to be considered for expansion of lane restrictions.

Another significant truck initiative that is being considered in the Houston District and other districts as well is the future I-69 corridor for NAFTA trade. In 2002, the Houston District was faced with choosing from among four corridors one which would be best for I-69. The four corridors were: 1) the Grand Parkway to the east, 2) the Grand Parkway to the west, 3) Beltway 8 east, and 4) Beltway 8 west. Some of the earlier options considered a bypass to avoid the city of Houston, but origin-destination studies indicated a high percentage of truck trips using this segment of I-69 oriented to or from Houston. The next phase needed to revisit some elements because of continued high traffic growth.

The Transportation Planning and Programming (TPP) Division was handling many aspects of the study since the I-69 project spans several districts, but the Houston District is handling some aspects as well. The Houston District will probably have a bigger challenge compared to other districts along the corridor due to the size of the urban area, environmental issues, and some of the restrictions they will face. In late 2002 or early 2003, the district planned to hire another consultant to complete the analysis and select the final corridor. In a previous study *(4)* a consultant reduced the initial 32 alternatives down to the current four.

One desire of the public that was voiced at hearings was that trucks should be separated from passenger cars by barriers. Some of the public input came at about the same time as two serious truck crashes in Houston, so separation of trucks would naturally be of great concern to the public.

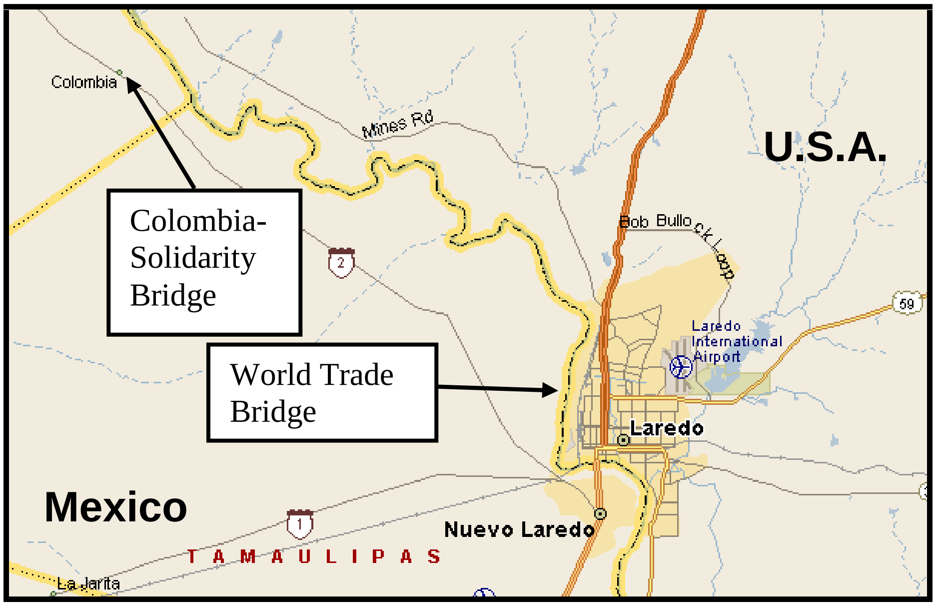
2.3.4.2 Laredo District

The following information came from a meeting with an engineer in the planning and design section of the Laredo District office in February 2002. This engineer is also a member of the Laredo Metropolitan Planning Organization (MPO). There has been some speculation pertaining to the future of maquiladoras with the opening of the border. This engineer believes that a lot of commercial vehicle trips will stay the same as they are now. However, if the border opens, the trips may spread along the border rather than remaining concentrated in specific areas. Another influence on truck traffic along the border is the economy. When the economy improves, there will be additional truck traffic.

Another change that may influence truck traffic and development in general is discontinuing building frontage roads. This department spokesperson believes that, without frontage roads, property will develop differently and adjustments will eventually be made, but the engineer did not see lack of access as a problem. Other specific needs pertaining to trucks are rest areas and truck parking as well as some intersections. Along the border, there have been increased delays to trucks following the events of September 11, 2001.

A second interview with the Laredo bridge system supervisor for the World Trade Bridge (Laredo's Bridge no. 4) in February 2002 revealed another viewpoint. The World Trade Bridge and the Colombia Solidarity Bridge (Laredo's Bridge no. 3) now carry all the truck traffic crossing the international border in the Laredo area. Only commercial vehicles are allowed to use Bridge 4. Figure 2 shows these two bridges. Although delays have increased due to security concerns, the biggest bottlenecks to traffic occur in construction areas. Additional bridge lanes have helped as well as making the toll portion of the process completely automated. Specific bottlenecks occur on Mines Road where left turn queues back up at turns into roads where trade companies and drayage companies are located. Another problem identified by the bridge system supervisor was the U.S. 83 pavement south of downtown Laredo, which was visibly rutted in the outer lanes. This problem causes congestion in the inner lanes.

A third viewpoint came from a bridge director of the Laredo Bridge System. He commented that although everyone is imagining great changes with the opening of the border, it is simply too expensive to have great changes and a great increase in Mexican trucks coming over the border. Drivers on both sides are apprehensive when it comes to driving too far into the interior of the other country. A big part of this issue is the language barrier and the difference in business customs. Companies do not have the infrastructure in the other country to handle logistics and support issues. For example, it would be much harder and more expensive for a Mexican truck owner to deal with a major repair problem in Dallas than it would inside Mexico. Many carriers are not willing to deal with that yet on a large scale, and it is simply easier to maintain the status quo. The maquiladoras will continue to increase and enlarge as NAFTA opens the border.



Source: Reference (5).

Figure 2. Map of South Texas Showing the Two Laredo Ports Used by Trucks.

This bridge director does not foresee a big change in the drayage business. This is especially true after September 11, 2001 and the pursuant increases in security. Companies do not want to see their drivers and trucks tied up in long lines waiting to cross the border. Drayage drivers are also familiar with the process to actually cross a load. One of the technological improvements at Bridge no. 4 that can potentially reduce delay is the use of Automatic Vehicle Identification (AVI) transponders or a pre-purchased magnetic swipe card. There are no cash transactions done in lanes. Agencies need to standardize databases and procedures to decrease delay while maintaining security. Technology can definitely help if the Federal agencies would cooperate and work with the city bridge systems; sharing information and databases would allow more thorough security checks and less waiting.

The magnitude of delays due to security concerns has become significant; northbound traffic faces a 3-hour wait for Customs. This wait is long, but according to this spokesman some delays are even worse. At the Peace Bridge (Canada) and other crossings, the wait was as long as 13 hours. The limiting factor in all cases is Customs. An additional trend anticipated by this bridge director is an increase in traffic for the Colombia Bridge in the future because of infrastructure improvements on the Mexican side of the border. There will be a four-lane bypass of Nuevo Laredo opening soon that will utilize the Colombia Bridge and facilitate traffic movement to and from Monterrey.

2.3.4.3 San Antonio District

According to the San Antonio District Design Engineer, the district is incorporating greater numbers of trucks in current design practice in a number of ways. When upgrading existing freeways, the district is using elevated turnaround lanes more frequently. The issue with elevated turnaround lanes is structural damage, particularly at critical points where vehicles need to make a sharp 90-degree turn. As a result, the district is now designing elevated turnaround lanes taking into consideration trucks (even if the anticipated percentage of trucks is very low). Ideally, the district would like trucks to stay on their lanes as much as possible, and this objective drives the design process.

The district is now trying to use 16.5 ft vertical clearances in situations where an interchange needs to be replaced. If the upgrade only involves widening, the district might choose to stay with the current minimum allowed 14 ft clearance. In a recent example, the district decided to rebuild the bridge structure at Loop 410 at Babcock when they realized that by widening Loop 410, the vertical clearance would be lower than the minimum acceptable. The new bridge has a 16.5 ft clearance. In this case, the district also converted the four-span bridge to a three-span bridge (one span for each turnaround lane and the middle span for both directions of traffic on Babcock). This configuration improves visibility and reduces geometric constraints for trucks.

At U.S. 90 at 36th Street, the district is upgrading the signalized intersection with concrete pavement (as opposed to flexible pavement). This is significant, considering that the district uses flexible pavement for practically all of its pavement needs. The reason for the upgrade is that 36th Street feeds into Kelly USA (a former Air Force Base), which is being promoted as a major inland port facility for San Antonio. The city will upgrade 36th Street to six lanes.

The district is replacing New Jersey barriers with 3-ft single slope barriers. The new barrier is effective for blocking headlights (the New Jersey barriers need a headlight fence), it has a lower rate of rollover following impact, and it allows faster incident clearing. The district is using the single slope barrier concept both for medians and for retaining walls.

The district has not used any lane restrictions or truck roadways thus far. The only example of a restriction to truck traffic in the district is the designation of Loop 410 as a hazardous materials route to prevent through hazardous materials traffic from going too close to downtown San Antonio. In addition, the district is studying the feasibility of using some kind of truck lane restriction and/or separate truck facility on the I-35 corridor from downtown San Antonio to Loop 1604 (northeast part of the city). Currently, the district is using a consultant to evaluate possible schematics for the corridor, with consideration given the issue of increased truck traffic on the corridor. Apparently, the consultant has encountered difficulties because of the lack of guidelines concerning the use of truck lane restrictions and/or separate facilities.

The district spokesman stated that if TxDOT were to design totally for trucks, it would give serious thought to widening traffic lanes from 12 ft to 14 ft. Additional issues to consider related to geometric design are as follows:

- impact of increasing percentage of trucks on superelevation values,
- stopping sight distances, and
- long-term effect of heavier fleets on bridge life.

2.3.4.4 Waco District

In early 2002, the Waco district engineer and the engineer responsible for on-site decisions for the I-35 reconstruction project provided input pertaining to truck accommodation. The district was improving a 94-mile segment of I-35 from the Williamson County line to the I-35 E-W split near Hillsboro. The basic cross-section will be four lanes in each direction with frontage roads. At the time of the meeting, it was predominantly a four-lane freeway (two lanes each direction with two-lane frontage roads) except through Waco, Temple, and Belton. In those areas, it widened to three lanes in each direction. The district was concerned about access to properties adjacent to the freeway if the policy changes to not build frontage roads.

One of the improvement scenarios being considered by the Waco District is "Alternative 4," entitled Trade Focus Strategy. It focuses on the southern portion of the corridor between Dallas/Ft. Worth, and Laredo where the truck traffic demand projections are the highest. Two truckway options are being considered: 1) a separate facility and 2) a truckway within the existing I-35 right-of-way. The latter strategy assumes a partial NAFTA truckway with larger truck sizes and weights, but for this alternative, the more liberal sizes and weights are to be used only where their implementation could result in lane savings to I-35 *(6)*.

The Waco District had concerns about some of the TPP traffic forecasts, so the district conducted its own counts at two locations. Historical data indicated that the traffic on I-35 doubled every 20 years, so district personnel considered TPP forecasts to be low. TPP projected a growth rate in the 2 to 3 percent per year range, whereas district experience was closer to 5 percent. The Waco District does not experience much seasonal variation in truck flows; temporal time-of-day variations are significant, however.

Waco District personnel believe the future I-69 will help reduce truck traffic on I-35, but I-69 is not the ultimate solution for them. I-69 does not offer an immediate solution to the truck congestion problem, so the current design of I-35 cannot be reduced by some number of lanes because of the other facility. District personnel believe I-69 is 20 to 30 years from being able to carry substantial truck traffic. Another major concern with the I-69 corridor is that traffic must still go through Houston, which is considered a much worse constraint to truck and other traffic flow than San Antonio or even Austin. Also, there is a problem today with air quality in Houston requiring a reduction in speed limits to 55 mph on some area roadways. With the expected doubling of truck traffic in the U.S. in 20 years and the goal of reducing crashes involving trucks by 50 percent, there is a real challenge facing transportation professionals. There are many old freeways in Texas; for example, I-35 was originally designed in the 1950s with a 16-ft median so head-on crashes were a big problem. The newer design for I-35 will utilize a taller 42-inch barrier. District experience with the 32-inch barrier was that trucks did not go completely through it but often leaned over or rolled over after striking it.

Another improvement on the I-35 corridor will be in the design of interchanges to provide upgrades on exit ramps to help vehicles, especially trucks, decelerate. The standard diamond ramp configuration provides this desired condition where the crossing roadway is above the freeway. Where this scenario is not feasible, the district is designing for an “X” ramp configuration at interchanges that would otherwise be diamonds. Other issues pertaining to trucks are tight geometry on existing exit ramps and merging that is taking place on frontage roads. The old TxDOT policy for ramp design speed maintained 30 percent of the main lane design speed on ramps. Today, TxDOT designs for 50 to 70 percent of mainline speeds on ramps. A philosophical question is whether TxDOT should be encouraging drivers (through design practice) to go that fast on ramps.

The district has experienced severe truck parking shortages along I-35. It is evident along rural areas of the corridor from midnight to 3:00 a.m. where truckers typically park on ramp shoulders entering and exiting the parking areas. They normally do not park on shoulders of the main lanes. Trucks are 50 percent of the total traffic stream during the early morning hours. Some of the problems caused by public rest areas are trash, maintenance of bathroom facilities, and security if women work the parking area. Districts face the dilemma of whether to pave larger areas so trucks can park or build curbs to discourage truck parking.

There is a question of who should pay for improving an interchange when a large truck stop is built nearby. The intersection might operate acceptably under existing conditions (probably with limited numbers of trucks), but it might not function well at all under heavy truck traffic. TxDOT normally pays the full cost of needed improvements, but there might be more consideration given to requiring the developer to pay for improvements needed *because of* that development. TxDOT does not want to discourage development either because the development generates revenue. Costs covered by the developer might include signalization, widening to accommodate turn lanes, increased curb radii or some set amount of money based on past experience.

There was discussion of performance characteristics of large commercial vehicles, and whether power-to-weight ratios are the appropriate parameter to track. The NCHRP study that is now underway *(7)* will address this topic, so project 0-4364 should not need to. Another issue has to do with placement of signs to provide adequate advance visibility where the numbers of trucks are high. The Waco District is placing critical signs overhead so that all motorists have a better chance of seeing them, given the high probability of ground-mounted signs being blocked by trucks.

There was some discussion to clarify or define the Texas Trunk System of roadways. The Trunk system of highways is predominantly four-lane divided non-Interstate routes that can serve as relief routes to the Interstate system. The designation of this network has since changed, but is a subset of the National Network of highways within Texas.

2.3.4.5 Design Division

TxDOT districts either do their own geometric design, or they use consultants. The Design Division in Austin recently added a new section to handle geometric design and to produce plans. The Design Division is currently responsible for establishing geometric criteria for TxDOT districts to use during plan production. The Design Division also produces roadway standard detail sheets for use in construction plans. An example is standard details for guardrail installations. Districts may comply with the geometric design criteria established by the Design Division or they can submit a request for a *design exception*. For example, if the Design Division set criteria for lane width of 12 ft for a certain roadway classification and traffic volume, and a district believes that 11-ft lanes are appropriate in a particular circumstance, the district has to submit a request in the form of a design exception. Districts, on the other hand, handle *design waivers*.

The elements that qualify for design waivers and those that qualify for design exceptions are in the *Roadway Design Manual (2)*, which is available on the TxDOT web site. Many of the TxDOT manuals are now available on-line. Depending on roadway classification and traffic volumes, an example of a design exception might be lane width, and an example of a design waiver might be curb offset.

Selection of the appropriate design vehicle is crucial to effective design. The design vehicle for some portions of I-35 might be the WB-67; however, some portions of I-10, which have over 50 percent trucks at night, might use a WB-69 as the design vehicle. One possible trend that should be investigated in this research is increases in the number of 57- and 59-ft semitrailers. Certainly longer trailers have an impact on offtracking, and therefore on intersection design. To determine offtracking characteristics of various vehicles, TxDOT still uses software developed a few years ago by TTI, but is converting to commercial software packages.

The AASHTO *Green Book* continues to emphasize consideration of trucks in geometric design. The 1984 edition utilized the University of Michigan Transportation Research Institute (UMTRI) truck research; the 1990 edition utilized Caltrans research; and the newest 2001 edition will include some consideration of “NAFTA” vehicles. There are geometric implications of long vehicles negotiating roundabouts. The design criteria shown below are the ones that are most likely affected by truck characteristics. Some of the changes are noted in italics. For example, there has been a change in the 2001 AASHTO *Green Book* regarding reaction time for intersection sight distance based on revisions to the model by Midwest Research Institute. What this amounts to is a change in gap acceptance by entering vehicles. This topic was first addressed in the 1990 *Green Book* pertaining to freeway ramps.

The representative of the Design Division made a few comments pertaining to the following list of design issues. Comments are shown in italics.

1. Sight Distance

Stopping Sight Distance: *Has changed in the 2001 Green Book*
Decision Sight Distance
Passing Sight Distance
Railroad-Highway Grade Crossing Sight Distance
Intersection Sight Distance: *Has changed in the 2001 Green Book*

2. Horizontal Alignment

Curve Radius
Superelevation
Intersection and Channelization Geometrics
Pavement Widening

3. Vertical Alignment

Critical Length of Grade
Downgrades

4. Cross-Section Elements

Lane Width
Shoulder Width and Composition: *TxDOT uses same depth shoulder as lane*
Sideslopes and Drainage Features: *sideslopes are both a roadside safety issue and an environmental issue*
Pavement Cross-Slope
Vertical Clearance: *set at the national level for defense highways*
Traffic Barrier: *can be provided in various heights*
Passive Signs
Curbs
Acceleration Lanes

Adoption of the AASHTO *Green Book* is different among the various states. Smaller states use the *Green Book* directly, but large ones like Texas are more likely to develop their own design manuals. States can adopt their own geometric design aspects as long as FHWA approves them for use on federal aid projects. The FHWA has adopted AASHTO design criteria as the national standard and compares state manuals to that national standard when considering approval for a state design criteria manual. If no federal aid funding is involved, states can establish their own design criteria. Use of nationally accepted design criteria, or state design criteria based on the nationally accepted standard, may provide some level of improved defense with respect to tort liability.

The Design Division spokesman believes there would be little change pertaining strictly to geometrics if TxDOT were designing for 100 percent trucks. For example, the current 12-ft lanes and 10-ft shoulders typically used on Interstate highways are adequate for trucks, although a 13-ft lane might be considered for an exclusive truck facility design. Also, very tight or close geometrics at intersections or on connector ramps might be enhanced for efficient truck operations. There might be some different designs or combinations of pavement materials used on exclusive truck facilities as well. TxDOT designs and builds shoulders of the same thickness as the main lanes but has sometimes used asphalt shoulders with concrete on main lanes. An example of an older design where this combination has not worked as well as desired is U.S. 75 North near Plano (Dallas area). The asphalt shoulders are showing much more wear than the concrete main lanes.

There are examples of design pertaining to roadside hardware that do not always accommodate large truck impacts. While the standard 32-inch concrete barrier has successfully redirected large commercial vehicles when the impact angle is low, there are examples where a taller 42-inch Single-Slope Traffic Barrier (SSTB) has been chosen, largely because of possible impacts by trucks. The New Jersey Turnpike Authority uses a similar 42-inch barrier in the median to separate directions of traffic flow and has found that the taller barrier performs better when hit by large commercial vehicles. In a recent crash on I-35 (January 2002), a tractor semitrailer combination hit a 32-inch barrier at a fairly low angle of impact and did not go through the barrier. TxDOT installed 42-inch SSTB on sections of I-35 between Austin and San Marcos at costs that were slightly higher than the standard safety shape 32-inch barrier. Full-scale tests by TTI of the "Texas Tall Wall" indicate that it works extremely well in containing large trucks and their loads, but its cost precludes its use except in extreme circumstances. The SSTB is now the Texas standard.

Vehicle parking along freeway ramps, and especially along the mainline, can be a significant problem in Texas and elsewhere. Texas law states that parking on shoulders is illegal except for emergencies. However, when the number of trucks exceeds the number of parking spaces in rest areas and private truck stops, drivers tend to find the most convenient place to park. Forcing drivers to continue driving when they are fatigued or when they will exceed their legal hours of service is not appropriate either. There are lots of issues to address in locating parking areas for trucks such as safety (a rested driver is a safer driver), security, noise and air pollution, grades, and proximity to delivery points.

2.3.4.6 Maintenance Division

The current approximately 100 rest areas are deficient in serving the needs of truckers across the state of Texas, so TxDOT has an ongoing $70 million program to improve the state's truck parking situation. At the current rate of spending, this sum of money will probably be depleted within about four years, beyond which there will be an additional need for $110 million (in 2002 dollars) to complete the program. There were nine truck parking areas under construction across the state in early 2002. The goal of this program is to provide truck parking areas spaced no farther apart than 60 to 90 miles along designated travel corridors carrying at least 5000 vehicles per day. This spacing assumes that urban areas already offer truck parking space such as at private truck stops.

There is much demand for strategically located truck parking near urban areas created by just-in-time deliveries. Motor carriers have a tight margin for delivery of freight, so drivers need parking areas near destinations to time deliveries accurately.

TxDOT does not currently have a database or maps that show the locations of rest areas for trucks, but the Facilities Branch Manager in TxDOT's Maintenance Section, Maintenance Division, is beginning to develop such a database to document the number of truck parking spaces and locations. For some of the current sites, the number of parking spaces is difficult to determine because of parallel parking and the lack of lines that delineate spaces for the trucks to park. TxDOT is engaged in an aggressive program to build new truck parking or improve existing sites to better accommodate the demand. An example is on I-40 where TxDOT has just built two new sites with space to accommodate 50 trucks. When the department rehabilitates a truck parking area, it provides a minimum of 23 to 25 spaces, and that usually requires about 30 acres. Existing truck parking areas occupy 5 to 7 acres.

Individual private truck stops do not generally support state Departments of Transportation (DOTs) building parking areas for trucks because truck stop operators believe these rest areas reduce their business. However, the National Association of Truck Stop Operators supports it. Besides, if states provided only parking areas for cars, trucks would undoubtedly use that parking space anyway and diminish its effectiveness for intended vehicles.

Some states are investigating innovative uses of non-traditional truck parking areas. One of these is Minnesota, which is using park-and-ride lots for truck parking. These lots are not used at night anyway, so some of the night demand can be satisfied this way. A problem with this solution is that the pavement is not designed for the heavier wheel loads of large trucks.

2.3.4.7 Transportation Planning and Programming Division

The Transportation Planning and Programming Division has assigned an engineer to oversee statewide corridor projects such as I-35 and future I-69. In 2002, there was also an ongoing study of the I-10 corridor through all eight states where it exists. Its focus was on freight flow and the contractor is using the same Reebie database as used by this project's researchers. It will also address the issue of truck parking. The Intermodal Surface Transportation Efficiency Act (ISTEA) was the original source of funding for I-69, and like I-35, I-69 had a coalition seeking support. HNTB and Wilbur-Smith were the two main consultants on the I-35 feasibility study, which is now complete (see Chapter 4 for more details on this study and the Ports-to-Plains study). As for which corridors will have the highest priority early, the TPP spokesperson stated that I-35 from San Antonio to Dallas would be first and I-69 would probably be second. TxDOT was also actively working on the Trans Texas Corridor plan and anticipates it becoming a reality. This 75-year plan will probably utilize tolls for financing.

One of the discussion points with the TPP spokesperson was the motivation behind TxDOT investigating truckways (separate truck roadways) as a solution to truck problems. I-10 is a good example of a roadway with a high truck volume, and when truck incidents occur, the result is often catastrophic. Even if truck incidents are infrequent and even if fatalities are few, the magnitude of each crash is usually sufficient to give special attention to trucks. For the I-35 study, one scenario moved 50 percent of the trucks off the mixed flow lanes between Laredo and Dallas. In that study, rail did not make a significant difference in the number of trucks on the highway. An interesting aspect of the effects of NAFTA highway freight is how much dispersion there is a few hundred miles north of the Mexico border. The Houston district conducted its own investigation of anticipated effects of NAFTA on the number of trucks on highways in the Houston District. It found that the NAFTA part of I-69 was not as significant as many thought.

2.3.5 Motor Carrier Interviews

This effort began with a meeting in Austin with the Texas Motor Transport Association, followed by office visits with a few carriers. Some of the carriers were in Texas and a few were in other states.

2.3.5.1 Texas Motor Transport Association

TMTA personnel are concerned that TxDOT is converting some of its rest areas into DPS enforcement operations. If that happens, during periods of heavy traffic, truck queues will extend to the travel lanes and become a serious safety problem. Motor carriers are open to the idea of using toll roads, but they want to always have a non-toll alternative and not be forced to use the toll facility. Even when motor carriers use toll roads, they are still paying heavily for non-toll facilities so they feel like they are paying twice. Motor carriers support multiple options, so if a toll road saves enough time, a business decision can be made that it may be worth the additional cost. Motor carriers need to be represented in major highway decisions.

A previous lieutenant governor once made the statement, “Freight does not vote.” The TMTA is not opposed to investigating ways to get freight off the highways. The nature of trucking has changed over the past few years. Truckload (TL) carriers today might have five stops, whereas 20 years ago that would have been considered less-than-truckload (LTL). A truck might have one origin, but deliver to six destinations. Just-in-time delivery is now “continuous move” so trucks are expected to deliver to the end of the belt just as the shipment is needed and get the best utilization or least warehousing (near-zero inventory). Shippers pick the date and the time and expect the trucker to meet the schedule.

People blame trucks for many problems, but trucks are on the nation’s roadways because there is a demand for this service. The same people who complain about trucks and problems associated with them still expect goods to be delivered on time and in good condition. Many do not realize that in many cases trucks are the only feasible means of delivery for some items. Also, it is the shippers who are forcing truckers to go to certain places and deliver at unpopular times. The public often sees the motor carrier as the bad guy, and not the grocery store. If the trucker does not meet shipper demands, the shipper will find another trucker to haul the freight.

The TMTA spokesman stated that TxDOT’s discontinuing building frontage roads will have a negative impact on traffic operations and on development. Without frontage roads, the congestion will be focused at the interchanges. Frontage roads along I-30 from Dallas to

Texarkana have helped distribution centers to locate away from the interchanges and disperse traffic more efficiently. Also, for accessibility, two-way frontage roads are better for trucks than one-way.

There has been discussion of limiting truck operations during the peak periods. Truckers prefer not to be stuck in traffic, so they already avoid those delays if possible. However, shippers are forcing trucks to deliver at selected times, and trucks are obligated to meet shipper demands.

Trucks need information that Intelligent Transportation Systems can provide (e.g., changeable message signs) at least one hour in advance of urban areas in order for the information to be useful. Signs telling truck (and other) drivers about congestion when they are already in the middle of it has no value. For example, there needs to be information given to northbound trucks on I-35 near Hillsboro if there are races at the track on I-35W north of Ft. Worth. One idea is to tell all motorists to take I-35E on race day.

Some carriers have invested in Automatic Vehicle Location (AVL) equipment, but according to the TMTA spokesman, many carriers do not use them very often. In some cases, carriers only use them in response to a problem. Many of the large long-haul carriers utilize cell phones, and many feel that AVL does not offer a big advantage beyond what cell phones offer.

Some of the larger LTL carriers like American Freightways and Yellow Freight have a need for longer 57-ft or 59-ft semitrailers, but there does not seem to be an overall shift to longer trailers. This 57-ft trailer can haul one more pallet than a 53-ft semitrailer. Mexico now allows an overall length (tractor plus trailer) that accommodates 53-ft semitrailers. J.B. Hunt now has 11,000 power units and 19,000 trailers, so changing over to a slightly longer semitrailer would be very expensive. If there is a trend to longer semitrailers, it will be because shippers demand it. Motor carriers and TMTA recently spoke out against size/weight increases such as to allow expansion of longer combination vehicles (LCVs) because carriers do not get paid anything more. Only a few TMTA members need more cube space today due to low-density freight. There is some support for a 96,000 lb gross vehicle weight (GVW) truck on six axles (using a trailer tridem), but whatever gains may be achieved are really shipper gains anyway, so why should carriers want it? Again, many problems come as a result of shippers dictating what is done. The large TL carriers such as Yellow and Roadway have been thinking about increases in size, and now UPS and FedEx are doing the same. UPS has reached the limit of efficiency in current vehicles, so it is evaluating other vehicles.

There was discussion about the “corridors” that are being designated as truck corridors such as the I-69, the I-35, and the Ports-to-Plains corridors. Truck drivers will select the best routes, and spending a lot of money on a particular route will not necessarily attract a lot of trucks to use it. Commerce follows opportunity. Building a bypass around Austin will not automatically attract trucks to use it. It is interesting that people who already have lots of trucks along congested corridors want trucks to go somewhere else, while some that do not have trucks want more. The truth may be that trucks are not really wanted, but trucks are the way to attract the money to improve roads. A big question pertaining to the Trans Texas Corridor is how to pay for it. Some freight cannot go on rail, but many motor carriers have invested heavily in rail and will use it when it is efficient. For example, UPS is a big customer of rail.

2.3.5.2 Motor Carrier No. 1

A relatively small carrier in San Antonio is a general commodities/truck load carrier with 120 power units and 180 trailers. The carrier owns trailers that are mainly 53 ft dry vans. The carrier operates in 42 states as well as the provinces of Ontario and Quebec, and its trucks travel through 44 states.

For this motor carrier's drivers, some of the geometric design situations that are the most difficult to handle are entrance ramps and the associated weaving problems. In the San Antonio area, the specific location that challenges drivers is the area surrounding the I-410 and I-35N interchange as well as the Rittiman Road entrance ramp (see Figure 3). This interchange has weaving problems associated with vehicles entering I-410/35 and immediately trying to cross lanes to get to the I-410 exit in the left lane. Drivers using the Rittiman entrance ramp to the freeway also report a blind spot due to the angle of the entrance ramp. A similar blind spot exists for the Eisenhower and Walzem exits on I-410/35 as well. Insufficient weaving distance for ramps built some time ago is also a problem at Rittiman, Eisenhower, Walzem, and others.

Source: Reference *(5)*.

Figure 3. San Antonio Problem Area for Trucks.

Geometric features that impede trucks or are unsafe for trucks in addition to weaving areas are low clearances on some freeways used by this carrier's trucks. Drivers familiar with these locations often use another route. In addition to avoiding those situations, drivers also try to use other routes during congested traffic conditions.

Trucks sometimes have trouble negotiating freeway ramps and connector roadways where there are left-hand exits. Trucks typically travel in the right lanes, so left exits require moving across freeway lanes from right to left. This movement is more difficult in large trucks due to their size and car drivers not being willing to yield. Also, trucks have trouble negotiating some ramps in heavy traffic because of tight turning radii.

A representative of this carrier favors the Trans Texas Corridor, but he felt it would not become reality due to the amount of right-of-way involved and because of environmental issues. He had no opinion on Super 2 roadways. He was in favor of Texas adopting the Prepass® System due to already spending $1200 per month to use it. It is a good value considering the time saved especially in just-in-time and time-sensitive deliveries.

2.3.5.3 Motor Carrier No. 2

Motor carrier No. 2 is a private grocery company fleet in San Antonio that operates two fleets. The first company-owned fleet is composed of more than 350 trucks that travel 54 million miles a year. A typical round trip for one of these trucks is 225 miles. The fleet travels most of South and Central Texas, and also Lake Charles, Louisiana, where the company has one store. Carrier No. 2 operates 19 stores in Mexico (the company trailers actually go into Mexico, but drivers do not). Carrier No. 2's second fleet is a company-owned subsidiary that operates 270 trucks. Individual operators own the tractors, and the carrier owns the trailers. The fleet coverage is nationwide.

Most of Motor Carrier No. 2's operation takes place on major highways: IH, U.S., and state routes; very little takes place on two-lane roadways. For safety reasons, this carrier's drivers try to avoid two-lane roads.

This carrier operates just over 100 57-ft semi trailers out of a total of 1900 semitrailers. The rest of the trailers are 53-ft lengths; none are 48-ft. The carrier bought most of the 57-ft trailers around 1996 and until as recently as 1998 but does not plan on buying more trailers longer than 53 ft. The power units used by this carrier do not have sliding fifth wheels, so some effort was required to determine exactly where to place the fifth wheel for these longer trailers. The resulting position was 16 inches ahead of the centerline of the drive tandem. Other trailer dimensions of the 57-ft units are axle spacing – 49 inches, front of trailer to kingpin – 36 inches, and distance from kingpin to center of trailer axles – 45 ft 8 inches. According to a trailer distributor in San Antonio, most 53-ft semitrailers measure 39 ft 2 inches from kingpin to center of rear tandem. The longer trailers used by this carrier usually stay within Texas; the only exception is trips into Louisiana to the one store. Ninety-nine percent of the commodities hauled are general groceries, with less than one percent non-grocery related.

The carrier representative mentioned a few geometric design situations that are difficult to handle in a large truck. Merge areas and acceleration lanes are the most challenging design situations for truck drivers. Very short weaving distances are a problem, particularly in situations where a truck needs to make several lane changes in order to take an exit lane (e.g., if the entrance ramp is on the right side, but the exit lane is on the left side). Drivers have perceived that very few acceleration lanes in Texas provide adequate space for a truck/trailer combination to accelerate and merge with the traffic stream. Another deficiency is lack of adequate signing (Yield, Merge, etc.) and lack of adequate traffic safety education by the general population. Most motorists do not understand the operating characteristics of large trucks. Other general examples of geometric problems are narrow intersections and turnaround lane curves.

Vertical clearances are normally not a problem as all of this carrier's trucks are 13 ft 6 inches tall. Sharp horizontal curves, however, are sometimes a problem. To deal with this situation (and also to help balance the load), all company trailers have sliding rear axles.

There are specific locations where large trucks currently experience geometric problems. The northbound entrance ramp to Loop 410 at Rittiman Road in San Antonio is a good example (see Figure 3). The acceleration lane is very short at this location, so when trucks get to the point of merging with northbound Loop 410 lanes, their speeds are still considerably slower than the speed of vehicles on Loop 410. This causes safety and traffic flow problems.

Another example is southbound traffic on Loop 410 between Rittiman Rd and Loop 410 at the I-35 split. Truck drivers that enter Loop 410 southbound at Rittiman Rd and that want to continue on Loop 410 South after the Loop 410/I-35 split have to move to the left lane over a very short distance. Although this carrier has not experienced a serious crash at this location, apparently other carriers have.

This carrier representative admitted that he was not very familiar with the Trans Texas Corridor plan, but his perception was that the plan would benefit mostly interstate traffic as opposed to intrastate traffic. He noted that there are three types of carriers: long haul, LTL, and local. Long-haul carriers would be the ones mostly using the proposed corridors. His company and others like UPS are in the second category and would continue to use the existing interstate system. Local trucks would also continue to use the existing infrastructure. This carrier, like other carriers, tries to minimize costs, so if there is no perceived value in paying a toll for the use of a highway then it will not do so. Currently, for example, this carrier does not use the toll roads in Houston. Because of their operation, they also do not foresee using the toll road that will bypass Austin.

2.3.5.4 Motor Carrier No. 3

Motor Carrier No. 3 is a global carrier with operations in all 50 states, as well as Mexico, Canada, Central and South America, Europe, and Asia. It is a less-than-truck load operator. In Texas, the carrier covers roughly 85 percent of the state with the remaining portions covered through "interlining" (or subcontracting). The carrier's most common trailers are 42-ft and 45-ft semitrailers and 28-ft double trailers. According to the terminal manager, the geometric design situations that are difficult to handle in a large truck are as follows:

- Sharp curves can be challenging, particularly for some old 45-ft trailers that do not have sliding rear axles.

- Very short weaving distances and acceleration lanes are a problem.

  Specific locations in the San Antonio area and elsewhere in Texas are:

- the northbound entrance ramp to Loop 410 at Rittiman Road in San Antonio,

- the southbound entrance ramp to Loop 410 at Rittiman Road for trucks that continue on Loop 410 South after the Loop 410/I-35 cutoff have to weave to the left lane over a very short distance,

- the two interchanges at U.S. 281/Loop 410 and U.S. 281/Loop 1604 do not have direct connectors,

- weaving on I-35 WB between U.S. 281 and I-10 north of downtown San Antonio for trucks wanting take I-35 SB toward Laredo,

- I-35 westbound at I-10 westbound direct connector still has a very short radius curve that is still dangerous despite recent improvements,

- I-10 between Ackermann Road and Foster Road where new truck stops have been built resulting in serious congestion on I-10 eastbound, and

- construction on I-35 in New Braunfels due to construction requiring trucks to take I-10 east to Seguin and then take Route 123 to San Marcos.

The spokesman expressed concern about toll roads in general because deregulation has made trucking less profitable, especially for carriers like this one that are unionized. For this carrier, cost control is critical so paying tolls could only be justified if it resulted in lower costs. In a final comment about Super 2 roadways or climbing lanes in general, he stated that those lanes will be more critical now that low-pollution engines (less powerful) are being mandated and phased in.

2.3.5.5 Other Truck Driver Input

When project personnel met with the New Jersey Turnpike Authority, they also spent time at service plazas along the turnpike to observe trucks and talk with a few truck drivers. Reactions of drivers to outer lanes designated for trucks and buses were almost always positive. However, drivers who were willing to spend a little more time with interviewers emphatically stated that the facility should not allow cars on the commercial vehicle lanes. In other words, truck drivers favor a facility that is only for trucks and buses, and not cars. Reasons given for this position were that automobile drivers do not understand the different operational characteristics of large commercial vehicles and car drivers are often distracted by talking on cell phones or other activities that divert attention from the driving task.

A truck driver stopping at a convenience store on the outskirts of El Paso was very helpful regarding difficulties pertaining to geometric design. On that day, he was leaving his terminal on the east side of El Paso to go westbound on I-10. When asked what geometric problems he had encountered on Texas roads, he responded that many entrance ramps merge with the main lanes at an undesirable angle, creating a blind spot for many trucks. The angle is sometimes too large for the driver to use rear-view mirrors but so small that he or she cannot look out the window and see past the sleeper. There are some ramps that this driver avoids altogether if possible because of this problem.

2.3.5.6 Truck Driver Survey by TTI

In other recent TxDOT sponsored research, TTI completed a study to determine the effectiveness of signs and pavement markings for truck drivers using Texas roadways *(8)*. Even though the survey did not focus on geometric issues, some of the survey responses pertain to this study. The open-ended question posed during the truck driver survey asked in part, "What is your primary criticism of current roadways in Texas?" Tables 4, 5, and 6 summarize the comments from truck drivers based on surveys conducted on I-35, I-45, and I-10, respectively. These comments are subsets of the full list since only part of the comments reflected upon geometric design. Not all comments in each cell are geometric issues, but the authors left all comments in those cells to keep the percentages accurate.

Table 4. I-35 Survey – Concerns Pertaining to Texas Roadways.

Category	Percent of Participants (n=40)	Example of Criticisms
Entrance and Exit Ramps	23%	- Ramps are too short. - No acceleration lanes. - Layout of ramp is not marked.
Lane Width	8%	- Narrow lanes. - Secondary roads are not wide enough.
Miscellaneous	33%	- Inexperienced truck drivers. - Passenger vehicle drivers. - Congestion. - Frontage roads (one-way vs. two-way). - Split speed limits.

Source: Reference (8).

Table 5. I-45 Survey – Concerns Pertaining to Texas Roadways.[a]

Category	Percent of Participants (n=40)	Example of Criticisms
Entrance and Exit Ramps	8%	- Not long enough. - Need more room to weave and merge.
Lane Width	3%	- Roads too narrow.
Miscellaneous	33%	- Passenger vehicle drivers. - Differential speed limits (day vs. night; truck vs. car). - Speed limit too low at night. - Center median barriers are needed. - Need more rest areas.

[a] 40 comments from 33 participants

Source: Reference (8).

Table 6. I-10 Survey – Concerns Pertaining to Texas Roadways.[a]

Category	Percent of Participants (n=41)	Example of Criticisms
Entrance and Exit Ramps	20%	- Exit and entrance ramps too short. - Entrance and exit ramp combinations. - Lack of traffic yielding to ramp traffic. - Yield system easily violated.
Lane Width	2%	- Some roads are too narrow.
Miscellaneous	27%	- Split speed limit. - Too much traffic. - Weight restrictions. - Passenger vehicle drivers. - Truck only lanes.

[a] 45 comments from 34 participants

Source: Reference (8).

CHAPTER 3. TEXAS TRUCK FLEET

3.1 INTRODUCTION

The Texas Department of Transportation is experiencing increased truck traffic on most, if not all its facilities. TxDOT districts are facing tremendous challenges in attempting to keep roadways maintained at a desirable level under the constant growth in truck traffic.

3.2 METHODOLOGY

This section presents information on vehicle registration as provided by the TxDOT Vehicle Titles and Registration (VTR) Division, and as obtained from the Vehicle Inventory and Use (VIUS) Texas report. The research team requested data pertaining to the Texas truck fleet from VTR personnel and requested VIUS data to complement VTR data. The VTR database does not provide details on the breakdown of truck registrations by truck configuration or truck type.

3.3 DESCRIPTION OF THE CURRENT FLEET

3.3.1 Size and Make-up of the Texas Truck Fleet

First, there is a need to understand some of the VTR definitions in order to compare VTR data with data from VIUS. VTR uses the following definitions *(9)*:

- *Power units.* These units are subdivided into two categories: 1) combination power units, which are those used in intrastate operations; and 2) apportioned power units, which are those used in interstate operations.

- *Single-unit trucks.* Since 1995, VTR has divided single-unit trucks into trucks with gross vehicle weights that are less than 10,000 lbs and trucks with GVW greater than 10,000 lb. (This study is concerned with single-unit trucks that are greater than 10,000 lb.) Prior to 1995, there was only one category called “trucks,” which included all types of trucks (pickups, utilities, and others).

- *Token trailers.* These trailers can be operated in combination with a truck-tractor or a tractor-semitrailer combination. Token trailers cannot be used in a truck and trailer combination due to special registration conditions.

Table 7 summarizes truck registrations in Texas for the period between 1994 and 1999. The total number of single-unit trucks registered in 1999 was 138,871. There were 68,172 combination power units registered in Texas in 1999 and 123,593 apportioned power units for the same year. In addition to truck-tractors, the apportioned power unit category also includes straight trucks used for interstate operations and buses (the majority of the units in this category are truck-tractors). Between 1994 and 1999, combination power units accounted for between 33 and 45 percent of all power unit registrations, and apportioned power units accounted for the remaining 55 to 66 percent. The number of combination power units and apportioned power units remained approximately constant from 1994 through 1997, and then increased in 1998 and 1999.

Table 7. Texas Truck Registrations between 1994 and 1999.

Year	Trucks > 10,000 lb.	Token Trailers	Combination Power Units	Apportioned Power Units*
1994	N/A	126,686	58,086	99,639
1995	111,361	118,605	59,227	109,328
1996	107,072	111,918	51,893	100,303
1997	116,567	120,555	59,518	95,461
1998	124,758	131,128	63,759	103,409
1999	138,871	140,012	68,172	123,593

Note: These statistics are based on Registration Class Code counts in Master File Report.
* This includes truck-tractors, straight trucks, and buses; the majority are truck-tractors.
Data Source: Reference (9).

Based on the latest VIUS report, the total number of trucks over 10,000 lb Gross Vehicle Weight registered in Texas in 1997 was 260,000 *(10)*. This total places Texas with the second highest registered truck population in the U.S. after California. The Texas truck fleet represents approximately 6 percent of the national fleet (California represents 12 percent and Florida is third at just over 4 percent). Table 8 shows truck registrations in Texas by vehicle configuration for 1992 and 1997.

Table 8. Texas Truck Fleet.

Truck Type	1997 VIUS	1997 (%)	1992 TIUS	1992 (%)
Single Unit Trucks	159,400	61.3	167,300	63.3
Single Unit w/Utility Trailer	3,800	1.5	9,100	3.4
Truck + Trailer	2,300	1.0	9,800	3.7
Tractor + Semitrailer	93,800	36.1	77,300	29.2
Tractor + Double-Trailer	700	0.3	1000	0.4
TOTAL	**260,000**	**100.0**	**264,500**	**100.0**

Data Sources: Reference (10) Texas VIUS Report, 2000 and Reference (11) Texas TIUS Report, 1994.

Based on the VIUS, more than eight of every 10 registered single-unit trucks have two axles and just over 10 percent have three or four axles. Between 1992 and 1997 there was a 4.9 percent decrease in the number of single-unit trucks. The number of two-axle trucks decreased by approximately 10 percent and trucks with three or more axles increased by 27 percent. Approximately 40 percent of trucks registered in Texas are combinations consisting of tractor-semitrailers and truck-trailer combinations. Seventy-two percent of combinations have five or more axles.

Table 9 shows the distribution of registered trucks from the 1997 VIUS by main body type and compares them to the 1992 Truck Inventory and Use Survey (TIUS). (Information regarding trailer body types is only available from the VIUS/TIUS and not from VTR.) The body type category in the VIUS refers to the type of body that is either permanently attached to the tractor (or truck in the case of truck-and-trailer combinations) or most frequently used with a truck-tractor as a tractor-semitrailer combination *(10)*. The table shows that in 1997, the most common body type was the basic platform followed by the basic enclosed van. Together, these two body types comprised over 45 percent of all body types. The number of both of these body types increased from the 1992 numbers. Totals show just under a 3 percent reduction in registered trucks since 1992 when the total number was 264,500.

Table 9. Number of Trucks Registered in Texas by Body Type.

Body Type	1997 VIUS		1992 TIUS	
	Number	**Percent**	**Number**	**Percent**
Basic Platform	67,900	26.4	61,300	23.2
Basic Enclosed Van	49,700	19.3	39,200	14.8
Dump Truck	20,900	8.1	23,800	9.0
Tank Truck (liquids or gases)	18,200	7.1	16,300	6.2
Insulated Refrigerated Van	14,200	5.5	10,400	3.9
Platform with Added Devices	14,100	5.5	10,500	4.0
Multistep or Stepvan	12,100	4.7	17,600	6.7
Other Body Types	60,500	23.5	85,400	32.3
TOTAL	**257,600**	**100.0**	**264,500**	**100.0**

Note: Excludes pickups, minivans, utility sports, and station wagons.
Data Source: Reference (10) Texas VIUS Report, 2000 and Reference (11) Texas TIUS Report, 1994.

Regarding the average GVW of trucks registered in Texas, the VIUS shows that almost 63 percent of the truck fleet in Texas has an average gross vehicle weight of less than 40,000 lb, which generally requires no more than three axles. About 75 percent of the fleet has average GVW levels less than 60,000 lb, which generally requires no more than four axles. Over 99 percent of the fleet has average GVW levels less than 80,000 lb, which generally requires no more than five axles. Less than 1 percent of the truck fleet has weight levels requiring more than six axles. These numbers imply that most trucks operate most of the time at weight levels below the maximum gross vehicle weight limit available to them. Table 10 summarizes the information available in the 1999 VIUS report.

Table 10. 1997 Average Gross Vehicle Weight for VIUS Column D Trucks in Texas.

Average GVW (lbs)	Texas Fleet	
	Number	Percentage
40,000 or less	162,200	62.5
40,001 - 60,000	34,500	13.3
60,001 - 80,000	61,400	23.7
80,001 - 100,000	1,500	0.6
Total Column D Trucks	**259,600**	**100.0**

Note: Excludes pickups, minivans, utility sports, and station wagons.
Data Source: Reference (10) Texas VIUS Report, 2000

3.3.2 Trucks Allowed by Oversize/Overweight Permitting

From the standpoint of accommodating trucks in road design in the future, continuous monitoring of developments in the oversize/overweight (OS/OW) arena both within Texas and in adjacent jurisdictions is important for three reasons:

- OS/OW permitting arrangements for both non-divisible and divisible loads are often cited as a potential means to proceed with relaxing truck size and weight (TS&W) limits under the specification of performance-based standards (e.g., the most recent Statement of Research Needs of the Transportation Research Board [TRB] Motor Vehicle Size and Weight Committee; TRB TS&W Issues and Options Special Report 225);

- OS/OW permitted vehicles are the ones that typically “stretch” the limits of existing geometry; and

- developments in adjacent jurisdictions can lead to industry pressure for matching developments in a home jurisdiction.

Multi-jurisdictional oversize and overweight permitting of non-divisible loads is a growing phenomenon. The definition/interpretation of a non-divisible load may lead to variations in how these permits are administered. While the Western Association of State Highway and Transportation Officials (WASHTO) member states have expanded further in this area than others across the country, AASHTO also has a number of initiatives directed at expanding the regional permitting concept, and indeed developing national standards.

Road design and traffic engineering practice must accommodate trucks operating under oversize/overweight permits. The difference, of course, is that these trucks have to be specially authorized for operation—generally with one group of them being permitted routinely without reference to design/maintenance engineering functions, the other requiring such reference. It is the first of these groups that is of most obvious interest to standard design requirements for trucks. A particularly important requirement is for OS/OW vehicles that Texas has agreed to routinely permit by multi-jurisdictional agreement, wherein jurisdictions beyond Texas can permit vehicles for Texas operation.

Texas is a member of the WASHTO Western Regional Permit Agreement. This agreement is intended to establish a system for issuance of permits for the operation of non-reducible oversize or overweight vehicles operating in more than one jurisdiction in accordance with the regional permit *(12)*. The agreement authorizes member jurisdictions to issue regional permits allowing the operation in other member jurisdictions on specified routes of vehicles handling non-reducible loads subject to the following maximum weights and dimensions:

WEIGHT
- 600 pounds per inch of tire width
- 21,500 pounds per axle
- 43,000 pounds per tandem axle
- 53,000 pounds per tridem axle (8 to 13 foot wheelbase)
- 160,000 pounds GVW, subject to sum of axles limit
- minimum of 5 axles

DIMENSIONS
- length—110 feet overall
- width—14 feet
- height—14 feet

These permits apply to operation on regional highway networks defined by each jurisdiction. Certain time of day restrictions, and other detailed requirements in different jurisdictions may apply. Current members of the agreement as of March 21, 2001, were Arizona, Idaho, Montana, New Mexico, Oregon, Texas, Utah, and Washington. Other prospective members in 2001 were Alberta, British Columbia, Nevada, Wyoming, North Dakota, South Dakota, Arkansas, Georgia, Kansas, Alabama, and Colorado.

3.3.3 Semitrailers Longer than 53 Feet

Texas and at least 17 other states allow the use of semitrailers longer than 53 ft either under normal practice or they require a permit. Table 11 shows the lengths allowed by these states. Texas allows the legal operation of 59-foot semitrailers on all highways in the state. There is no overall length limit on the tractor-semitrailer combination, as well as no kingpin setting restriction *(13)*. The legal use of 57-foot semitrailers has been in place in Texas for approximately 12 to 15 years, but the use of 59-foot semitrailers is relatively new—about 6 years. A small number of (generally) large private and for-hire carriers utilize long semitrailers (57- or 59-foot). Examples of principal commodities being transported with these units include tissue paper, empty cans, hay, cotton, empty storage container drums, household goods, snack foods, and general freight.

One of the large for-hire carriers interviewed in the study indicated that its long semitrailer fleet is expanding; another said it had tried these units in dedicated situations for a number of years, but was slowly removing them from the fleet because of difficulties in achieving efficient utilization. In general, motor carriers understand that there are certain shippers who specifically request these units, particularly in the southern states, and that in order to obtain their business, they must provide long semitrailers.

Regarding articulation problems associated with these units, the study revealed that the general perception of enforcement officials and motor carriers is that there are no concerns different than those associated with the use of the more common 53-foot semitrailers. Some

Table 11. Maximum Semitrailer Length in States that Allow Long Semitrailers.

State	Maximum Semitrailer Length (feet and inches)	
	NN highways	Non-NN highways
Alabama	57-0	53-6
Arkansas +	59-6*	59-6*
Arizona	57-6	NR
Colorado	57-4	57-4
Florida*	57-6*	57-6*
Idaho #	57-0*	48-0
Kansas	59-6	59-6
Kentucky	57-0*	53-0
Louisiana	59-6	NR
Mississippi	57-0*	57-0*
Montana	57-0*	57-0*
Nevada ^	57-0*	57-0*
New Mexico	57-6	NR
Oklahoma	59-6*	59-6
South Dakota	60-0*	60-0*
Texas	59-0	59-0
Utah^^	57-0*	48-0
Wyoming	60-0	60-0

NN means National Network
NR means not restricted but there are overall length restrictions
* Operation requires permit
+ On routes designated at time of permit application, could be NN or non-NN
# Only on Interstate highways due to off-track restriction
^ There are five road sections where these units are not allowed to operate
^^ Only allowed on Interstate highways

transportation engineers, however, expressed some concern regarding articulation problems associated with these units, indicating that if 53-foot semitrailers have trouble negotiating intersections, 57-foot semitrailers would do worse in these situations. Most of the officials interviewed indicated that the driver must become familiar with the equipment before it can be operated, and that it is important to be aware of the limitations of these combinations.

One potential operational concern about long semitrailers as cited in some interviews involves the issue of their stability. Based on practical experience, one major private carrier now prohibits use of its high cube long semitrailers under high winds (more than 40 mph), requiring drivers to park the vehicles during such periods. One state prohibits the use of these vehicles while empty.

In summary, there is a niche market for long semitrailers in many states. That market may grow as the density of certain payloads decreases, and large shippers discover more convenient logistical opportunities for these units. That growth may also be stimulated by the wide scale acceptance of six-axle tractor-semitrailer combinations limited to 90,000 pound gross vehicle weight limits.

3.3.4 Truck Length and Width Exclusive Devices

The March 29, 2002, FHWA ruling (effective April 29, 2002) on truck length and width exclusive devices poses provisions which some believe provide new opportunities for increasing truck widths and lengths beyond current basic FHWA requirements. These opportunities arise from the fact that, under the Surface Transportation Assistance Act (STAA), the Secretary of Transportation has the authority to exclude from the measurement of vehicle length and vehicle width any "safety and energy conservation devices found necessary for the efficient operation of trucks." Initially, the FHWA ruling provided this authority only for situations where any new length device could not have "by design or use, the capability to carry cargo." This new rule "applies to vehicles authorized by STAA while operating on the National Network and routes giving reasonable access to the NN." Some provisions of the rule have created opportunities and/or clarified interpretations that some believe could lead to unintentional increases in vehicle size as noted below:

- "Non-rigid aerodynamic devices that do not extend more than 5 feet from the rear of a trailer in the operational position" are permitted. There is no specific reference to these being "non-load carrying" devices.

- "Tarp and tarp hardware" not exceeding 3 inches from either side of a vehicle are permitted. This can lead to an effective width of 108 inches on flat deck equipment with a clear 102 inch loading deck.

- "Stake pockets and stake racks" are permitted. This can also lead to an effective width of 108 inches on flat deck equipment. Federal law has permitted this for a long time.

Included below are some relevant interpretations, opinions, and additional considerations about these provisions:

- States must permit these devices for STAA vehicles operating on NN routes and access routes.

- WASHTO believes that the Notice of Proposed Rulemaking (NPRM) allows too much room for interpretation which may result in longer and wider trailers.

- The Oregon DOT was concerned that the NPRM was too broad in its scope and could easily result in unintentional increases in vehicle width and length. Oregon was particularly concerned about the tarp issue, which it contends results in a vehicle that is in fact 108 inches wide. FHWA contends that this is no different than the long-standing practice of allowing stake pockets within 3 inches.

- The Wisconsin DOT expressed similar views to those of Oregon—to the effect that the NPRM was too expansive about what could be excluded from measurements and that the ultimate result would be wider and longer vehicles.

- Pursuant to ongoing NAFTA discussions, FHWA is preparing an NPRM to consider an extension from 3 to 4 inches for non-property carrying devices.

- The Illinois, Maryland, and Oregon DOTs oppose rolling tarp systems as they believe these systems result in wider vehicles (i.e., up to 108 inches). Illinois and Maryland also oppose these systems because they provide increased efficiency for only one portion of an industry, an action they consider potentially discriminatory in a business sense.”

CHAPTER 4. MAJOR TRUCK CORRIDORS IN TEXAS

4.1 INTRODUCTION

This chapter begins with a description of the Geographic Information System (GIS) platform and related metadata considerations used for analysis and presentation in the research. There is also analysis of current levels of truck activity in Texas, as reflected in commodity flows and truck traffic. Additionally, there is a summary of anticipated changes in truck traffic for Texas, based on projections enunciated in recent freight systems studies and corridor project reports. The chapter also contains a brief overview of trucking-related considerations in the Trans Texas Corridor plan. The chapter concludes with a framework for a threshold concept model for truck improvements.

4.2 METHODOLOGY

Much of the information in this chapter came from the TRANSEARCH® database either directly or was derived by the research team. TRANSEARCH® is a leading commercial source for understanding freight movement in the United States. Reebie Associates produces this proprietary database for use by state and federal governmental agencies, motor carriers, air carriers, railways, and others, largely for origin-destination (O-D) type evaluations. TxDOT purchased the elements of the database that are pertinent to Texas, and then researcher personnel requested its use for this project. The University of Manitoba's Transport Information Group (UMTIG) developed the mapping for this chapter. The chapter first evaluates commodity flow, and then converts flows into truck trips between major urban areas or regions.

4.2.1 GIS-T Platform

This section provides information on the GIS-T platform used throughout this project. The discussion subdivisions are spatial data, attribute data, data integration processes, and software.

4.2.1.1 Spatial Data

Key geographic datasets used in this analysis are the Texas road network, pertinent political boundaries, urban areas, and traffic counting locations. A brief description of each follows:

- Texas road network – single centerline highway layer provided by TxDOT,
- political boundaries – state, province, Bureau of Economic Analysis areas and county boundaries acquired from the Bureau of Transportation Statistics (BTS),

- urban areas – geographic boundary of urbanized areas in Texas acquired from TxDOT, and

- traffic counting locations – point layer identifying traffic counting and vehicle classification sites provided by TxDOT.

4.2.1.2 Attribute Data

Traditional databases containing a variety of highway inventory, traffic and commodity flow data were attached to the listed spatial datasets. The principal attribute datasets used in the research were:

- Texas highway inventory – Texas reference marker (TRM) data provided by TxDOT,

- Texas traffic data – raw data provided in 2CD and 4CD format by TxDOT, and

- commodity flow data – 1998 Reebie TRANSEARCH database, provided by TxDOT.

4.2.1.3 Data Integration Processes

Key data integration processes used during the GIS-T platform development were:

- datum conversion – NAD27 to NAD83;

- linear referencing – attaching the Texas highway inventory database to a single centerline highway dataset; and

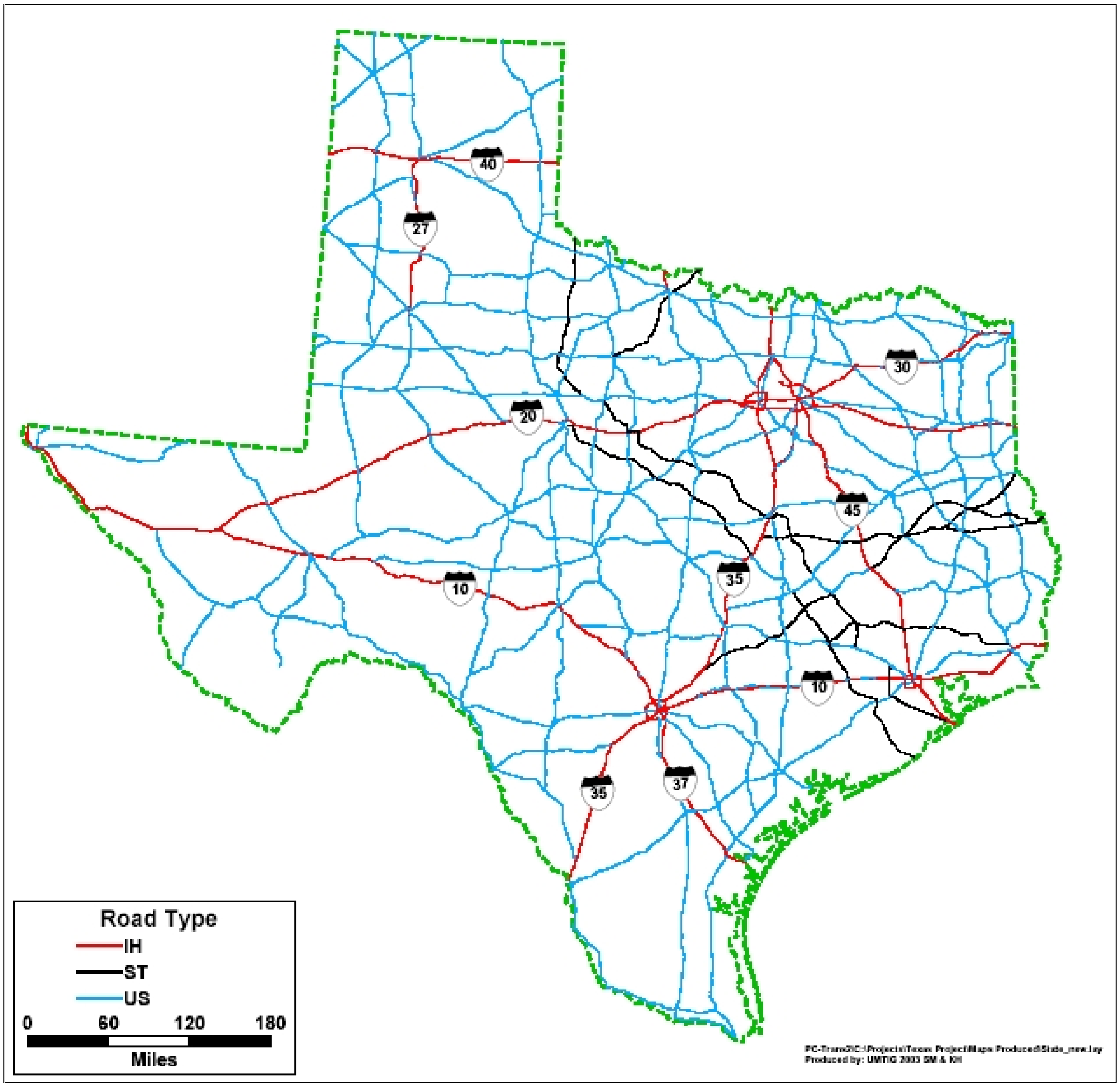
- restructure and attachment of attribute datasets – 2CD, 4CD and Reebie datasets were prepared and attached to appropriate spatial datasets.

4.2.1.4 Software

Multiple software packages were used in the project to ensure data interoperability. Key GIS packages used were Maptitude and TransCAD. UMTIG generated all maps presented in this report using one of the above software packages based on the spatial and attribute datasets developed for this project.

4.2.2 Road Network

For the purposes of developing the maps and related databases discussed here, the research team selected some road classes to be retained and some to be removed from the total network file. The goal in the selection process was to cover at least the National Highway System network in Texas, but the selected network is actually more than that network. Road classes retained are Interstate, U.S. highways, and a subset of state highways. Figure 4 shows the resulting network.



Source: UMTIG, based on TxDOT Information.

Figure 4. Texas IH-US-Partial ST Highway Network.

4.3 CURRENT LEVELS OF TRUCK ACTIVITY

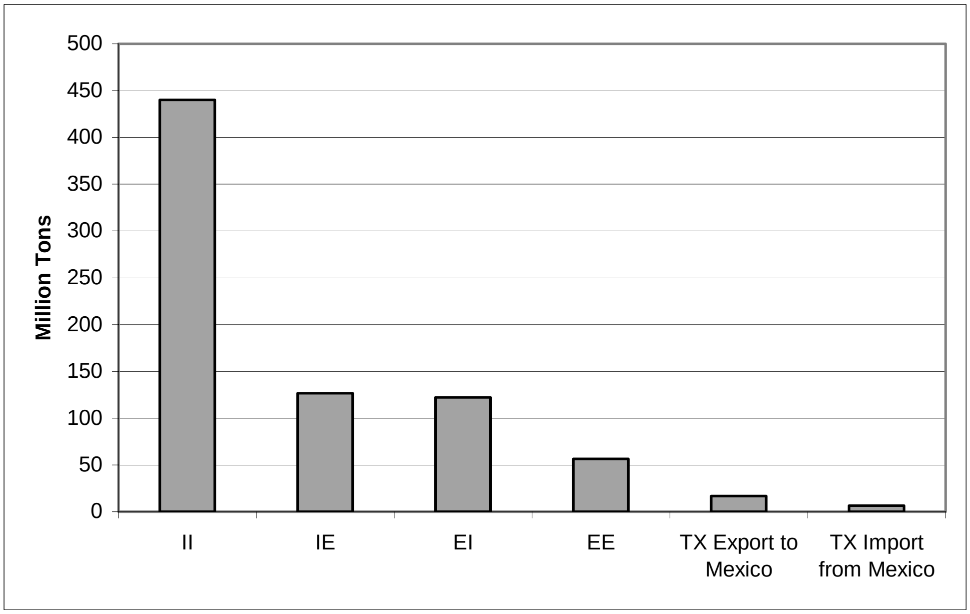
4.3.1. Commodity Flows and Derived Truck Movements

This section covers the truck-transported commodity movements and derived truck movements, based on the freight movement database, TRANSEARCH, provided by Reebie Associates through the state of Texas for 1998. The complete database contains freight movement of all transportation modes, but this analysis only considers the truck transport data.

4.3.1.1 Commodity Movements by Truck Related to Texas

In 1998, trucks moved a total of 769 million tons of commodities on Texas highways. This included 23.3 million tons of commodities moved between Texas and Mexico. Figure 5 is a plot of the six categories listed below:

- II – Intra Texas movement (57 percent of the total),
- IE – Texas originated Interstate movement (16 percent),
- EI – Texas bound Interstate movement (16 percent),
- EE – Interstate movement through Texas (7 percent),
- TX Export – Texas originated Mexico bound movement (2 percent), and
- TX Import – Texas bound movement from Mexico (1 percent).



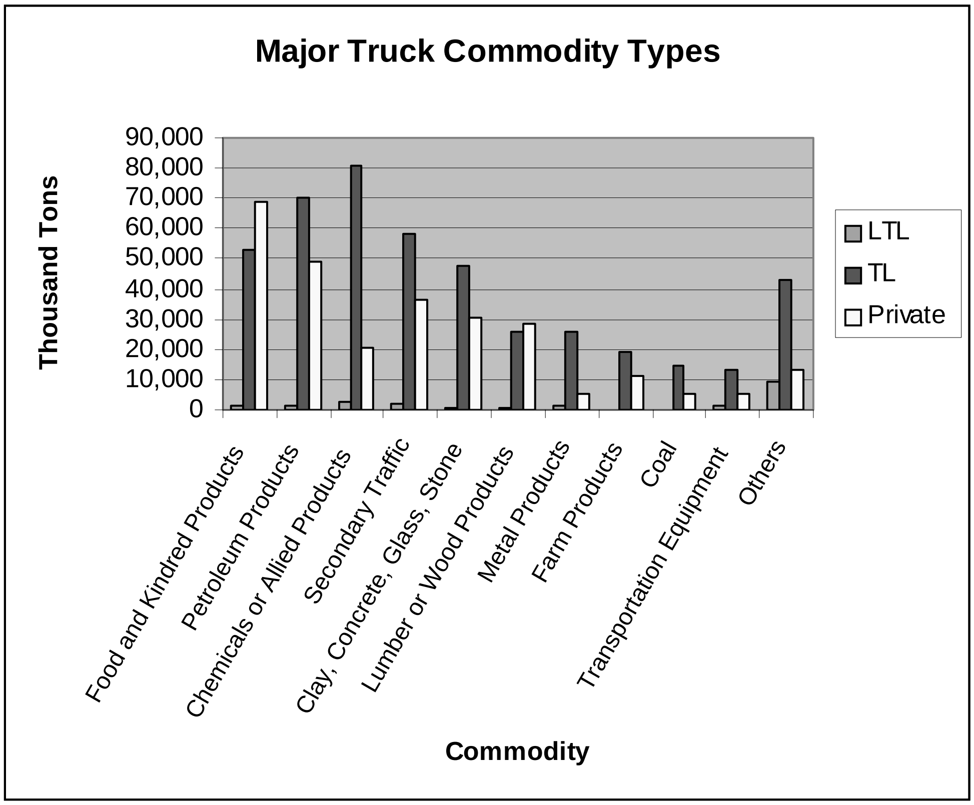
Source: Reference (14).

Figure 5. 1998 Texas-Related Commodity Movements by Movement Type.

This figure clearly indicates two important conclusions:

- Intrastate and interstate movements totally dominate truck activity in Texas.
- Texas-Mexico international movements account for just 3 percent of the total movement.

The Reebie database further subdivides the "within U.S." component of this total tonnage into commodity types by carrier type (TL, LTL, and private). Figure 6 provides a graphic of these values.



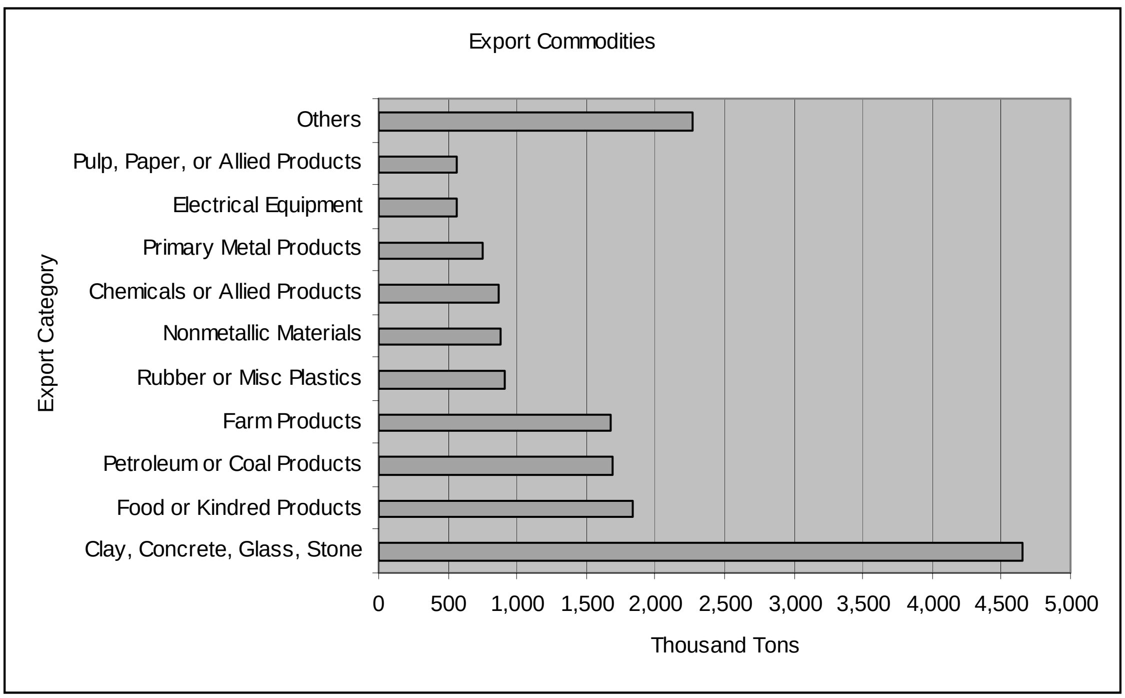
Source: Reference (14).

Figure 6. 1998 Tonnage Shipped by Major Truck Commodity Types.

Of the total 745.4 million tons of commodities, 61 percent are moved by truck-load carriers, 37 percent by private carriers, and 3 percent by less-than-truck-load carriers. From the commodity perspective, food and kindred products top the list and are followed by petroleum or coal products, and chemicals or allied products. These top three commodities account for 47 percent of the total tonnage. The top 10 commodity types listed account for 89 percent of the total tonnage. Figures 7 and 8 show the tonnage movements by major commodity types for exports and imports, respectively, for the Texas-Mexico movement. For Mexico-bound movements, the top 10 commodity types account for 86 percent of the total tonnage. For Texas-bound movements, the top 10 account for 85 percent of the total tonnage.

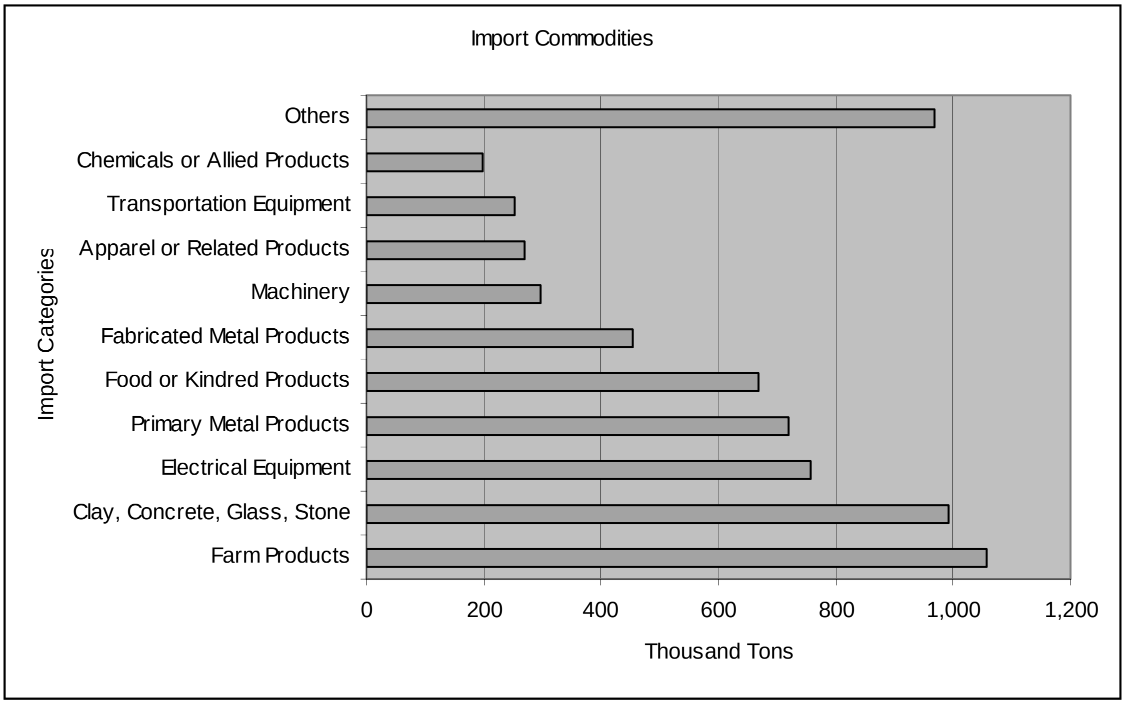
4.3.1.2 Commodity-Derived Truck Trips Related to Texas

The Reebie database converts the tonnages of commodity movements by truck into the number of annual loaded truck movements by origin-destination combinations. It also provides estimates of empty truck movements by origin-destination combinations. Table 12 summarizes average commodity-specific payload figures for loaded truck movements from the Reebie database. The calculated average payload of loaded trucks is 16.9 tons, ranging from a low of 9.2 tons (for trucks handling rubber or miscellaneous plastics) to a high of 21.6 tons (for trucks handling petroleum or coal products). Assuming all commodities use 5-axle tractor semitrailers (3-S2s) having a tare weight of 15 tons, these payloads indicate that the average GVW for such trucks operating in Texas is about 63,800 pounds (versus the basic GVW limit of 80,000 pounds).



Source: Reference (14).

Figure 7. Major Texas/Mexico Export Commodities by Tonnage.



Source: *Reference (14).*

Figure 8. Major Texas/Mexico Import Commodities by Tonnage.

Table 13 summarizes the total truck trips estimated by Reebie by origin-destination type pair and by loaded versus empty trucks. Figure 9 shows the related truck trips per day. Reebie's estimated loaded and empty truck trips sufficed for II, IE, EI, and EE movements. However, for Texas-Mexico movements, analysts used 17-ton truck trips for comparison based on the 17-ton truck payload, based on average payloads observed in the Reebie database *(14)*.

Results indicate that II movements account for 56 percent of the total estimated truck trips. IE and EI movements account for about 20 and 15 percent of total trips, respectively, and EE truck trips account for 7 percent. Texas Export and Import truck trips (between Texas and Mexico) account for 1.4 and 0.6 percent, respectively, and empty truck trips account for one-third (34 percent) of all truck trips.

4.3.1.3 Details of the Origin-Destination Movements of Reebie Derived Truck Trips

For the analysis of intrastate and interstate truck movements derived from the TRANSEARCH database, Texas is divided into 14 regions according to Bureau of Economic Analysis' (BEA) economic areas. Table 14 lists the BEA areas used in the analyses. Figure 10 shows the geographical locations of the BEA areas in Texas and adjacent states, and the county borders and urban areas within each BEA.

Table 12. Average Truck Payload by Commodity Calculated from the Reebie Database.

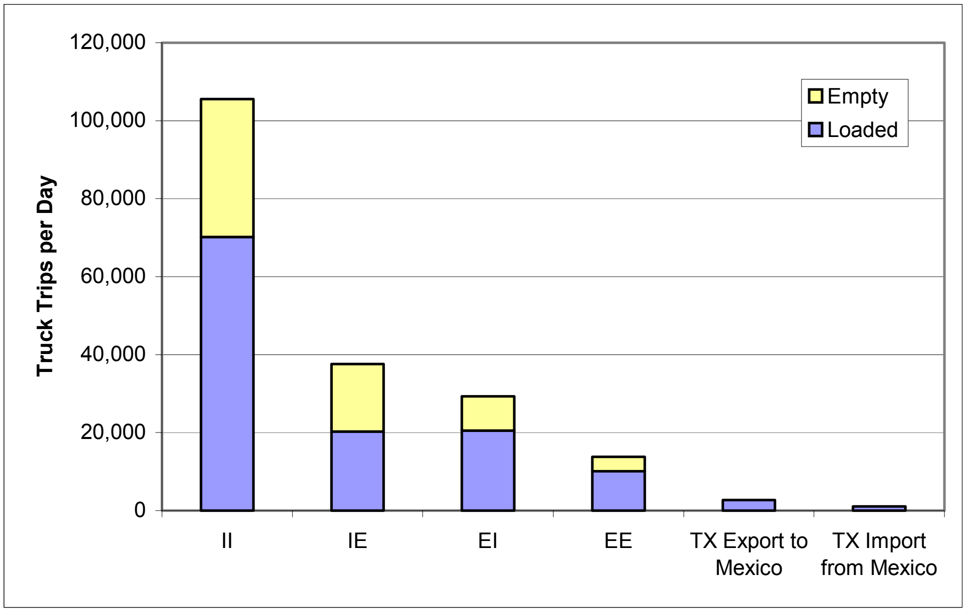
Commodity Description	Ave Payload/truck (ton)
Petroleum or coal products	21.6
Lumber or wood products	21.1
Primary metal products	19.9
Pulp, paper, or allied products	18.5
Food or kindred products	18.0
Chemicals or allied products	16.9
Tobacco products	16.6
Textile mill products	16.3
Coal	16.1
Secondary traffic	16.1
Farm products	15.9
Miscellaneous manufacturing products	14.6
Clay, concrete, glass, or stone	14.4
Fabricated metal products	14.3
Printed matter	13.8
Electrical equipment	12.9
Apparel or related products	12.4
Furniture or fixtures	11.4
Transportation equipment	11.3
Leather or leather products	11.2
Machinery	10.8
Instruments, photo equipment, optical equip	9.6
Rubber or misc plastics	9.2
Total Average	16.9

Source: Reference (14).

Table 13. 1998 Texas-Related Truck Trips Derived from Reebie Commodity Flows.

	Tonnage	Total Trips	Loaded Trips	Empty Trips	Loaded/day	Empty/day
II	440,205,655	38,517,818	25,604,677	12,913,141	70,150	35,378
IE	126,661,964	13,723,961	7,400,166	6,323,795	20,274	17,325
EI	122,068,719	10,685,369	7,483,265	3,202,104	20,502	8,773
EE	56,511,713	5,029,528	3,689,975	1,339,553	10,110	3,670
TX Export	16,662,111	980,124	980,124		2,685	
TX Import	6,627,952	389,880	389,880		1,068	
Total	768,738,114	69,326,679	45,548,086	23,778,593	124,789	65,147

Source: Reference (14).



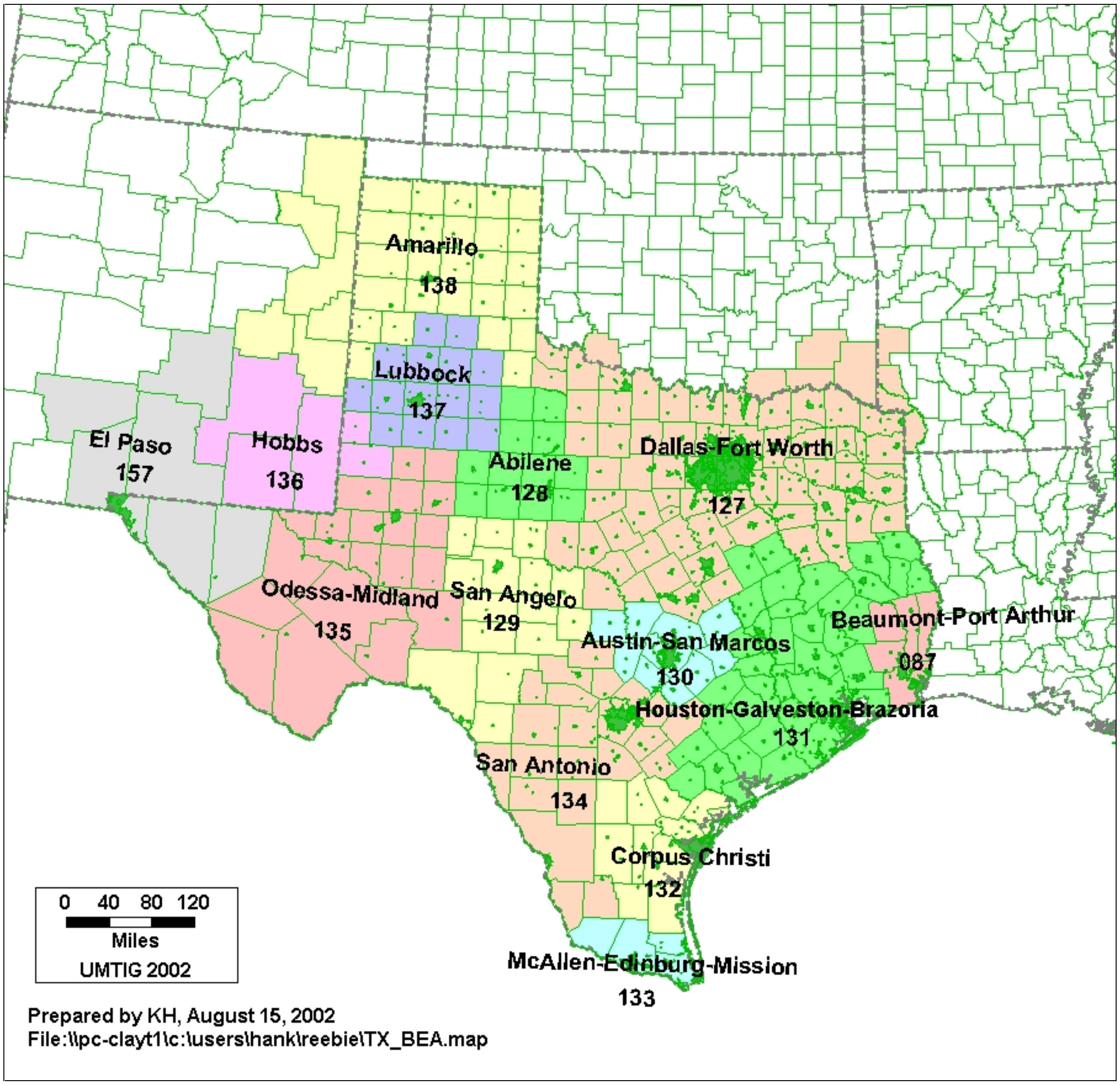
Source: Reference (14).

Figure 9. 1998 Texas-Related Truck Movements by Movement Type.

Table 14. BEAs in Texas.

BEA NAME	BEA CODE
Abilene	128
Amarillo	138
Austin-San Marcos	130
Beaumont-Port Arthur	87
Corpus Christi	132
Dallas-Ft. Worth	127
El Paso	157
Hobbs	136
Houston-Galveston-Brazoria	131
Lubbock	137
McAllen-Edinburg-Mission	133
Odessa-Midland	135
San Angelo	129
San Antonio	134

Data Source: Bureau of Economic Analysis.



Data Source: Bureau of Economic Analysis.

Figure 10. BEA Economic Areas in Texas and Adjacent States.

Intrastate Movements. Tables 15, 16, 17, and 18 show the origin-destination patterns for Texas intrastate truck movements in terms of Reebie estimated loaded truck trips per day, empty truck trips per day, total truck trips per day, and two-way combined total truck trips per day, respectively. Figure 11 shows the origin-destination of these intrastate truck movements for those components which average more than 480 two-way truck trips per day.

Table 15. Origin-Destination Patterns for Loaded Texas Intrastate Truck Movement. [a]

Origin \ Dest'n	Abilene	Amarillo	Austin-San Marcos	Beaumont-Port Arthur	Corpus Christi	Dallas-Ft. Worth	El Paso	Hobbs	Houston-Galveston-Brazoria	Lubbock	McAllen-Edinburg-Mission	Odessa-Midland	San Angelo	San Antonio	Total
Abilene	5	29	33	18	16	207	15	1	245	15	17	9	9	54	672
Amarillo	26	231	160	74	96	1071	70	4	917	185	74	51	70	237	3267
Austin-San Marcos	13	71	89	50	43	695	53	2	754	28	51	28	16	479	2372
Beaumont-Port Arthur	23	64	124	179	103	1111	119	3	820	46	107	74	20	256	3048
Corpus Christi	13	50	74	63	110	558	53	2	531	36	57	48	16	167	1778
Dallas-Ft. Worth	160	597	962	611	478	8991	617	17	7265	312	607	285	167	3030	24,099
El Paso	8	47	44	35	27	357	243	1	397	16	33	14	8	93	1324
Hobbs	0	5	2	1	1	18	1	0	111	2	15	1	2	3	162
Houston-Galveston-Brazoria	156	635	845	769	455	6892	642	23	8825	344	563	392	155	2766	23,462
Lubbock	9	68	52	33	34	378	28	1	411	27	43	19	14	105	1222
McAllen-Edinburg-Mission	13	49	68	50	51	586	50	2	691	32	57	25	11	186	1870
Odessa-Midland	6	25	36	28	22	254	34	1	328	16	26	24	10	64	874
San Angelo	3	18	17	5	7	107	8	0	137	8	8	6	8	26	359
San Antonio	36	149	203	148	151	1,541	131	6	1945	76	181	75	42	956	5641
Total	469	2038	2711	2066	1594	22,766	2064	63	23,378	1142	1838	1051	549	8422	70,150

Data Source: Reference (14).

[a] Reebie estimated loaded truck trips per day

Table 16. Origin-Destination Patterns for Empty Texas Intrastate Truck Movement. [a]

Origin \ Dest'n	Abilene	Amarillo	Austin-San Marcos	Beaumont Port Arthur	Corpus Christi	Dallas-Ft. Worth	El Paso	Hobbs	Houston-Galveston-Brazoria	Lubbock	McAllen-Edinburg-Mission	Odessa-Midland	San Angelo	San Antonio	Total
Abilene	4	18	9	7	9	65	1	1	44	4	2	9	2	17	190
Amarillo	32	415	350	27	391	1350	13	9	531	78	27	553	18	499	4295
Austin-San Marcos	20	122	57	25	81	383	6	3	243	29	18	85	11	121	1203
Beaumont-Port Arthur	12	43	19	35	11	225	3	0	134	25	28	11	3	82	631
Corpus Christi	12	77	32	17	34	212	2	1	153	26	37	27	6	201	837
Dallas-Ft. Worth	82	679	221	207	300	2094	36	13	1459	173	119	294	42	512	6230
El Paso	24	101	42	28	68	422	4	13	275	39	33	59	8	153	1270
Hobbs	1	8	1	0	5	17	0	0	9	6	2	4	0	9	64
Houston-Galveston-Brazoria	133	670	283	180	695	3109	42	11	2384	261	312	489	55	1114	9738
Lubbock	15	179	26	15	52	209	2	6	147	20	11	40	7	43	772
McAllen-Edinburg-Mission	38	156	167	31	69	556	3	17	455	52	6	207	27	123	1906
Odessa-Midland	29	111	63	11	71	372	3	3	178	48	27	110	10	158	1193
San Angelo	11	90	73	7	89	329	2	3	131	14	6	131	9	124	1018
San Antonio	120	389	261	259	176	2079	12	26	1183	168	195	75	35	1052	6032
Total	533	3056	1604	849	2049	11,423	130	106	7326	944	822	2096	232	4209	35,378

Data Source: Reference (14).

[a] Reebie estimated empty truck trips per day

Table 17. Origin-Destination Patterns for Total Texas Intrastate Truck Movement. [a]

Origin \ Dest'n	Abilene	Amarillo	Austin-San Marcos	Beaumont-Port Arthur	Corpus Christi	Dallas-Ft. Worth	El Paso	Hobbs	Houston-Galveston-Brazoria	Lubbock	McAllen-Edinburg-Mission	Odessa-Midland	San Angelo	San Antonio	Total
Abilene	8	47	42	25	25	272	16	2	288	19	19	18	11	71	862
Amarillo	58	646	510	101	487	2422	83	13	1448	263	101	603	89	736	7562
Austin-San Marcos	33	193	146	76	124	1078	58	4	997	58	69	113	27	600	3575
Beaumont Port Arthur	35	107	143	214	113	1335	121	3	954	71	135	85	23	338	3679
Corpus Christi	24	127	106	80	144	771	55	3	685	62	94	75	22	368	2615
Dallas-Ft. Worth	242	1276	1184	817	778	11,085	653	31	8724	485	726	579	209	3541	30,329
El Paso	32	148	86	63	96	779	248	14	671	56	66	73	15	246	2594
Hobbs	2	12	4	1	6	35	1	1	121	8	17	5	2	12	226
Houston-Galveston-Brazoria	289	1305	1128	949	1150	10,002	684	34	11,208	605	874	881	210	3881	33,200
Lubbock	24	247	78	48	85	586	30	7	558	47	54	59	21	149	1993
McAllen-Edinburg-Mission	51	205	235	80	120	1142	53	18	1146	84	63	232	38	308	3776
Odessa-Midland	35	135	99	39	93	626	37	4	507	64	53	134	20	222	2067
San Angelo	14	107	90	13	96	435	10	3	268	22	14	137	17	150	1376
San Antonio	156	538	465	407	327	3621	143	32	3128	244	376	151	78	2009	11,673
Total	1002	5094	4315	2915	3642	34,189	2194	169	30,703	2086	2661	3147	781	12,631	105,528

Data Source: Reference (14).

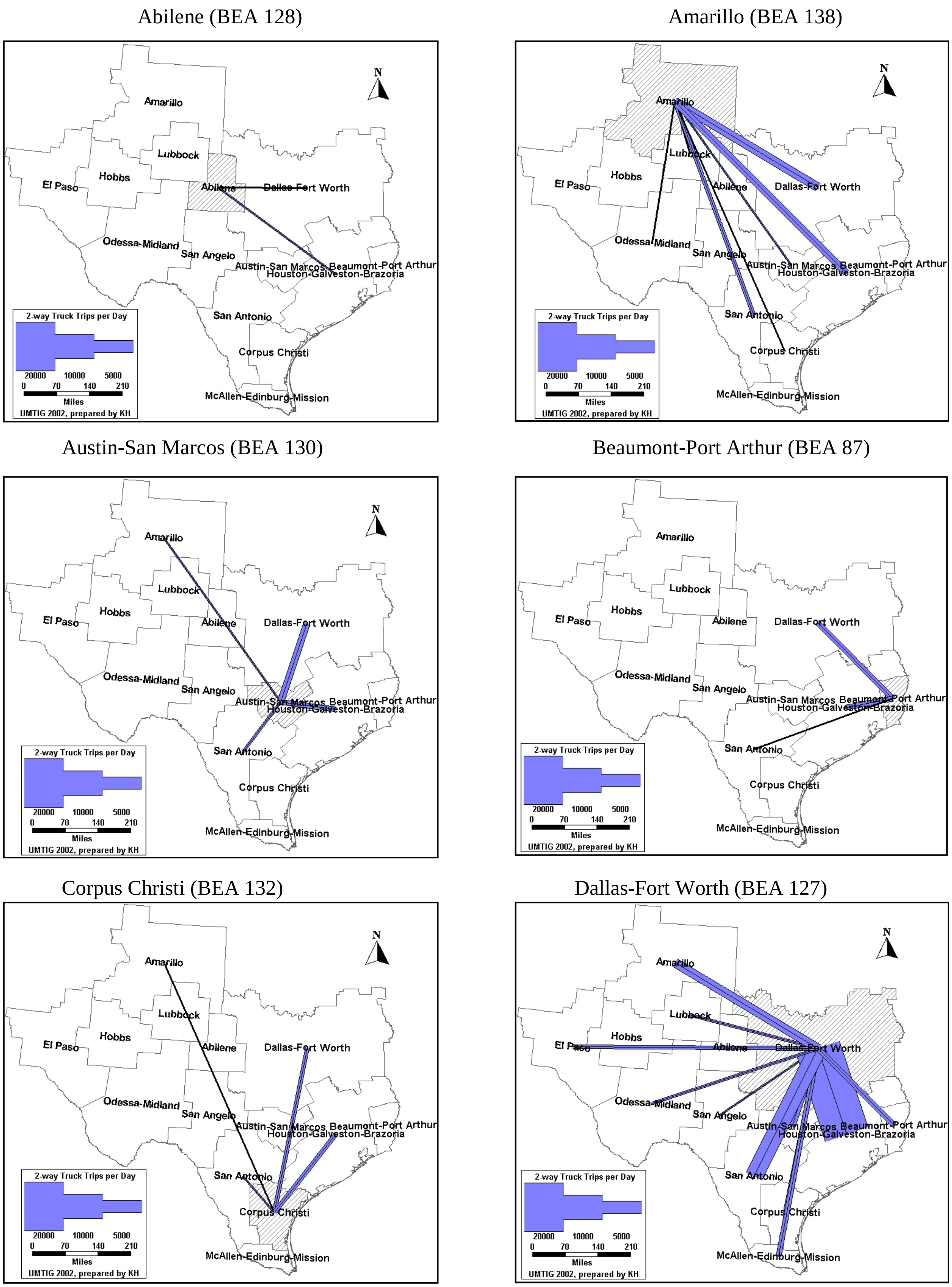
[a] Reebie total truck trips per day

Table 18. Origin-Destination Patterns for Combined Total Texas Intrastate Truck Movement. [a]

Origin \ Dest'n	Abilene	Amarillo	Austin-San Marcos	Beaumont Port Arthur	Corpus Christi	Dallas-Ft. Worth	El Paso	Hobbs	Houston-Galveston-Brazoria	Lubbock	McAllen-Edinburg-Mission	Odessa-Midland	San Angelo	San Antonio
Abilene	8													
Amarillo	105	646												
Austin-San Marcos	75	703	146											
Beaumont-Port Arthur	60	209	218	214										
Corpus Christi	50	614	230	193	144									
Dallas-Ft. Worth	514	3697	2262	2153	1548	11,085								
El Paso	48	232	145	184	151	1432	248							
Hobbs	3	25	8	5	9	66	15	1						
Houston-Galveston-Brazoria	577	2753	2125	1903	1835	18,726	1356	155	11,208					
Lubbock	43	510	136	119	147	1071	86	15	1163	47				
McAllen-Edinburg-Mission	69	306	304	215	213	1867	119	35	2020	138	63			
Odessa-Midland	52	739	212	125	168	1205	110	9	1388	123	285	134		
San Angelo	25	196	117	35	118	644	25	5	478	43	52	157	17	
San Antonio	227	1274	1065	745	695	7162	389	44	7009	392	685	372	227	2009

Data Source: Reference (14).

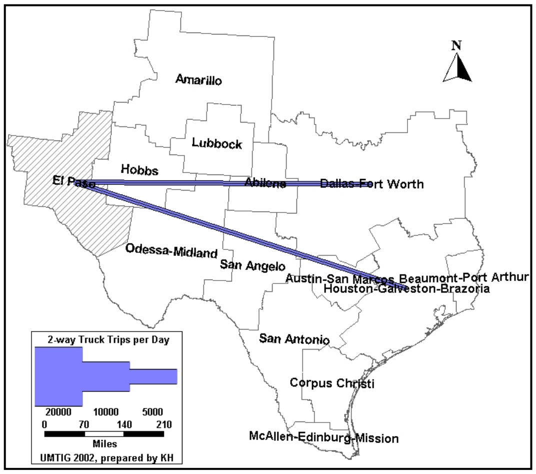
[a] Reebie total truck trips per day, two-way combined



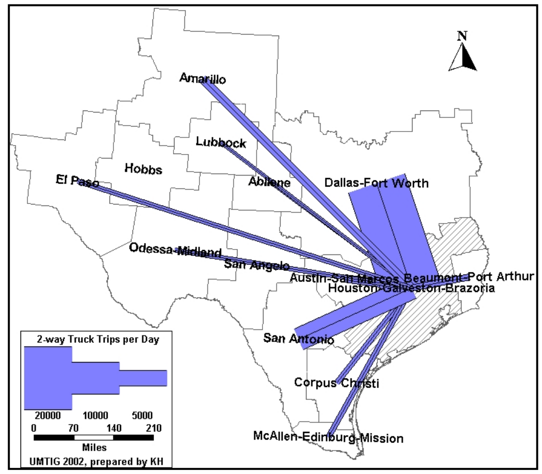
Data Source: Reference (14), (Reebie estimated two-way total truck trips per day).

Figure 11. Texas Intrastate Truck Movement between Origin BEA and Other BEAs.

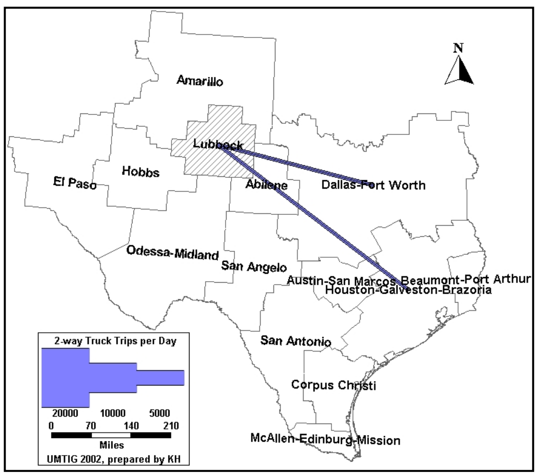
El Paso (BEA 157)



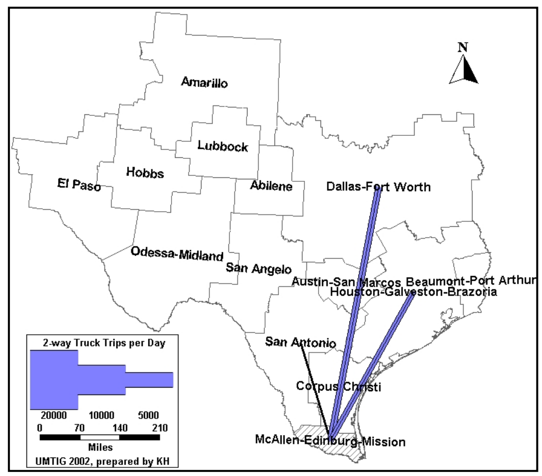
Houston-Galveston-Brazoria (BEA 131)



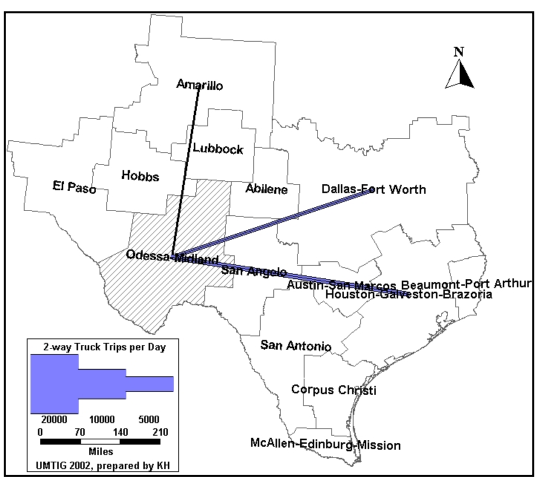
Lubbock (BEA 137)



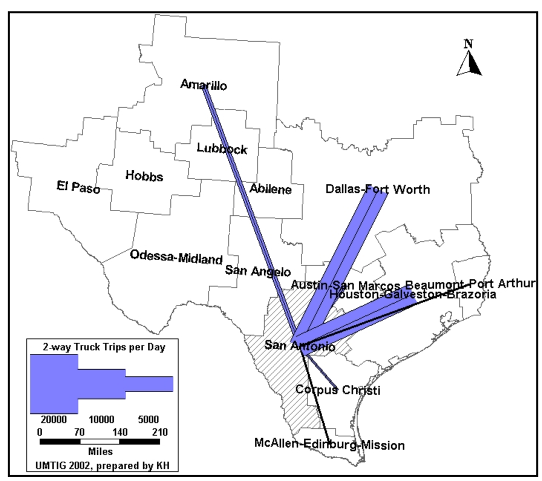
McAllen-Edinburg-Mission (BEA 133)



Odessa-Midland (BEA 135)



San Antonio (BEA 134)



Data Source: Reference (14), (Reebie estimated two-way total truck trips per day).

Figure 11. Texas Intrastate Truck Movement between Origin BEA and Other BEAs (Continued).

San Angelo (BEA 129) is not included in the figure because there is only one movement to be shown (i.e., between San Angelo – BEA 129 and Dallas-Ft. Worth – BEA 127). The figure showing BEA 127 shows this movement.

As indicated by these graphics, Houston-Galveston-Brazoria (BEA 131) and Dallas-Fort Worth (BEA 127) each accounts for about one-third of all intrastate truck trip origins and one-third of all intrastate truck trip destinations. About one-third of intrastate truck trips originating in BEA 127 and BEA 131 remain within their respective areas. Another one-third is destined for the other BEAs. In the case of other BEAs, most intrastate truck trips are destined for BEAs other than the originating BEA. Between one-half and two-thirds of their originating trips are destined for the two above mentioned BEAs.

Interstate Movements. This analysis groups interstate commodity movements into two types: (1) those originating in Texas destined for other states; and (2) those originating in other states destined for Texas. Of all truck trips originating in Texas, 26 percent are interstate movements. The major destination states are: Louisiana, Missouri, Oklahoma, California, Florida, Arkansas, Rhode Island, and New Mexico. Together, these states account for about one-half of all the truck trips originating in Texas. Figure 12 shows O-D patterns for truck trips originating in Texas destined for other states.

Data Source: Reference (14).

Figure 12. Interstate Truck Movements with Origins in Texas.

Major origins for the interstate truck trips in Texas are Houston-Galveston-Brazoria (BEA 131) and Dallas-Fort Worth (BEA 127), followed by San Antonio (BEA 134) and Beaumont-Port Arthur (BEA 87). Table 19 lists interstate truck movements by origin BEA areas.

Table 19. Interstate Truck Movement by Origins in Texas (BEAs).

BEA Name	BEA Code	Tonnage	Total Trips	Loaded Trips	Empty Trips
Houston-Galveston-Brazoria	131	58,397,186	5,734,907	3,271,942	2,462,965
Dallas-Fort Worth	127	26,790,008	3,471,519	1,687,041	1,784,478
San Antonio	134	9,076,091	1,121,026	601,167	519,859
Beaumont-Port Arthur	87	8,841,685	789,610	478,340	311,270
El Paso	157	4,614,196	562,897	282,332	280,565
Corpus Christi	132	5,700,985	441,277	279,077	162,200
Amarillo	138	3,727,302	409,408	210,831	198,577
McAllen-Edinburg-Mission	133	2,863,855	359,384	177,342	182,042
Austin-San Marcos	130	1,634,967	230,439	107,216	123,223
Lubbock	137	1,560,848	196,780	93,717	103,063
Odessa-Midland	135	1,576,835	161,868	89,848	72,020
Abilene	128	846,512	122,771	60,196	62,575
Hobbs	136	713,391	83,969	42,073	41,896
San Angelo	129	318,103	38,106	19,044	19,062

Data Source: Reference (14).

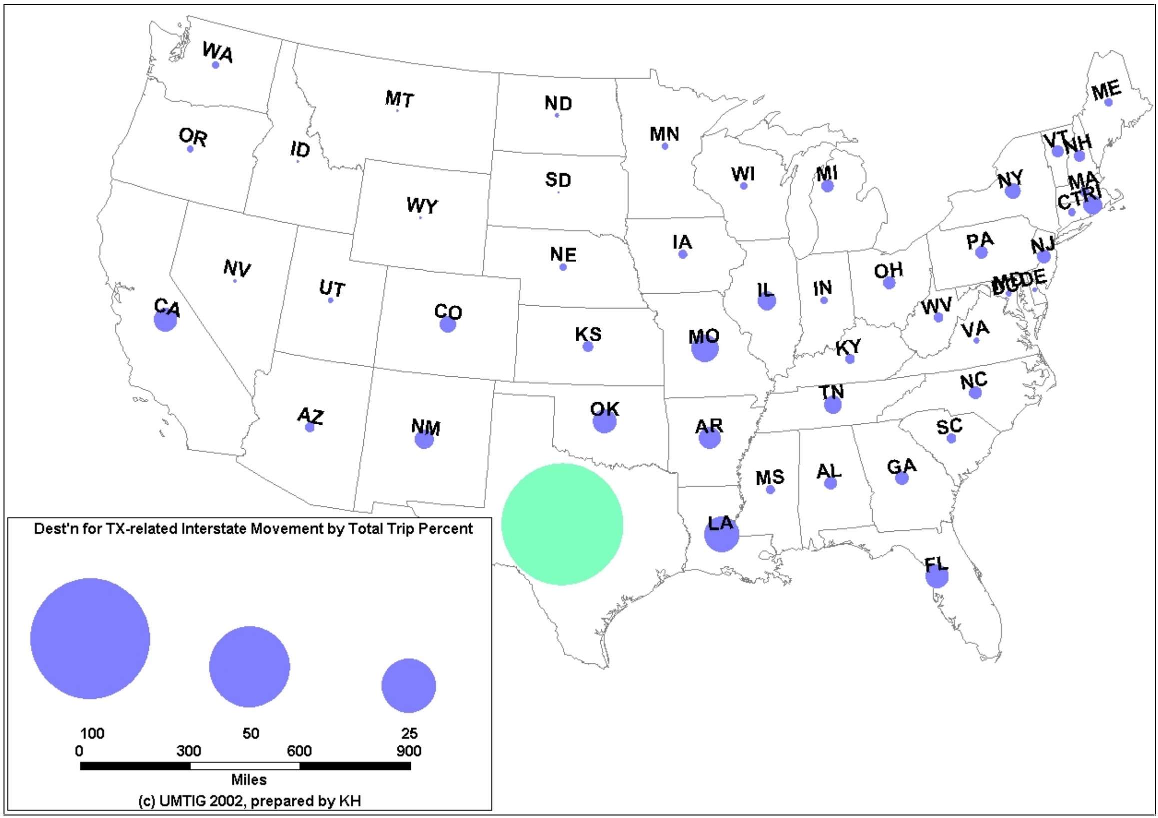
Of all the truck trips destined for Texas, 21 percent originates in states other than Texas. The major origin states are: Louisiana, Alabama, Oklahoma, Arkansas, Oregon, Tennessee, Colorado, Missouri, and California. Together, these states account for over one-half of the total interstate truck trips destined for Texas. Figure 13 shows O-D patterns for truck trips originating in other states destined for Texas.

Major destinations for the interstate truck trips in Texas are Houston-Galveston-Brazoria (BEA 133) and Dallas-Ft. Worth (BEA 127), followed by San Antonio (BEA 134). Table 20 lists interstate truck movements by destination BEA areas.

4.3.2 Truck Flows

4.3.2.1 Average Annual Daily Truck Traffic and Percent Trucks

Annual average daily truck traffic on a given road section is the total truck traffic on that section in one year divided by 365 days. This is synonymous with the term annual average daily traffic (AADT) used to characterize total traffic, including trucks. Percent trucks is AADTT divided by AADT. AADTT and AADT values represent two-way flows except as noted.



Data Source: Reference (14).

Figure 13. Interstate Truck Movements Destined for Texas.

Table 20. Interstate Truck Movement by Destinations in Texas (BEAs).

BEA Name	BEA Code	Tonnage	Total Trips	Loaded Trips	Empty Trips
Houston-Galveston-Brazoria	131	52,299,282	4,218,979	3,169,237	1,049,742
Dallas-Fort Worth	127	38,441,461	3,318,864	2,381,557	937,307
San Antonio	134	10,796,651	901,797	694,233	207,564
Corpus Christi	132	1,933,282	361,481	115,236	246,245
El Paso	157	4,962,076	337,618	290,659	46,959
Amarillo	138	3,312,877	326,731	199,316	127,415
Odessa-Midland	135	992,262	321,722	61,943	259,779
Austin-San Marcos	130	2,213,496	271,885	136,992	134,893
Beaumont-Port Arthur	87	2,400,408	242,321	141,179	101,142
McAllen-Edinburg-Mission	133	2,492,503	179,520	154,806	24,714
Lubbock	137	1,432,362	125,615	88,203	37,412
Abilene	128	407,799	41,430	24,952	16,478
San Angelo	129	223,468	26,099	14,434	11,665
Hobbs	136	160,793	11,308	10,519	789

Data Source: Reference (14).

Truck-miles-traveled on a given road segment is the product of AADTT for that segment times the segment length. TMT on a given road sub-system (e.g., interstate highways) or road (e.g., I-40 from the New Mexico border to the Oklahoma border) is the sum of TMTs on all of the road segments in the sub-system or road of interest. This is again synonymous with the concept of, and calculated in the same way, as vehicle-miles-traveled (VMT) estimates.

TxDOT estimates AADT for all traffic segments on the Texas highway system each year. Percent truck figures are estimated for each road segment either by direct measurement (usually based on 24-hour counts using automatic vehicle classification [AVC] equipment) or indirectly (estimating the AADTT on a link by the half volume method and subsequently calculating a percent truck value for the segment). In the Texas traffic information system, all trucks that are Class 3 and greater in the FHWA Scheme F are designated as trucks. Figure 14 shows the details of the types of vehicles included in this definition of truck for both the FHWA and Texas 6 Classification Schemes.

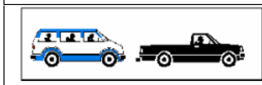
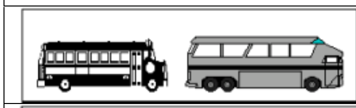
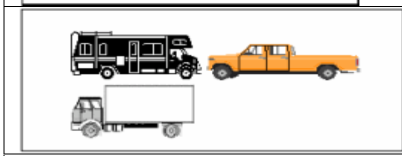
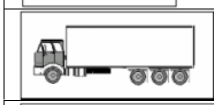
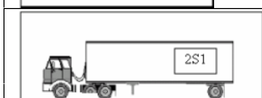
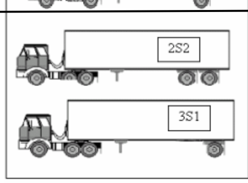
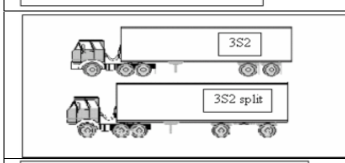
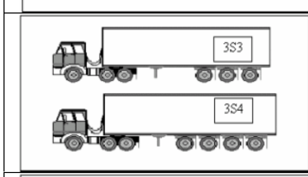
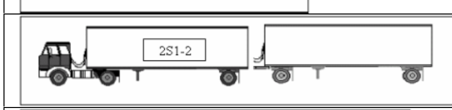
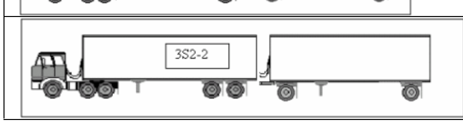
The mapping process associates the values of AADT and percent truck for each traffic segment with each unique link identified (characterized by a unique ID number) in the highway inventory system for the state. Those ID numbers – either directly or by linear referencing – can be related to the spatial data file of the Texas highway system, permitting direct plotting of traffic flows in the network using a GIS-platform. For the resulting network, Figures 15, 16, and 17 show the year 2000 AADTT, AADT, and percent trucks, respectively.

4.3.2.2 Distribution of Truck Travel on the Texas Highway System by AADTT Category and Highway Type

Table 21 shows the AADTT categories developed for the purposes of this analysis. Table 22 shows the logic supporting the ranges in Table 21. Table 22 shows basic density and spacing characteristics for each of the AADTT categories used in this analysis. Researchers selected the categories to give a practical physical sense of different levels of truck traffic when functioning in an idealized – BASIC FLOW – manner. Calculating BASIC FLOW characteristics assumed that the AADTT is evenly split in each direction; travels in one lane in each direction; experiences no seasonality, day-of-week, or time of day variation; that all trucks travel at 60 mph (88 ft/sec); and that all trucks travel at constant time and spacing headways varying only by AADTT level.

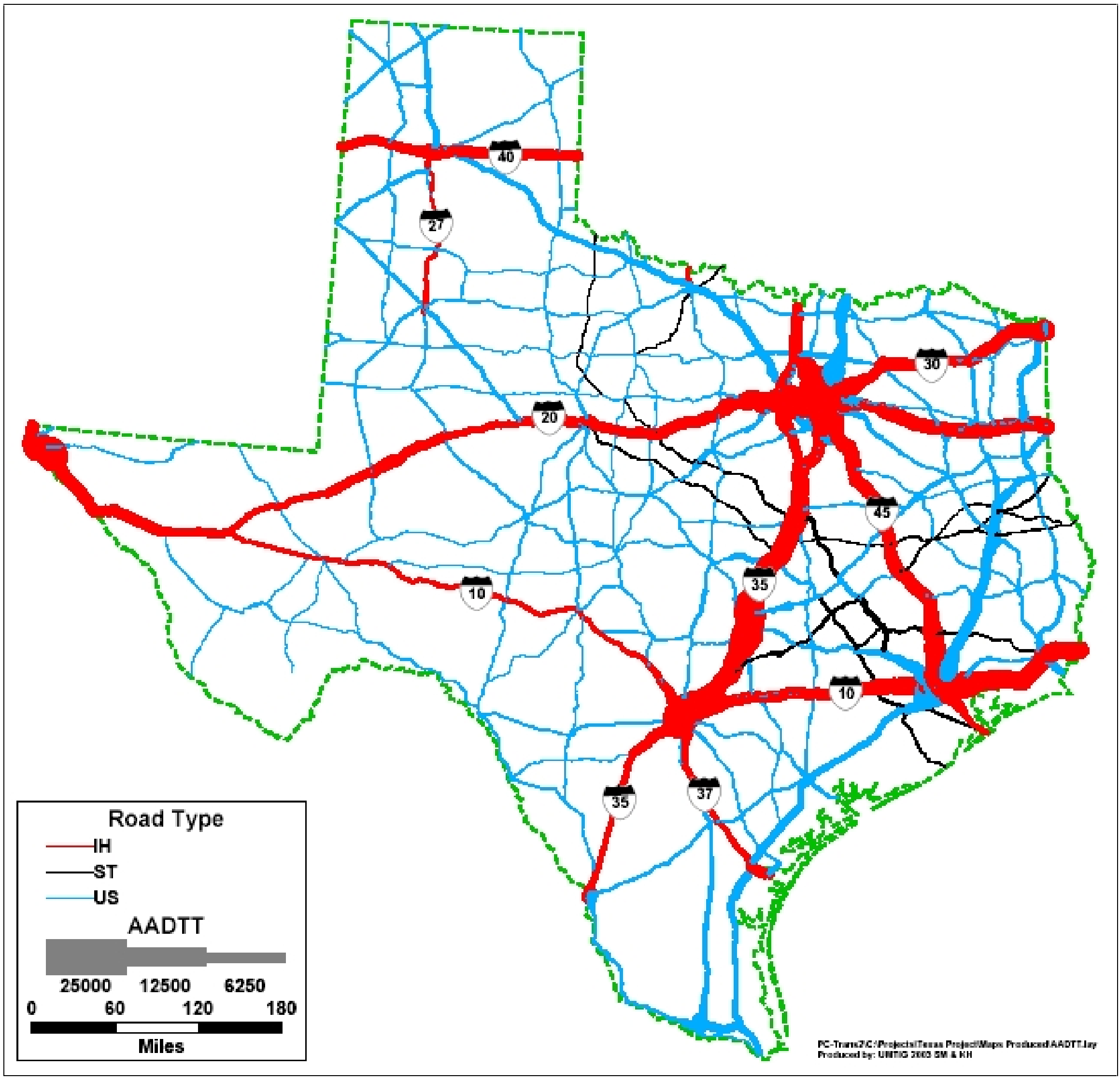
Table 21. AADTT Categories.

CATEGORY NAME	AADTT RANGE
Very Low	0-480
Low	480-960
Medium	960-2880
Medium High	2880-5760
High	5760-11520
Very High	11520 plus

Typical Vehicle Type	Texas 6 Classification	FHWA Classification
	**Class 2**: 2 axles, 4-tire single units	**Class 3**: 2 axles, 4-tire single units, pickup or van (with 1- or 2-axle trailers)
	**Class 3**: Buses	**Class 4**: Buses
	**Class 4**: 2D – six tire single-unit (includes handicapped-equipped bus and mini school bus)	**Class 5**: 2D – 2 axles, six tire single units (includes handicapped-equipped bus and mini school bus)
	**Class 5**: 3 axles, single unit	**Class 6**: 3 axles, single unit
	**Class 6**: 4 or more axles, single unit	**Class 7**: 4 or more axles, single unit
	**Class 7**: 3 axles, single trailer	**Class 8**: 3 to 4 axles, single trailer
	**Class 8**: 4 axles, single trailer	
	**Class 9**: 5 axles, single trailer	**Class 9**: 5 axles, single trailer
	**Class 10**: 6 or more axles, single trailer	**Class 10**: 6 or more axles, single trailer
	**Class 11**: 5 or less axles multi-trailers	**Class 11**: 5 or less axles, multi-trailers
	**Class 12**: 7 or more axles multi-trailers	**Class 12**: 6 axles, multi-trailers
	**Class 13**: 6 axles, multi-trailers	**Class 13**: 7 or more axles, multi-trailers

Source: Reference (15).

Figure 14. FHWA and Texas 6 Vehicle Classifications (FHWA Class 3 and Up).



Data Source: TxDOT.

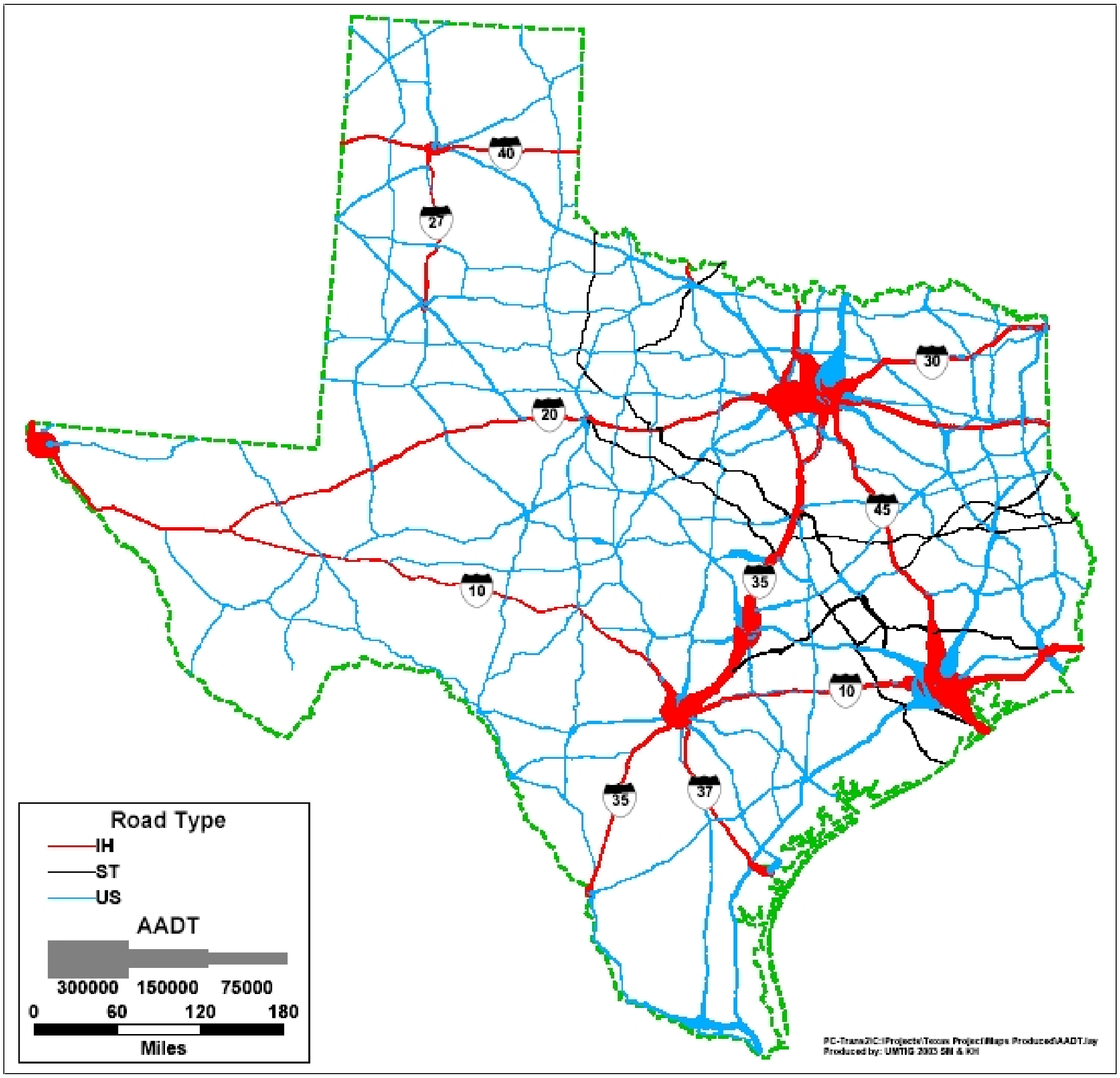
Figure 15. Texas 2000 AADTT Flow Map.

Table 22. BASIC FLOW Density and Spacing Characteristics by AADTT Category.

AADTT Category	Average Time Headway between Trucks (min) in Each Direction	Average Space Headway between Trucks in Each Direction	Average Space Headway in Typical 3-S2 Trucks (assume 66 ft length)	Average Truck Density per Mile in Each Direction @ 60 mph
0 - 480	0 to 6 min	Infinite to 6 mi		<<<1
480 – 960	6 to 3 min	6 mi to 3 mi	480 to 240	<<1
960 – 2880	3 to 1 min	3 mi to 1 mi	240 to 80	<1
2880 – 5760	1 to 0.5 min	1 mi to 2640 ft	80 to 40	1 to 2
5760 – 11,520	0.5 to 0.25 min	2640 ft to 1320 ft	40 to 20	2 to 4
11,520 – 23,040	0.25 to 0.125 min	1320 ft to 660 ft	20 to 10	4 to 8
23,040 – 46,080	0.125 to 0.0625 min	660 ft to 330 ft	10 to 5	8 to 16

Table 23 shows the number of route miles and truck-miles traveled in the year 2000 for seven AADTT categories and three highway types – interstate, U.S., and state. This tabular summary includes not just the subset of ST routes as noted earlier for maps but includes all state highways in addition to all IH and U.S. Figures 18 and 19 show these same totals graphically. Based on these totals, Table 22 facilitates the following findings by AADTT category:

- Highways with very low truck volumes (0-480 AADTT) account for 41 percent of the route miles and 6 percent of the annual TMT.
- Highways with low truck volumes (480-960 AADTT) account for 23 percent of the route miles and 9 percent of the annual TMT.
- Highways with medium truck volumes (960-2880 AADTT) account for 22 percent of the route miles and 21 percent of the annual TMT.
- Highways with medium high truck volumes (2880-5760 AADTT) account for 6 percent of the route miles and 15 percent of the annual TMT.
- Highways with high truck volumes (5760-11,520) account for 6 percent of the route miles and 31 percent of the annual TMT.
- Highways with very high truck volumes (11,520-23,040 +) account for 2 percent of the route miles and 18 percent of the annual TMT.

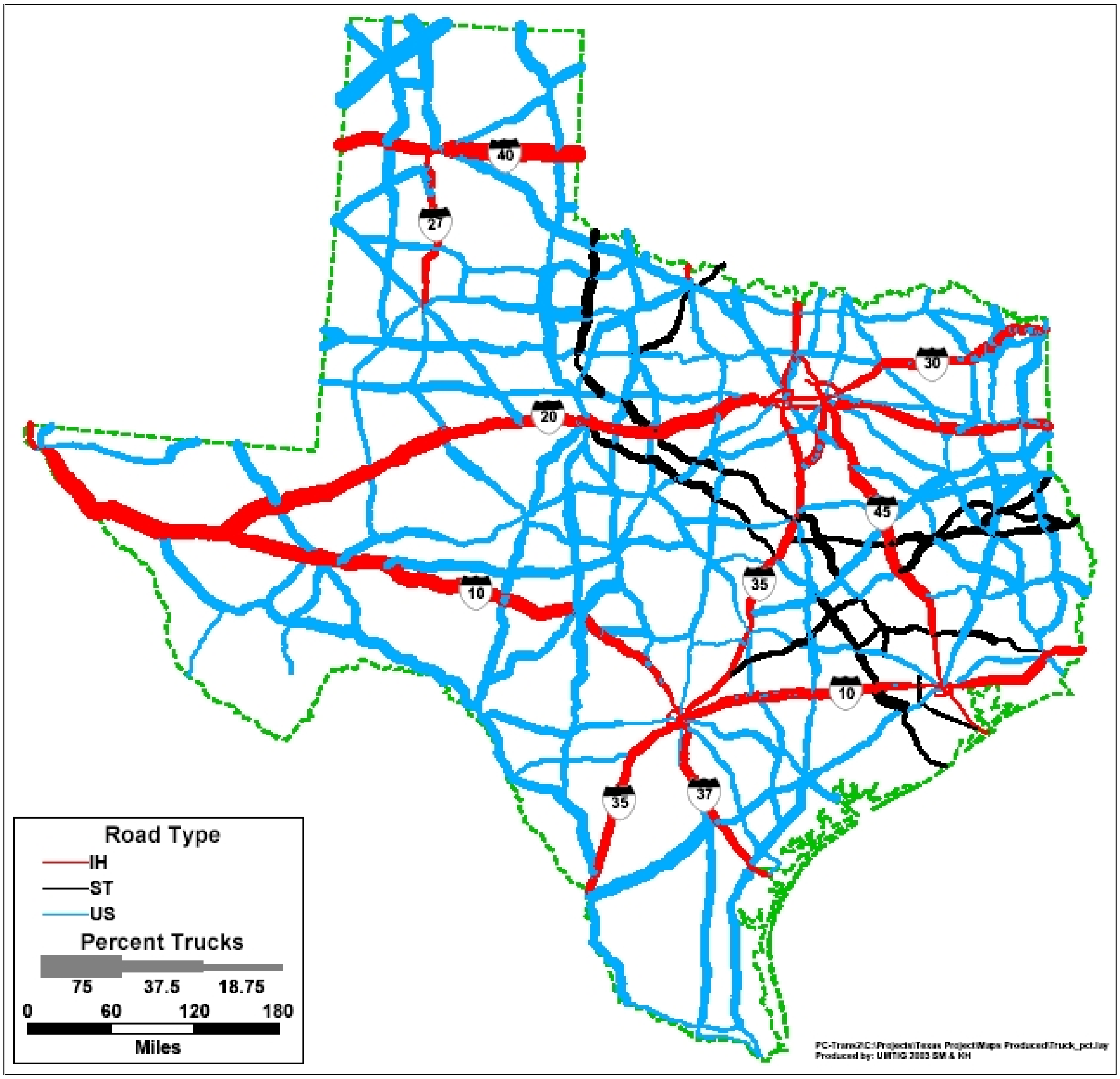


Data Source: TxDOT.

Figure 16. Texas 2000 AADT Flow Map.

Table 22 also facilitates the following findings by highway type:

- Interstate highways account for 11 percent of the route miles and 49 percent of the annual TMT.
- U.S. highways account for 40 percent of the route miles and 32 percent of the annual TMT.
- State highways account for 50 percent of the route miles and 20 percent of the annual TMT.



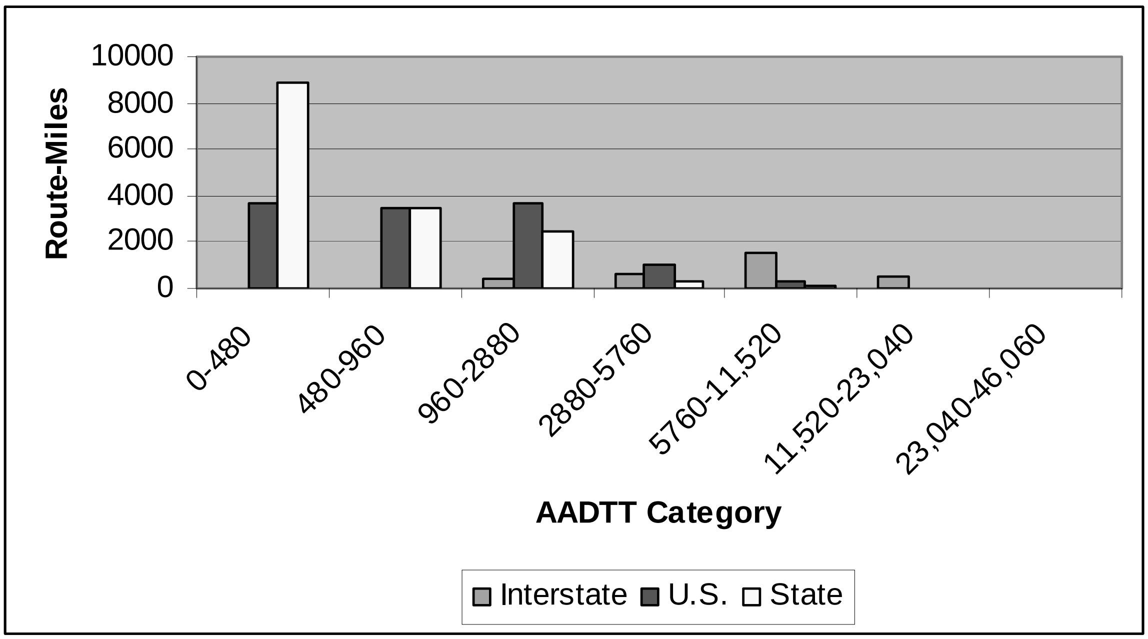
Data Source: TxDOT.

Figure 17. Texas Year 2000 Percent Truck Map.

Table 23. Route-Miles and Truck-Miles Traveled.

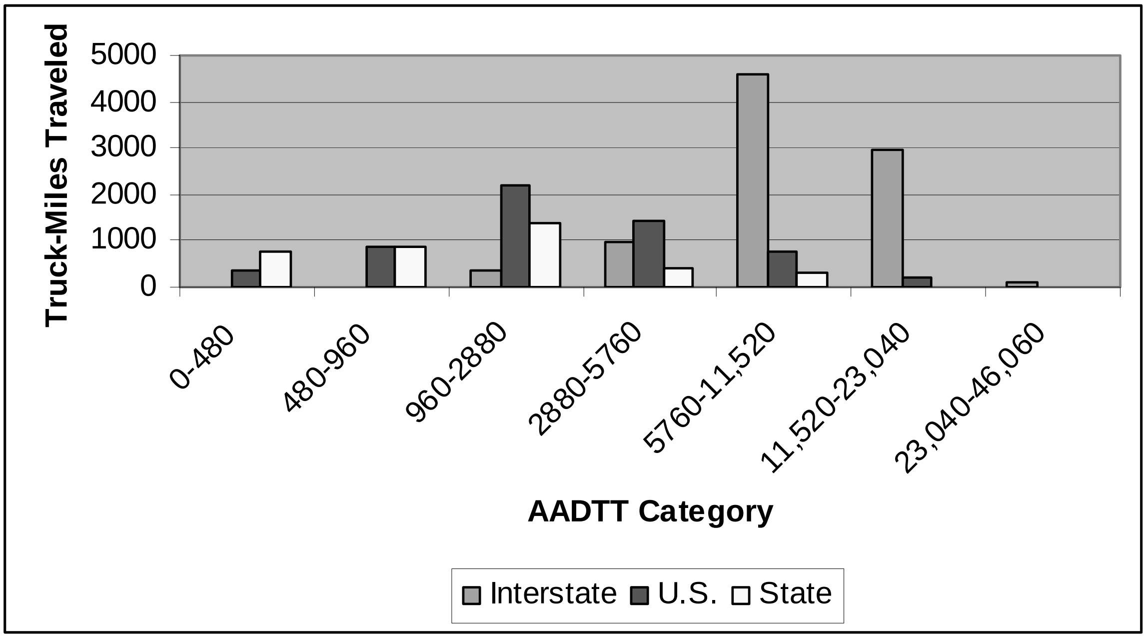
AADTT	Route Miles			Ann. Truck-Miles Traveled (Millions)		
Category	IH	U.S.	State	IH	U.S.	State
0-480	0.0	3635.2	8909.3	0.0	353.1	740.3
480-960	0.9	3505.5	3484.7	0.2	886.2	854.6
960-2880	443.9	3701.1	2441.6	381.3	2179.1	1364.0
2880-5760	656.8	983.8	300.1	992.5	1421.5	397.8
5760-11,520	1560.8	295.1	101.8	4602.5	780.0	284.3
11,520-23,040	558.8	40.1	0.0	2940.0	220.1	0.0
23,040-46,060	12.8	0.0	0.0	115.0	0.0	0.0
Total	3234.1	12,160.7	15,237.5	9031.4	5840.0	3641.0

Data Source: TxDOT.



Data Source: TxDOT.

Figure 18. Route-Miles Traveled by AADTT Category.



Data Source: TxDOT.

Figure 19. Truck-Miles Traveled by AADTT Category.

4.3.2.3 Directionality

Truck traffic often exhibits directionality characteristics – particularly through the course of a day. For example, petroleum trucks delivering product to retailers in rural areas will leave from a centralized distribution terminal for example in the early morning, deliver products at one or several locations, and return empty, possibly making several trips a day. So a general characteristic of their routing and scheduling is outbound in the morning, possibly with several trips through the day, returning empty in the evening. In a similar vein, the first truck traffic of the week moving from Dallas to California starts from Dallas on a Sunday, travels westbound on U.S. 270 connecting to I-40. Thus, one could expect to see concentrations of westbound truck traffic on I-40 on Sunday (but fairly light eastbound traffic). By Monday or Tuesday, one might observe heavy truck traffic originating in California destined for Dallas concentrating on I-40 in Texas in the eastbound direction. Strong directionality is also apparent at U.S./Mexican border points through the course of a day. For example, at Brownsville, truck traffic tends to peak during the morning periods for southbound movements, and peaks during the afternoon periods for northbound movements.

While directionality details obviously change from route to route, circumstance to circumstance, and through the course of the year, it is important to recognize that directionality considerations of truck traffic (by time of day and/or day of week) can have important effects on geometric requirements of particular routes, as well as important effects on flow quality and the performance of a traffic stream in shorter time intervals (i.e., 15-minute peaks, hourly, etc).

4.3.2.4 Temporal Variations in Truck Traffic

Three variations in the temporal characteristics of traffic are of general interest to analysis and design. These are seasonal (monthly), day-of-week (often grouped by weekday versus weekend), and time-of-day. The research team used the following four databases to analyze these temporal characteristics:

- TxDOT vehicle classification report for 2000,
- TxDOT AVC report for southern Texas 2000,
- TxDOT short-term vehicle classification raw data, and
- U.S. Customs truck traffic database for Texas-Mexico truck movements.

The short-term traffic count system currently used in Texas does not permit system-wide analysis of the seasonality of truck movements. It only conducts annual 48-hour classification counts at about one-third of some 1200 count locations located throughout the state, facilitating vehicle classification analysis and time of day analysis but not seasonal analysis. However, the special AVC continuous count program conducted in south Texas *(16)* does permit consideration of the seasonality issue for the area represented by the data. Figure 20 shows the locations of these 25 AVC stations. Appendix C includes summary findings concerning the seasonality of truck traffic at these 25 sites covering monthly Class 7 and up truck traffic at available border AVC stations. Key findings are:

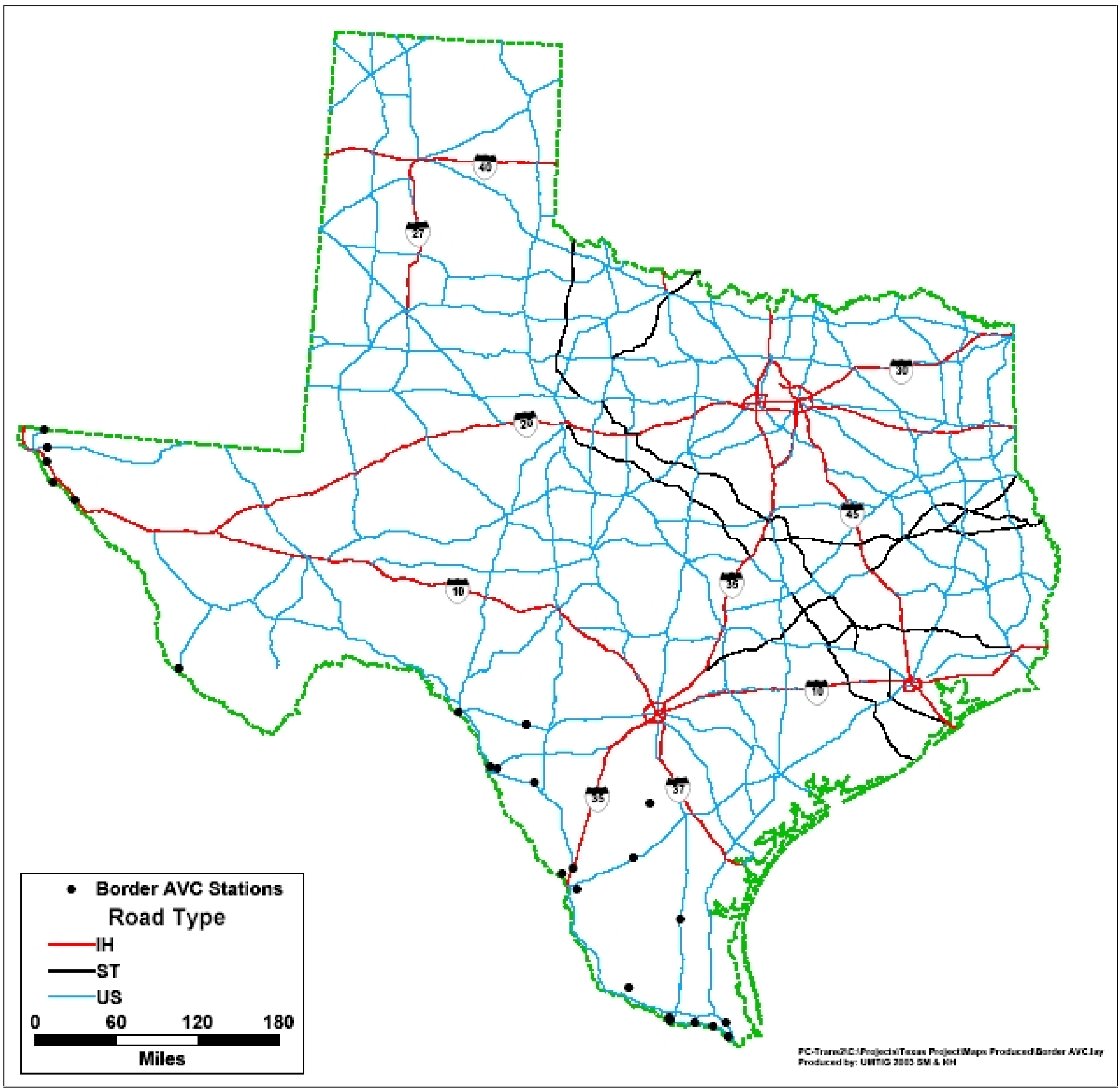
- There is limited observed seasonal variation in truck traffic.
- Crossings at Laredo (I-35) and El Paso (I-10) account for half of the total monthly truck volumes.
- The lower Rio Grande valley accounts for 15 percent of the border crossing truck activity (although U.S. Customs counts show the figure to be 23 percent).

As with the seasonality issue, the short-term count program does not permit day of week analysis of truck traffic variations, but the count program at the 25 permanent AVC sites does (for that region). Summary findings concerning the day-of-week distribution of truck traffic at these 25 sites are:

- The highest levels of truck traffic are observed Monday to Friday.
- Truck traffic levels on Saturday and Sunday are reduced 25-50 percent on average.

Analysis of the time-of-day distribution of truck traffic in Texas was limited to Interstate highways only. Section 4.3.2.2 developed categories of standard AADTT ranges. Figure 21 shows sections of Texas Interstates experiencing AADTT levels in each of the respective categories. Analyzing the TxDOT short-term classification count program for time-of-day variations followed this procedure:

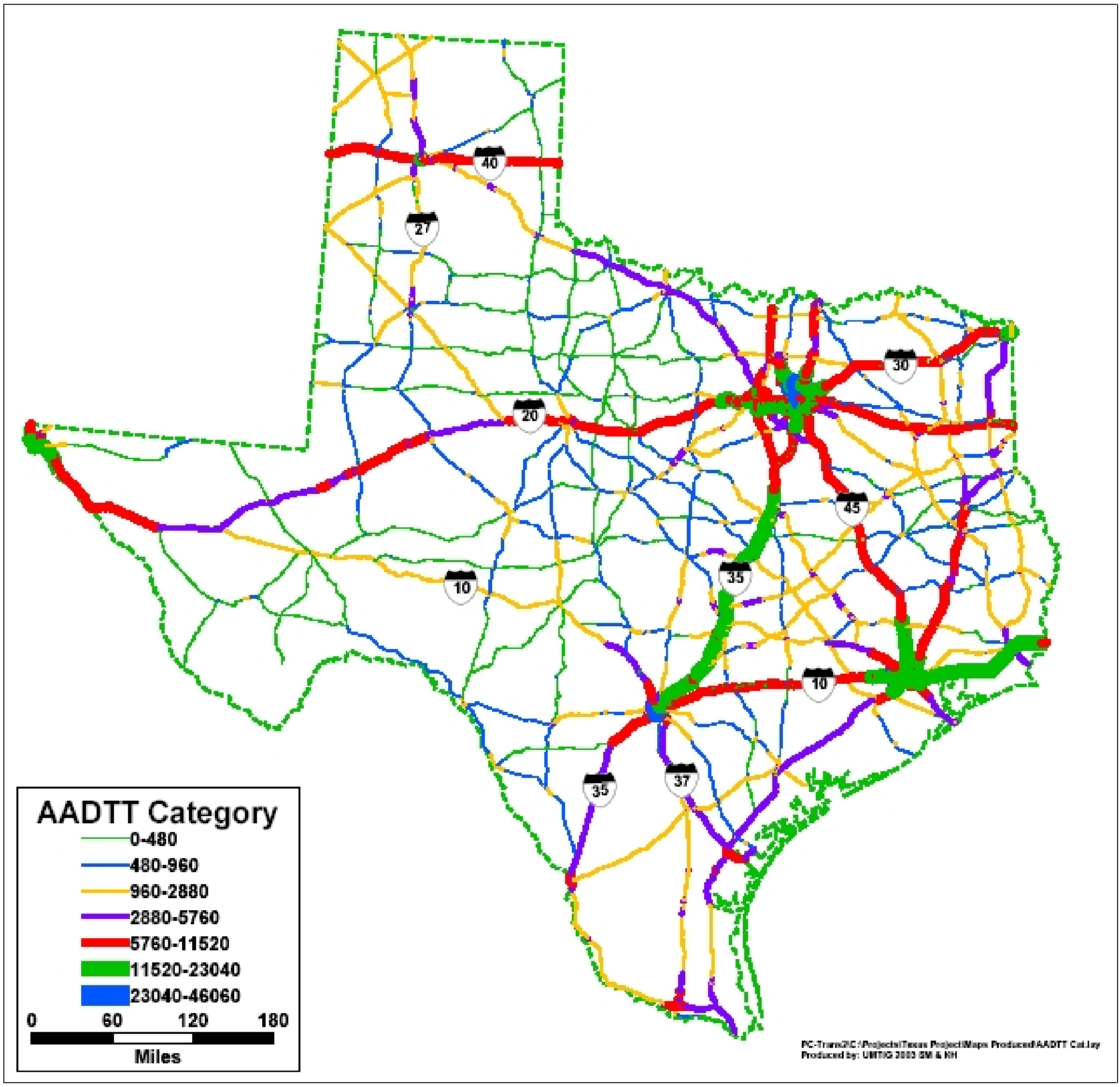
- Analysts extracted traffic data in 4CD format and placed the data in a non-relational database.
- The next step was linking the database directly to the GIS Platform Texas Highway Inventory.



Data Source: TxDOT.

Figure 20. Border AVC Stations.

- Querying the now linked 4CD traffic data by AADTT range followed for selected Texas Interstate highways.
- The final step was aggregating the two-day or 48-hour count and plotting by station.



Data Source: TxDOT.

Figure 21. Texas Highway AADTT Categories.

Key findings are:

- Truck traffic volumes are greatest between 6:00 a.m. and 6:00 p.m.
- Percent truck traffic is greatest between 6:00 p.m. and 6:00 a.m.
- Percent truck traffic increases by 150 to 200 percent between 6:00 p.m. and 6:00 a.m.

- Truck traffic volumes decrease by 30 to 50 percent between 6:00 p.m. and 6:00 a.m.

In general, observations about temporal distributions are *(16)*:

- Seasonal variations are low (±15%).
- Variations between weekdays are low.
- Variations between weekdays and weekends are high (±50%).
- Proportion of truck traffic of total traffic varies greatly through the day.

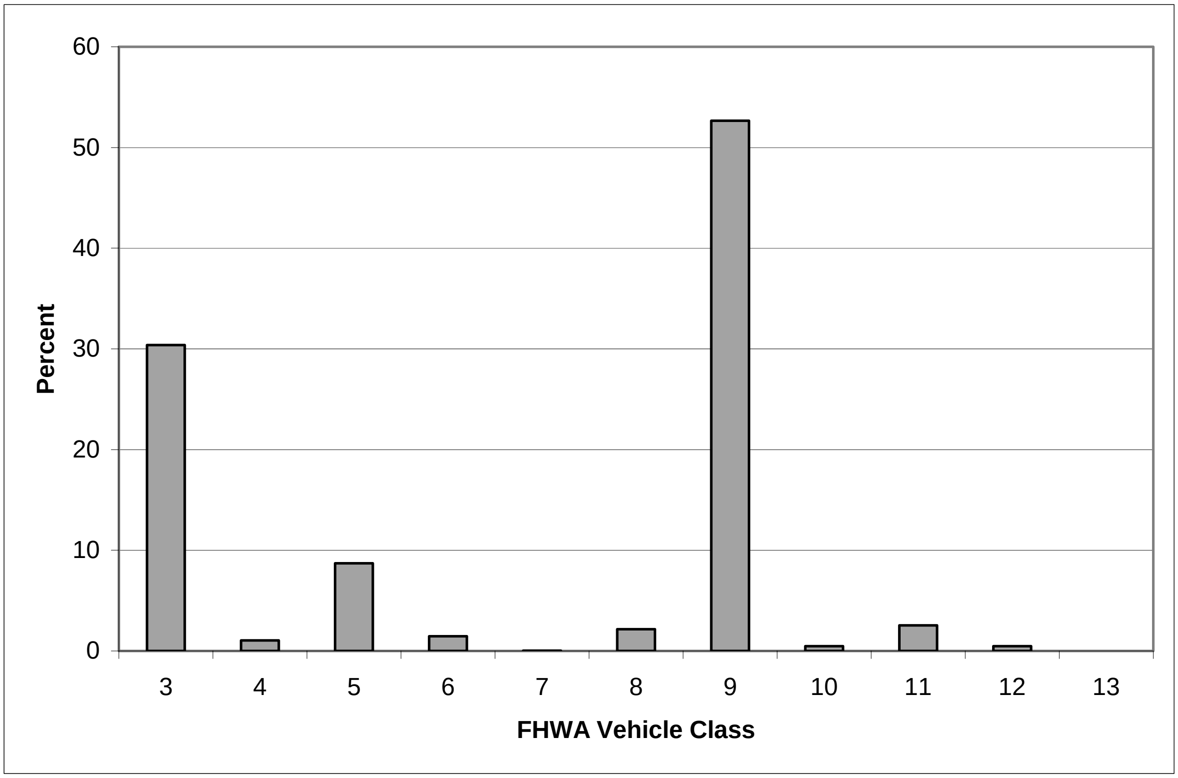
4.3.2.5 Fleet Mix Considerations

Figure 22 shows the percent vehicle class on selected Interstate highways for the 125,723 Class 3 and up vehicles classified at sites described by Table 24. Key observations for the Class 3 to 13 fleet are as follows:

- Forty-two percent of the fleet is Class 3 to 7; of these, 70 percent is Class 3 vehicles (2-axle, 4-tire single units).
- Fifty-five percent of the fleet is Class 8 to 10; of these, 95 percent is Class 9 vehicles (3-S2).
- Three percent of the fleet is Class 11 to 13; of these, 80 percent is Class 11 vehicles (2-S1-2).

This distribution of northbound truck traffic among ports-of-entry in 2001 was very similar to that experienced in 2000 (with maybe a slight shift from Brownsville to Pharr). Based on Texas Center for Border Economic and Enterprise Development (TCBEED) statistics (excluding El Paso for which no figures are given), truck flows in the southbound direction in 2001 were generally balanced with the above northbound flows over the course of a year. Principal exceptions were Brownsville and Pharr, with both experiencing a slight directional imbalance of 55 percent northbound and 45 percent southbound *(17)*.

Based on data from the Bureau of Transportation Statistics, northbound truck movements for 2001 were fairly stable through the year. For all crossings combined, Table 25 shows that the average daily northbound movement was 7964 trucks per day, with the seasonal distribution as indicated *(18)*.



Source: Reference (19).

Figure 22. Texas Fleet Mix on Selected Interstate Highways.

Table 24. Description of Sites Used for Fleet Mix.

Highway	AADTT	2CD Station	GIS Station	Directions	Description
I-10	960-2880	01F	M-173A	3,7	I-10 E of Ft. Stockton
I-10	960-2880	14	MS-14	3,7	6.0 Mi W of U.S. 277N Sonora
I-10	960-2880	217	MS-217	3,7	1.0 Mi W of U.S. 83S Junction
I-10	960-2880	518	LW-518	3,7	I-10 W of S.H. 27 West
I-27	960-2880	11E	M-1223	4,8	I-27 N of Tulia
I-27	960-2880	90E	L-16	1,5	I-27 N Lubbock Co Line
I-20	2880-5760	04F	M-1660	2,6	I-20 SW of Pecos
I-20	2880-5760	519	LW-519	3,7	I-20 W of Colorado City
I-37	2880-5760	512	LW-512	1,5	I-37 N of Three Rivers
I-37	2880-5760	54	MS-54	4,8	0.5MI SE of U.S. 59 George West
I-30	5760-11,520	13S	M-1940	3,7	I-30 W of Mt. Pleasant
I-30	5760-11,520	509	LW-509	3,7	I-30 E of Greenville
I-30	5760-11,520	05S	M-1065	3,7	I-30 W of Texarkana
I-40	5760-11,520	13D	M-1723		I-40 E of U.S. 385 Vega
I-40	5760-11,520	198	M-1741		8.7 Mi W of U.S. 83 Shamrock
I-40	5760-11,520	218	MS-218		0.4 Mi E of U.S. 287 Amarillo
I-10	11,520-23,040	964	Hp-964	3,7	I-10 W of Orange

Data Source: TxDOT.

Table 25. Northbound U.S./Mexico Truck Movements in 2001.

Month	ADTT in Month	Percent of AADTT	
		2001	2002
January	7719	97	92
February	8113	102	107
March	8241	103	107
April	7765	98	95
May	8347	105	105
June	8108	102	107
July	7460	94	94
August	8364	105	111
September	7744	97	101
October	8572	108	103
November	8072	101	97
December	7281	91	83
AADTT	7964	NA	NA

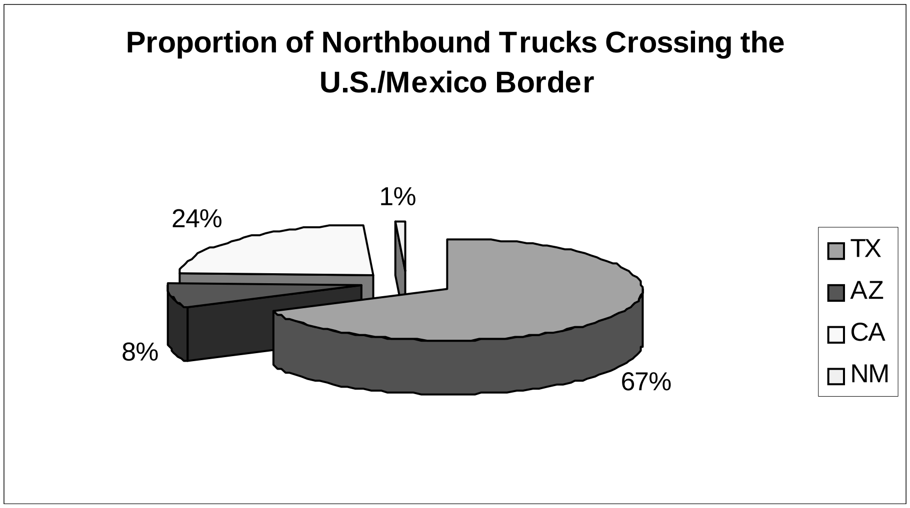
Source: Reference (17).

4.3.2.6 Truck Movements across the U.S./Mexico Border

There were significant increases in trucking activity to/from, along and across the Texas/Mexico border through the 1990s. This has been accompanied with, and influenced by, investments in highway and border crossing infrastructure, including major new bridge facilities catering to commercial vehicle movements at Brownsville, Los Indios, Pharr, Laredo, and El Paso. Other new commercial crossing facilities are being planned, while other existing facilities are being upgraded. Many of these developments have taken place in the last five or so years. Several have effected major changes in truck traffic characteristics and patterns along the border, and much more change can be expected. Key facts and trends about past and current truck movements across the border are summarized below.

Texas/Mexico Movements versus Total U.S./Mexico Movements. Figure 23 and Table 26 provide information on northbound (Mexico to U.S.) truck movements in 2001 by border crossing. Of the 4.3 million truck movements, Texas accounted for 67 percent, California for 24 percent, Arizona 8 percent, and New Mexico less than 1 percent. The 2001 movement was 5 percent less than that experienced in 2000 *(19)*.

In 2001, all seasonality factors were less than ±10 percent of the AADTT, with October being the highest (108 percent) and December being the lowest (91 percent). Comparatively, in 2000, most seasonality factors were less than ±10 percent of the AADTT, with the two exceptions being August (111 percent) and December (83 percent). Seasonal peaking is more intense at individual crossings, however, as shown in Table 27 (based on 2001 northbound statistics).



Data Source: TxDOT.

Figure 23. Northbound Truck Proportions by State.

Table 26. Trucks Entering the U.S. from Mexico.

Border Facility	U.S. Customs Operations Hours		FY2001 Commercial Vehicle Entries	
	Per Week	Per Weekday (Mon-Fri)	Value	Rank
Laredo-World Trade	96	16	1,151,387	1
Otay Mesa	86	14	700,453	2
Pharr	96	16	367,991	3
El Paso-BOTA	88	12	334,768	4
El Paso-Ysleta	88	16	321,489	5
Laredo-Colombia	96	16	267,778	6
Calexico East	77	14	259,174	7
Nogales West	66	11	251,474	8
Brownsville-Veteran's	96	16	205,589	9
Eagle Pass	90	16	100,983	10
Tecate	40	8	62,243	11
Del Rio	73	13	59,286	12
Brownsville-Los Indios	81	13	49,642	13
San Luis	48	8	39,908	14
Douglas	42	8	34,054	15
Santa Teresa	55	10	30,612	16
Rio Grande City	105	17	26,391	17
Progreso	40	8	16,649	18
Roma	40	8	12,141	19
Naco	40	8	9976	20
Presidio	45	9	7562	21
Lukeville	48	8	4271	22
Columbus	44	8	4239	23
Sasabe	54	9	2215	24
Andrade	45	9	1727	25

Source: Reference (18).

Table 27. Port-of-Entry Seasonal Factors.

Port-of-Entry	AADTT Northbound	Seasonal Factor (percent)	
		High	Low
Laredo	3846	Oct – 111	Dec – 89
El Paso	1810	Oct – 107	Jul – 83
Pharr	1009	Mar – 113	Dec – 88
Brownsville	689	Aug – 111	Dec – 85
Eagle Pass	268	May – 109	Dec – 78
Del Rio	164	Aug – 113	Mar – 78
Rio Grande City	70	Jan – 129	Jul – 81
Progreso	54	Oct – 133	May – 67
Roma	33	Aug – 109	Dec – 79
Presidio	19	Apr – 137	Jul – 68

Source: Reference (17).

In summary, seasonality factors related to the northbound movement of trucks from Mexico to Texas have monthly ADTT values that are less than ±10 percent different from the AADTT. This represents mild seasonal fluctuations in northbound truck traffic across the border as a whole. Also, as the crossing volume decreases, the intensity of seasonal variations increases, but the absolute number of "peaking" trucks per day becomes quite small. For example, at Del Rio, the 113 percent August peak translates into 21 additional trucks per day northbound during this month than during the average day. Comparatively, the same 113 percent peaking factor at Pharr translates into an additional 131 trucks per day northbound compared to the average day at this crossing.

Currently, commercial border crossing facilities and services are typically closed between midnight and 6:00 a.m. This scheduling factor affects time-of-day distributions of truck traffic in and around, and traveling to/from and across the border crossing centers. In personal interviews, officials at some border crossing facilities indicated that even during the open hours of the facility, there could be substantial fluctuations in truck movements. These fluctuations are typically beyond the control of facility operators. For example, there may be a period of no northbound demand for three hours at a particular facility, and then a rush of 300 trucks waiting to cross into the U.S. Such fluctuations are often unpredictable and uncontrollable. This phenomenon can cause substantial concentrations of truck border traffic in short random time periods during the day.

4.3.2.7 Specially Permitted Overweight Movements to the Port of Brownsville

Since March 1998, the Port of Brownsville has issued special overweight permits for truck movements between the port and the Veterans International Bridge at Los Tomates or the Gateway International Bridge using S.H. 4 and S.H. 48 or "the most direct route." Using a single-trip permit at a cost of $30 per one-way trip, trucks can exceed the legal weight limits by the following specified amounts:

- Tire weights are limited to 650 pounds per inch of tire width.

- Axle weights are limited to (assuming adequate tires):
  - 13,000 pounds on steering axles (with 2-10 inch tires),
  - 25,000 pounds on singles,
  - 46,000 pounds on tandems, and
  - 60,000 pounds on tridems.

- The gross vehicle weight is limited to:
  - 105,000 pounds on 3-S2s,
  - 119,000 pounds on 3-S3s, and
  - for other configurations, tandem limit is 46,000 lb and tridem limit is 60,000 lb.

Truck configurations typically using these permits are 5-axle tractor semitrailer combinations (3-S2s), six-axle tractor-semitrailer combinations (3-S3s), and since quite recently eight-axle tractor double trailer combinations (3-S3-S2 Mexican B-trains). Commodities handled under these permits include steel (the dominant commodity), scrap, grain, and petroleum. Most (90 percent) of these permits are issued for southbound movements of freight from the Port of Brownsville to Mexico (principally Monterrey). Table 28 provides information on the number of permits issued per year.

Table 28. Overweight Permits Issued by the Port of Brownsville.

Year	No. Permits Issued	Revenue
1998	28,699	$ 860,970
1999	32,135	$ 964,050
2000	34,411	$1,032,330
2001	32,526	$ 976,380
2002	28,108	$1,719,071

Source: Port of Brownsville.

For the three years ending in 2001, these figures translate into 90 permits per average day, ranging from 66 permits per day in the lowest month to 112 permits per day in the highest month. Officials advise that there are about 30 Mexican carriers that utilize these permits on a regular basis. These specially permitted operations account for about 13 percent of truck movements across the Veterans International Bridge.

4.4 ANTICIPATED CHANGES IN TRUCK TRAFFIC

4.4.1 Truck Forecasts for Specific Corridor Proposals

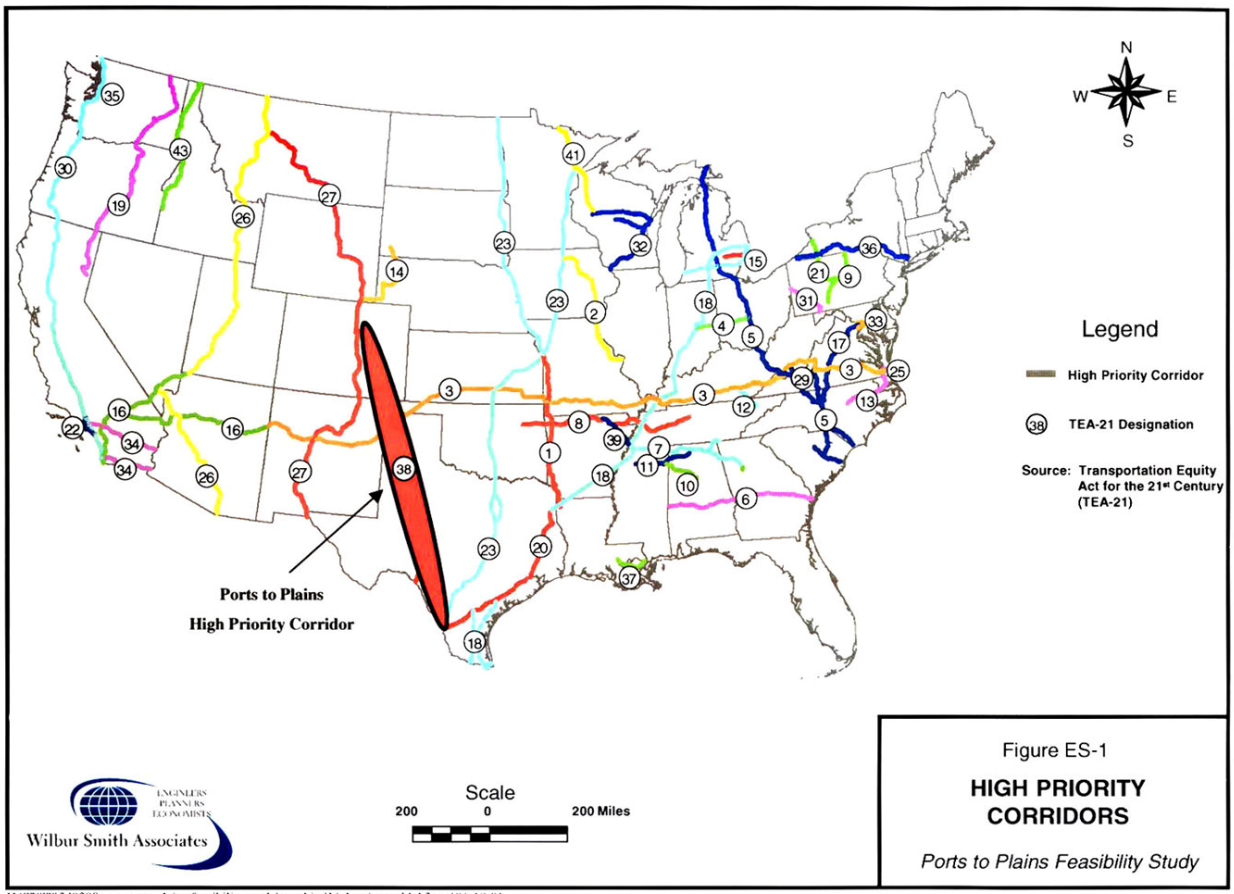
There are six high priority corridors designated in TEA-21 passing through Texas. These corridors are as follows:

- Corridor 3 (I-40 etc.);

- Corridor 18 (southeast and northeast Texas, part of proposed I-69);

- Corridor 20 (part of proposed I-69);
- Corridor 23 (I-35/29 Mid-Continent Corridor);
- Corridor 27 (to El Paso); and
- Corridor 38 (Ports-to-Plains).

Figure 24 illustrates these high priority corridors *(20)*. This section summarizes truck forecast information presented in readily available studies for three of these proposed projects—the I-69, the I-35, and the Ports-to-Plains corridors.



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Source: Port- to-Plains Study, Reference (20)

Figure 24. High Priority Corridors.

4.4.1.1 The I-35 Corridor

The purpose of the I-35 study "was to assess the need for improved local, intrastate, interstate, and international service on I-35 and to clearly define a general feasible improvement plan to address those needs." The study outlines a recommended investment strategy for the corridor, the purpose of which is to guide future, potential improvements *(21)*. The recommended strategy is called the Trade Focus Strategy (Alternative 4). This strategy included special provisions to accommodate truck traffic between Dallas-Fort Worth and Laredo. The need for these recommended provisions arose from the study's forecasted truck traffic for the corridor. The strategy envisages provision of a NAFTA Truckway (with larger truck sizes and weights) where their implementation could result in lane savings on I-35. Two truckway options were considered possible— 1) a separate facility and 2) a truckway within the existing I-35 right-of-way (ROW) *(21)*. The strategy assumes the truckway is located within the I-35 ROW for environmental and cost purposes. The alternative also assumes incorporating comprehensive ITS-CVO (commercial vehicle operations) facilities/services, and pre-clearance centers for customs activities.

The study presents the following ideas about potential new truck technology and truckway design features. For truck technology options, the new concept truck being developed by Freightliner Corporation and Wabash National has increased volumetric capacity 17 percent while keeping within legal size limits *(21).* Another concept assumed in the I-35 study is that longer combination vehicles would be permitted throughout the total length of the corridor.

For truckway design features, the concept of automated highway systems (AHS) will probably come to fruition. The basic concept would involve in-vehicle and roadside technologies to allow vehicles to operate automatically and safely at very high speeds and at closer headways than would be feasible with manual operation. Research and development programs are underway involving electronically-equipped vehicles that would operate on dedicated instrumented lanes. AHS technologies that are being developed can be combined to develop a super highway. With regard to freight transportation, the concept incorporates super truckways with special design enhancements for longer combination vehicles.

The super highway and truckway concept includes design requirements that fit the design speed and are substantially different from conventional Interstate highways. Some of the design features of a fully automated super highway are listed below *(21)*.

- Design Speeds: as high as 150 mph in flat terrain down to 75 mph for non-instrumented lanes.
- Cross-Section: Two conventional lanes in each direction for mixed non-automated vehicles, plus an instrumented AHS lane for passenger cars and a separate instrumented lane for trucks.
- Bridge Design Standard: HS-20.
- Interchange Spacing: No closer than 20 miles apart.

- ITS Features: Separate, fully automated lanes for passenger cars and trucks, including automatic merge/diverge, vehicle platoon stabilization, automatic emergency override and destination selection/routing.

  Additional truckway design features would include the following:

- pavements and bridges designed for heavier loads,
- maximum grade of 3 percent,
- longer acceleration and deceleration ramps at interchanges,
- wider pavement and flatter turning radii at interchanges, and
- additional space at rest areas.

Table 29 shows the projected daily truck volumes (including single, semi and multi-trailer trucks) in 2025 for the Texas portion of the I-35 recommended strategy. For comparison, Table 30 shows equivalent 1996 traffic volume estimates on the same sections.

Table 29. Projected Daily Truck Volumes on Rural Sections of the I-35 Corridor.

Section	2025 Truck Volume on I-35			Volume on Truckway Lanes	All Vehicles
	International	Other	Total		
Laredo – San Antonio	3700	600	4300	3400	12,400
San Antonio – Austin	3350	14,750	18,100	14,200	82,100
Austin – Waco	3010	11,590	14,600	11,400	69,100
Waco – Dallas	3050	6250	9300	7300	41,600
Dallas – Ok. City	610	9490	9900	NA	42,200

Source: Reference (21) (taken directly from Table S-3).

Table 30. 1996 Traffic Volumes on Rural Sections of the I-35 Corridor.

Section	1996 Truck Volume on I-35			All Vehicles
	International	Other	Total	
Laredo – San Antonio	2440	345	2785	8400
San Antonio – Austin	1880	6834	8714	49,000
Austin – Waco	1875	7981	9856	38,000
Waco – Dallas	1690	2447	4137	16,100
Dallas – Ok. City	340	4497	4837	21,000

Source: Reference (21) (taken from Figure IV-1 and IV-3).

Table 31 shows the annual average (compounded) growth rates for international and total truck traffic on the respective links using these values.

Table 31. 1996-2025 Truck Traffic Growth Rates on I-35 Corridor.

Section	Derived Approximate Average Annual Growth Rates (%) for Truck Traffic: 1996 to 2025 (assume 25-yr period)	
	International	Total
Laredo – San Antonio	2.0	2.0
San Antonio – Austin	2.5	3.0
Austin – Waco	2.0	2.0
Waco – Dallas	2.5	3.0
Dallas – Ok. City	2.5	3.0

Source: Reference (21) (derived from Tables 28 and 29).

As another comparison, the Ports-to-Plains report *(20)* shows the following truck traffic volumes on the Laredo to San Antonio link. In 1998, the AADTT was 4200 trucks per day, and the prediction on AADTT in 2025 is 6750 trucks per day. This also implies an approximately 2 percent increase per year compounded.

In summary:

- International truck traffic accounts for about 85 percent of all truck traffic between Laredo and San Antonio—both in the base year and forecast year of 2025.
- International truck traffic accounts for about one-fifth of all truck traffic between San Antonio and Waco—both in the base year and the forecast year of 2025.
- International truck traffic accounts for between one-third and 40 percent of all truck traffic between Waco and Dallas through the study period.
- International truck traffic accounts for about 7 percent of all truck traffic north of Dallas/Forth Worth to the Oklahoma border throughout the study period.
- International truck traffic is assumed to increase at 2 to 2.5 percent per year through 2025 along the I-35 corridor in Texas, whereas total truck traffic is assumed to increase at 2 to 3 percent.

4.4.1.2 The Proposed I-69 Corridor

The I-69 proposal is part of High Priority Corridor 18 defined in ISTEA 1991. Corridor 18 refers to existing I-69 between Port Huron, Michigan and Indianapolis, and its proposed extension from Indianapolis to the Lower Rio Grande Valley (LRGV) serving Houston. In the LRGV, it incorporates the following elements *(4)*:

- U.S. 77 from the Mexican border at Brownsville to U.S. 59 in Victoria, Texas;

- U.S. 281 from the Mexican border at McAllen to I-37, then following U.S. 59 to Victoria Texas;

- The Corpus Christi Northside Highway and Rail Corridor from the intersection of U.S. 77 and I-37 to U.S. 181; and

- FM 511 from U.S. 77 to the Port of Brownsville *(4).*

Issues enunciated in Reference *(4)* that are of specific interest to the trucking focus of this project are:

- The development would provide a continuous highway link designed to Interstate highway standards.

- There is a "high demand for NAFTA associated goods movements," but this source goes on to state that "short to medium trips far outnumber international traffic along the corridor."

- By diverting local and regional trips to the proposed improved facility, adjacent roads "will likely see a drop in overall traffic."

- The I-69 alignment "more directly serves a major portion of … NAFTA and international travel demand."

- The I-69 southern terminus provides "an important" linkage to Monterey and beyond in Mexico.

- I-69 in Texas would provide traffic relief on I-35 – particularly between Laredo and San Antonio.

- Reduced transport costs and improved travel times resulting from the project "can be expected to attract significantly more economic production activities" along the corridor.

Key truck traffic issues/estimates enunciated in Reference *(4)* of specific interest to the trucking focus of this project are:

- Table 32 shows the AADT and AADTT forecasts for 2020. For all alternatives, forecasted truck traffic for the year 2020 is the same on the common portions of U.S. 59 (at the extremities of the Houston District).

- Of the forecasted AADTT values, 1900 trucks involve through movements between U.S. 59 (S) and U.S. 59 (N) *(4).* One of the alternatives considered in the Houston District Study (West Alternative) would divert 74 percent of this through movement around the downtown area.

Table 32. AADT and AADTT Forecasts on I-69.

Location	AADT	AADTT	Percent Trucks
Leaving the district on U.S. 59 to the northeast	48,000	7600	16
Leaving the District on U.S. 59 to the southwest	56,000	10,900	19

Source: Reference (4).

- The highest AADTT forecast in this study for U.S. 59 is 45,000 (near the downtown area). This (presumably) includes a large volume of small (Class 3 and Class 4) trucks.

- "The impacts of NAFTA are gradually becoming evident in the Houston area" as summarized below in Table 33 *(4):*

Table 33. Forecast of NAFTA Daily Truck Trips on I-69.

Location	1996 truck trips per day	2020 truck trips per day
U.S. 59 southwest of Houston	500	3100
I-10 west of Houston	1700	Not Given

Source: Reference (4).

- Through traffic volumes along all alternatives represent only a small percentage (less than 1 and up to 6 percent) of all traffic due to the large number of local trips in the Houston metropolitan area.

- Study findings indicate that I-69 will attract some NAFTA traffic away from the I-35 corridor, although it does not provide specifics *(4)*.

4.4.1.3 The Ports-to-Plains Corridor

This corridor proposal considers a continuous four-lane highway between Denver and the Mexican border at Del Rio/Eagle Pass/Laredo. There are four distinct sections in the corridor, some with alternative alignments. The following compares the current and forecasted (year 2025) truck traffic movements (AADTT) on major links in each section with the "existing and committed" (E + C) highway network. The following data were derived from Figure 4-3 in the Ports-to-Plains Feasibility Study *(20)*.

In summary, this study assumed the following truck growth rates:

- for corridor highways U.S. 87 and IH-27 north of Lubbock, about 1.5 percent;

- for corridor highways U.S. 97, 84, 70, and 277 between Lubbock and San Angelo, about 1.5 to 2.0 percent;

- for corridor highway U.S. 277 between San Angelo and Del Rio/Eagle Pass, about 1.5 to 2.5 percent; and

- for corridor highway U.S. 83 south of I-10 to Carrizo Springs and Laredo, about 4.0 percent.

- **Northern Section – Denver to Amarillo**

  Alt. N1 – I-25 (Denver-Raton) U.S. 87 (Raton-Dumas)/U.S. 87 (Dumas – Amarillo)

	1998	2025 (E+C)	F/P Factor	Approx *i%*
U.S. 87 (Texline-Dalhart)	850	1224	1.44	1.5
U.S. 87 (Dalhart-Dumas)	1140	1596	1.40	1.5
U.S. 87 (Dumas-Amarillo)	2706	4095	1.51	1.5

  Alt. N4 – I-70 (Denver-Limon)/U.S. 287/87 (Limon-Amarillo)

	1998	2025 (E+C)	F/P Factor	Approx *i%*
U.S. 287 (Stratford-Dumas)	1200	1736	1.45	1.5
U.S. 87 (Dumas-Amarillo)	2706	4095	1.51	1.5

- **North Central Section – Amarillo-Lubbock**

	1998	2025 (E+C)	F/P Factor	Approx *i%*
I-27 (Amarillo-Lubbock)	1750	2500	1.43	1.5

- **Middle Section – Lubbock to San Angelo**

  Alt S7A, S7B, S8 – via U.S. 87

	1998	2025 (E+C)	F/P Factor	Approx *i%*
U.S. 87 (Lubbock-Lamesa)	720	1005	1.40	1.5
U.S. 87 (Sterling-S. Antonio)	1037	1860	1.79	2.0

  Alt S10A and S10B – via US 84, 70, and 277

	1998	2025 (E+C)	F/P Factor	Approx *i%*
U.S. 84 (Lubbock-Sweetwater)	1472	2484	1.69	2.0
U.S. 277 (Sweetwater-S.Antonio)	588	912	1.55	1.5

- **Southern Section – San Angelo to Del Rio/Eagle Pass/Laredo**

  Alt S7A, S7B, S7C, S10A, S10B – via U.S. 277 (to Carizo Springs) and U.S. 83 (to Laredo)

	1998	2025 (E+C)	F/P Factor	Approx *i%*
U.S. 277 (I-10 – Del Rio)	363	500	1.38	1.5
U.S. 277 (Del Rio – Eagle Pass)	529	1104	2.09	2.5
U.S. 83(Carizo Springs-Laredo)	576	1680	2.92	4.0

  Alt S8 – via U.S. 87 (to Eden) and U.S. 83 (to Laredo)

	1998	2025 (E+C)	F/P Factor	Approx *i%*
U.S. 83 (I-10 – Uvalde)	252	756	3.00	4.0
U.S. 83 (Carizo Sp. – Laredo)	576	1680	2.92	4.0

The study determined that a continuous four-lane highway along the complete corridor was not feasible, but it does identify other potential improvements including additional truck climbing lanes, intersection improvements, ITS measures, and consideration of relief routes in corridor towns/cities *(20)*.

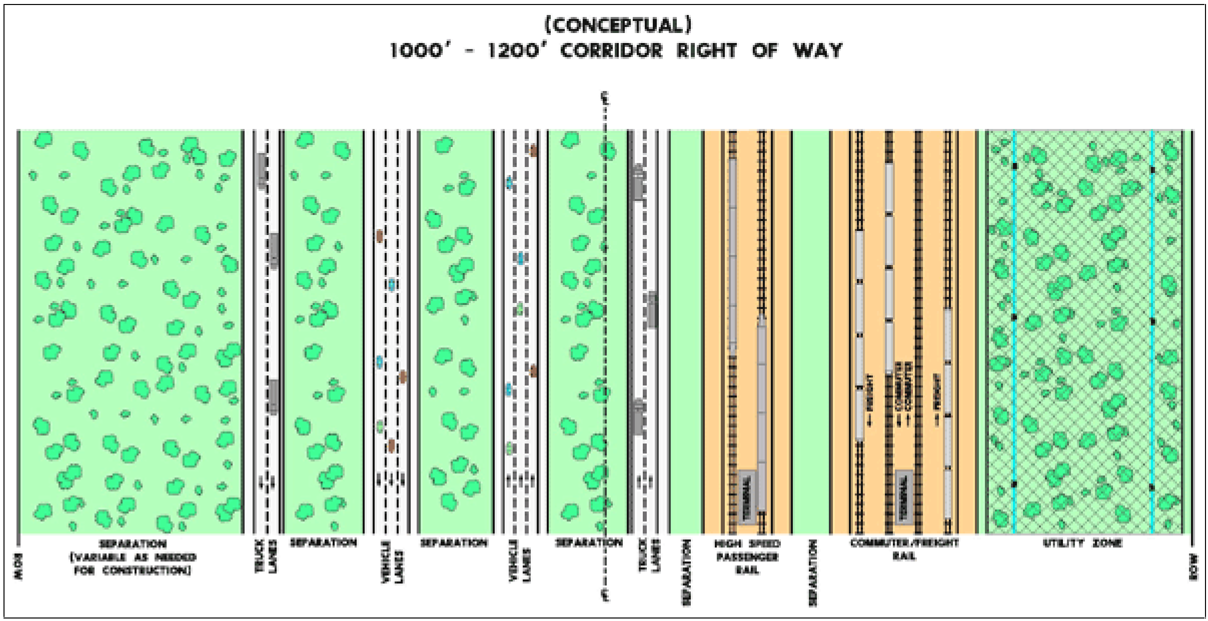
4.4.1.4 Trans Texas Corridor

One of the most revolutionary ideas for transportation in Texas and the largest engineering project ever proposed is the Trans Texas Corridor. It is a concept that will connect Texas and other states with a 4000-mile network of corridors up to 1200 ft wide with separate lanes for passenger vehicles (three in each direction) and trucks (two in each direction). The corridor as currently conceived will also include six rail lines (three in each direction), one for high-speed freight and one for conventional commuter and freight trains. There will also be a 200-ft wide dedicated utility zone. Figure 25 represents the general layout of these facilities.

The truck lanes and separate truck roadways would have the following geometric and structural features:

- 13 ft lane width (versus 12 ft for the passenger lanes),
- 12 ft outside shoulder width (versus 10 ft),
- 4 ft inside shoulder width (versus 10 ft),
- 80 mph operating speed on tollways, and
- significant load-carrying capacity on truck lane pavements only.

Researchers identified four corridors as priority segments; they will parallel I-35, I-37, and I-69 (proposed) from Denison to the Rio Grande Valley, I-69 (proposed) from Texarkana to Houston, and I-10 from El Paso to Orange. The Trans Texas corridor will connect to major cities while not sending traffic directly through them, and its design will take advantage of ITS. Development will occur in phases through several scenarios. For example, the plan might build the truck lanes first (two in each direction), requiring that they be shared initially by both cars and trucks. As traffic volumes increase and additional capacity is warranted, separate passenger lanes would be constructed so that cars and trucks would then be separated on their own roadways *(22)*.



Source: Reference (22).

Figure 25. Concept Plan View of the Trans Texas Corridor.

CHAPTER 5. TRUCK DESIGN IMPROVEMENTS IMPLEMENTED ELSEWHERE

5.1 INTRODUCTION

The number of trucks on many highways in Texas and across the nation has increased to the point that special or unique roadway design treatments may be warranted. Increases in truck traffic have resulted from a robust domestic economy, increases in time-sensitive freight (e.g., just-in-time deliveries), and the North American Free Trade Agreement. As particular corridors have become increasingly dominated by truck traffic, or in locations where truck traffic might reasonably be segregated, questions have arisen regarding accommodations and treatments to address issues caused by truck traffic that may be appropriate for those corridors.

5.2 METHODOLOGY

The contents of this chapter come from a comprehensive literature search using Texas A&M University's Sterling C. Evans Library, the Internet, and a variety of other sources to identify pertinent sources of information pertaining to design accommodations for trucks. Following the literature search the research team contacted agencies for follow-up visits to supplement initial information. The Research Supervisor traveled to several locations, including U.S./Mexico border facilities, the New Jersey Turnpike Authority, and California Department of Transportation facilities built for trucks.

5.3 RESULTS OF LITERATURE SEARCH

The passage of the Surface Transportation Assistance Act in 1982 and the Tandem Truck Safety Act (TTSA) in 1984 established a national network of highways as a designated large truck network. These acts, as well as the subsequent deregulation of the trucking industry and the passage of the North American Free Trade Agreement, have all greatly impacted the number of trucks on the nation's roadways. Large trucks are the principal means for moving goods in urban areas, and the number of trucks in the traffic stream is anticipated to increase with the full implementation of NAFTA. The role of large trucks is vital to the nation's economics; however, the public perceives that the presence of large trucks has a significant impact on road safety. Both the STAA in 1982 and TTSA in 1984 established a national network of highways as a designated large truck network. The law is insistent that state regulations should not interfere with interstate truck movements, as long as the trucks conform to size and weight limits established by STAA and TTSA *(23)*.

The steady increase in the number of trucks is not the only concern to roadway engineers, policy-makers, and motorists. The differential in size between trucks and passenger vehicles creates an intimidating psychological barrier, if not an actual barrier. Trucks have slower braking and acceleration rates than passenger cars, which increases frustration to drivers in congested situations. Additionally, the lack of maneuverability of trucks relative to passenger cars contributes to crashes *(24, 25)*. Due to the large size and weight of trucks, truck crashes generally result in more severe injuries or fatalities than crashes that do not involve trucks. Truck crashes also receive greater publicity *(24).*

In a 1999 study, Harwood et al. *(26)* examined the ability of roadway systems to accommodate large trucks. The authors found that large truck accommodation is constrained by geometric design of certain roadway features and that the distribution of these features is critical in assessing the adequacy of the roadway for truck accommodation. These critical features include: horizontal curves and grades on mainline roads, horizontal curves on interchange ramps, curb return radii at interchange ramp terminals and at-grade intersections, and steep grades. The study also examined the amount of off-tracking and swept-path width that occurs when large trucks make a turning movement. The swept path width is the maximum distance determined by the difference in paths of the outside front tractor tire and the inside rear trailer tire.

Harwood et al. then looked at roadways in nine states —New York, Pennsylvania, Florida, Tennessee, Illinois, Missouri, Kansas, Washington, and California— to determine the ability of existing roadways to accommodate larger combination trucks. This portion of the study found that about 5 percent of interchange ramps had horizontal curves of 100 ft or less, while 20 percent of rural and 30 percent of urban ramps had radii of 250 ft or less *(26).*

In a companion report to the study on accommodating large trucks and the associated geometric constraints *(26)*, Harwood, Glauz, and Elefteriadou *(27)* examined the estimated costs of accommodating potential future trucks on the existing roadway systems. This study took into account the constraints imposed by geometric features and the swept path widths of larger vehicles, as well as staging areas that would be required to break down the larger combinations into a dimensional unit that could operate in metropolitan areas. Truck configurations examined in the study included tractor-semitrailer combinations with one 48-foot trailer; Rocky Mountain doubles, B-train doubles, turnpike doubles, and triples. The authors examined three networks in five regions (the Northeast, Southeast, Midwest, West, and California) of the continental United States. The networks examined consisted of:

- a limited network (19,000 miles) composed of primarily freeway facilities;
- an intermediate network (38,000 miles) consisting of most freeways and some primarily western non-freeway facilities; and
- an extended network (56,000 miles) consisting of freeway and non-freeway facilities *(27).*

The effort then sampled the same nine states noted above —New York, Pennsylvania, Florida, Tennessee, Illinois, Missouri, Kansas, Washington, and California—to estimate improvements required to accommodate the larger truck combinations as well as a baseline vehicle—a tractor semitrailer (48-foot) combination. The cost of accommodating the baseline vehicle was estimated to be $207 million, $553 million, and $653 million for the respective networks and the cost of accommodating future larger trucks on the existing roadway system would be even more substantial *(27).*

5.3.1 Strategies for Truck Accommodation

Strategies or treatments for trucks that extend for long distances along the mainline can be categorized into: 1) *lane restrictions*, and 2) *truck preferred or truck only facilities*, although the information found in the literature search and reported in this chapter uses varying terminology. There will be other terms used to be consistent with literature sources to describe these categories of treatments. A distinction on the second category is that in one case non-trucks are allowed to use the facility, but sources are not always clear to what degree non-trucks are "encouraged" to use or not to use such facilities. The reader will see such other terminology as exclusive use lanes, separation and bypass lanes, and dual use lanes. This chapter treats *bypass facilities* in a separate section from the two extended length treatments noted above; they typically serve a short distance need for trucks to improve safety and operations near interchanges. One of the critical issues that must be addressed, especially in exclusive truck facilities, is public perception.

"Truck-only" facilities have not been successful except in rare instances for reasons of cost, public perception, and only a very small percentage of the total freeway mileage in the U.S. has the truck volumes to justify the need. The public must be able to observe reasonably full utilization of a facility that it believes it subsidizes, but is restricted from using. Underutilized high-occupancy vehicle (HOV) facilities have experienced a similar response over the past few years. Currently operating truck preferred facilities demonstrate considerable merit because passenger vehicle drivers have a choice. If the truck facility is more congested than the car facility, then auto drivers choose the car facility, and if the truck facility is less congested, passenger vehicle operators can go there. The size and maneuverability of cars allows them to move to the roadway with less impedance, thereby balancing the flow. Even though truck drivers prefer exclusive facilities (only large commercial vehicles), they tolerate cars.

The issue of increasing truck traffic is of vital concern to both traffic managers and the general public. Highway safety and traffic operations constitute the measure used by motorists of the quality of a facility. The characteristics that matter most to drivers are: safety, speed of travel, comfort, and convenience. As a result of increasing demand on highways, a variety of strategies or countermeasures for trucks have been implemented in an attempt to mitigate the effects of increasing truck traffic. Some of the most common strategies that have been considered are: lane restrictions, time of day restrictions, peak period bans, route restrictions, and exclusive truck facilities.

A relatively new idea, which TTI is now evaluating, is called "managed lanes." A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. The concept promotes adjustment of lane management operations at any time to better match regional goals. Managed lanes also offer peak period free-flow travel to certain user groups. Managed lane operations for trucks strategies include exclusive use lanes, separation and bypass lanes, dual use lanes, and lane restrictions *(28)*.

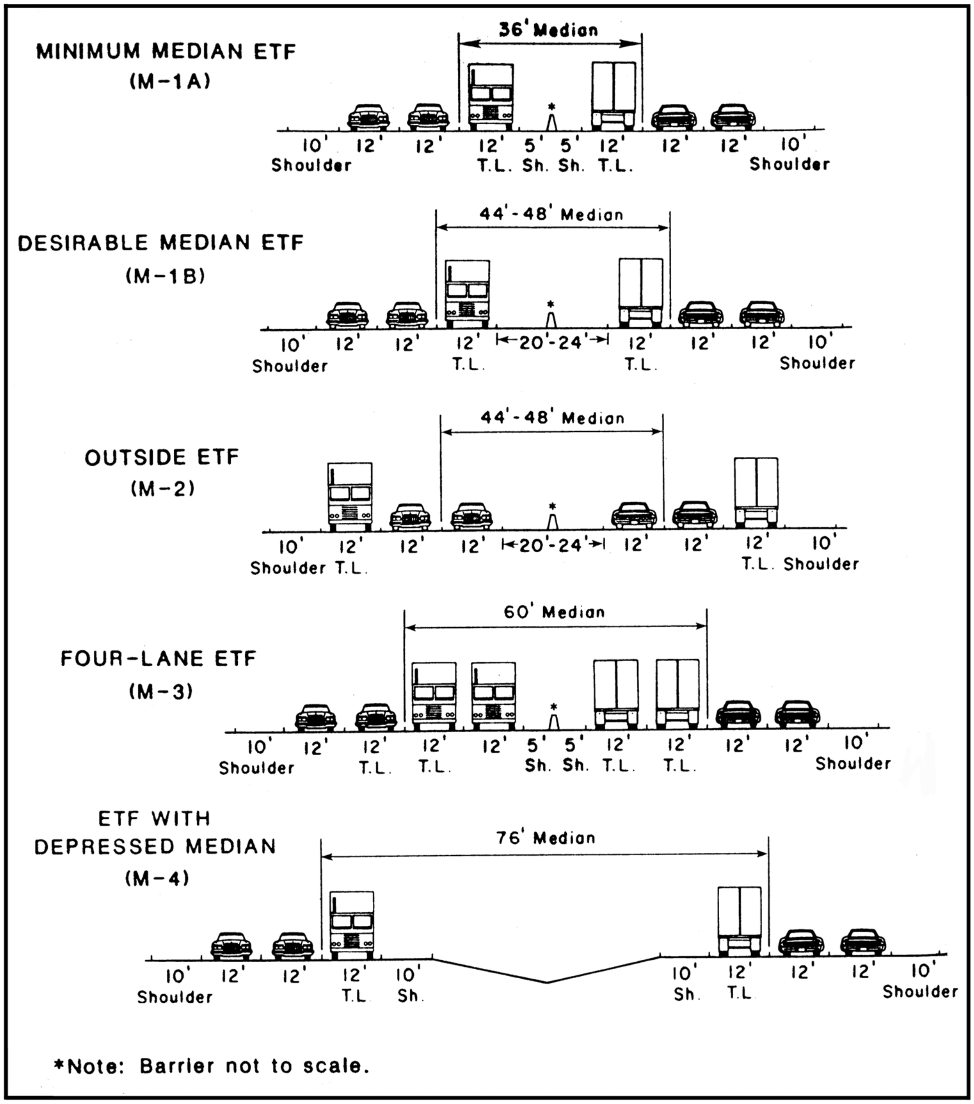
In 1986, the Federal Highway Administration asked its division offices to conduct a survey and report on experiences encountered by states with lane restrictions. The most common reasons for implementing lane restrictions were: improve highway operation, reduce crashes, pavement or structural considerations, and construction zones *(29).* A study in 1988 by Sirisoponsilp and Schonfeld *(30)* conducted a survey of states, the District of Columbia, and Puerto Rico. This survey yielded similar results, with states indicating that truck restrictions are intended to improve overall traffic operations and safety.

The strategies of lane restrictions and exclusive truck facilities are similar in intent. Both attempt to decrease the effects of trucks on safety and reduce conflicts by physically separating truck traffic from passenger car traffic. Lane restrictions separate traffic by designating specific usage of lanes by vehicle type, while exclusive truck facilities designate facility usage by vehicle type.

In previous TTI research performed in 1985, Mason et al. *(31)* described seven types of truck lane configurations as shown in Figure 26. Construction of all of these treatments could occur within an existing right-of-way, especially if sufficient median width remains unused. The first truck lane, designated as M-1A, is a minimum median truck lane. Trucks use 12-foot inside lanes that have a 5-foot inside shoulder, while other vehicles utilize the outside lanes. Lanes for trucks and cars are not barrier separated. The second truck lane, designated M-1B, is a desirable median truck lane. The configuration is the same as for the M-1A truck lane, with the exception of 10 to 12-foot inside shoulders. The third truck lane, known as M-2, is an outside truck lane. Trucks travel on 12-foot outside lanes that have 12-foot shoulders. These lanes are not barrier separated from the inside car lanes. The fourth configuration, designated the M-3 truck lane, is a four-lane truck facility. Trucks travel on two 12-foot inside lanes that have 5-foot inside shoulders, and trucks are not barrier separated from the outside car lanes. The fifth type of facility is the M-4, which is an inside 12-foot truck lane that has a 10-foot inside shoulder and a depressed median. The truck lane is not barrier separated from car lanes. The sixth type of configuration is the M-5 protected truck lane with a passing lane. Trucks travel on 12-foot lanes that have a 4-foot inside shoulder and a 10-foot outside shoulder. This facility is barrier separated from the outside car lanes. The final configuration is the M-6 elevated truck lanes. Trucks travel on 12-foot lanes that have a 4-foot inside (left) shoulder and a 10-foot outside (right) shoulder. This facility is elevated above the passenger car lanes. Both M-5 and M-6 have passing lanes that alternate by direction, resulting in a constant overall roadway width.

5.3.1.1 Lane Restrictions

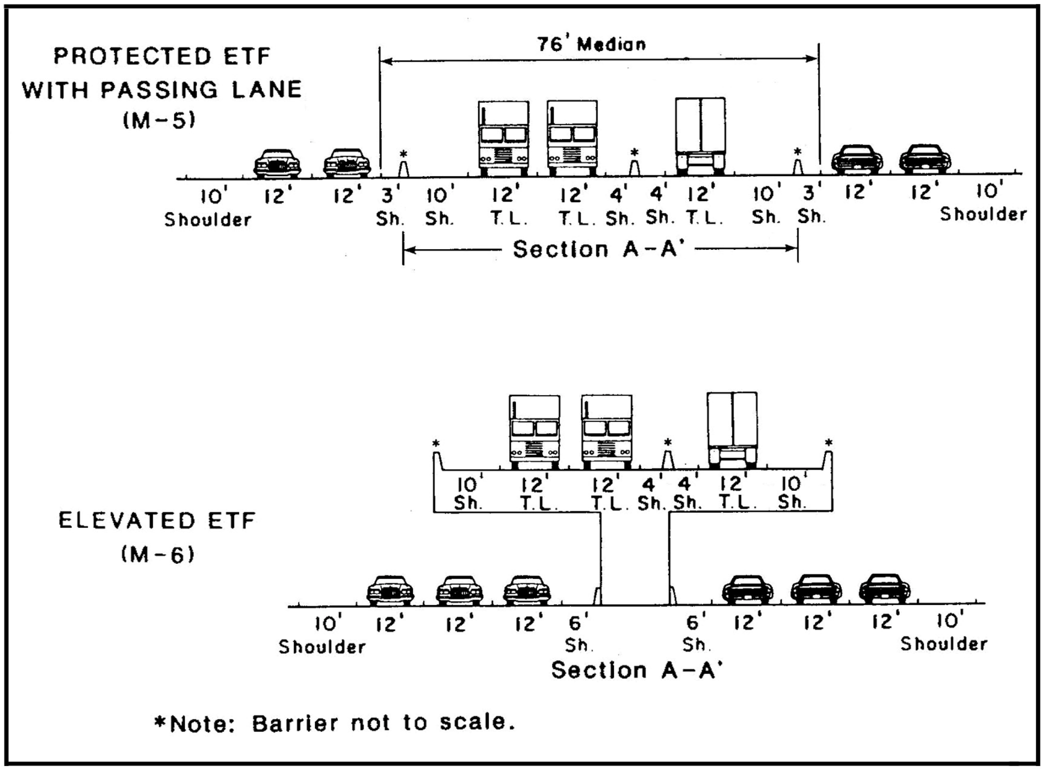
Truck restrictions have been implemented by a number of states in an attempt to increase safety, decrease congestion, and improve operations. The most prevalent form of restriction by far is lane restrictions. The next section addresses a related concept – reserved capacity lanes for trucks. State transportation officials usually have the authority to implement lane restrictions. In many instances, local jurisdictions have the authority through existing legislation to implement restrictions on state highways. The Surface Transportation Assistance Act in 1982 and Tandem Truck Safety Act in 1984 established a national network of highways as a designated large truck network. The law is insistent that state regulations should not interfere with interstate truck movements, as long as the trucks conform to size and weight limits established by STAA and TTSA *(23).*



Source: Reference (26).

Figure 26. TTI Truck Facility Cross-Sections.

In May 1997, the 75th Texas Legislature passed legislation that permits a local municipality to request lane restrictions on certain highways within the municipality's jurisdiction. The request for a lane restriction must be approved by the Texas Department of Transportation. Specific criteria must be met prior to TxDOT approval of a municipality's request. For example, the highway must be a state-maintained controlled access facility with at least three through-lanes in each direction, and an engineering study must be conducted by TxDOT to determine the feasibility of the proposed lane restrictions. To comply with this legislation, Jasek et al. developed guidelines to aid TxDOT in the implementation of requested truck lane restrictions in urban areas. The guidelines provide TxDOT with the necessary information to evaluate a municipality's request for lane restrictions. Researchers



Source: Reference (26).

Figure 26. Typical Truck Facility Cross-Sections (continued)

recommended a 12-step process to provide guidance on information related to the proposed lane restrictions that must be contained in the ordinance. The process would include conducting a traffic study, removing/installing the appropriate traffic control devices, and periodically reviewing the lane restrictions to ensure against any negative impacts that may result from the lane restrictions. Researchers recommended that TxDOT monitor the extent of which municipalities request truck lane restrictions *(32)*.

In September 2000, a truck lane restriction demonstration project began on the I-10 East Freeway in Houston. TTI monitored and evaluated the restriction throughout the project, specifically compliance, enforcement, crash records, freeway operations, and public perception. The project, deemed successful, found that compliance rates averaged between 70 and 90 percent, and that the highest compliance rate was among local drivers. Vehicle crashes along the freeway main lanes dropped by 68 percent during the 36-week monitoring period, while the operations impact was insignificant *(33)*.

Lane restrictions are a management strategy that limits certain types of vehicles to specified lanes. The most common type of lane restriction addresses truck traffic. A large presence of trucks, both in rural and urban areas, can degrade the speed, comfort, and convenience experienced by passenger car drivers. Some states, to minimize these safety and operational affects, have implemented truck lane restrictions or have designated exclusive truck lane facilities.

In 1990, Zavoina, Urbanik, and Hinshaw examined the effects of truck restrictions on rural Interstates in Texas *(34)*. This study analyzed the operational effects of restricting trucks from the left lane in Texas. Study sites were six-lane, rural interstate highway sections with speed limits of 65 mph for automobiles and 60 mph for trucks. The study examined vehicle distributions according to classification, vehicle speeds, and time gaps between vehicles. The study found no definitive safety improvements that could be attributed to the truck restriction. Although the lane distribution of trucks changed significantly due to the restriction, there were no measurable safety effects pertaining to the lane distribution of cars, speeds of either cars or trucks, or the time gaps between vehicles. The authors also concluded that even though truck lane restrictions should theoretically improve capacity and safety, the research evidence did not support this assumption.

Hanscom addressed the operational effectiveness of restricting trucks from designated lanes on multilane highways. His study involved sites near Chicago and in rural Wisconsin. Measures of lane restriction effectiveness included voluntary truck compliance, traffic congestion as determined from speeds and platooning of vehicles following trucks, and an all-vehicle sample of differential speeds between the restricted and adjacent lanes. The author concluded that favorable truck compliance effects were evident at all three locations. However, violation rates were higher at the two-lane site as a result of increased truck concentrations due to the truck restriction. Reduced speeds of impeded vehicles following trucks were also more prominent at the two-lane site. At the three-lane sites, the results of the lane restriction were beneficial traffic flow effects and reduced congestion. No speed changes (between the restricted and adjacent lanes) were observed to indicate an adverse effect of implementing the truck lane restrictions *(35)*.

Mannering, Koehne, and Araucto *(36)* conducted a study in the Puget Sound region that considered lane restrictions as a means of increasing roadway capacity, improving highway operations, improving the level of roadway safety, and encouraging uniform pavement wear across lanes. The study region had a truck volume of approximately 5 percent of the total traffic volume. The literature review revealed that although a number of states had instituted truck lane restrictions, very few states had documented the effects of the restriction. This study found that in nearly every instance where a comprehensive examination of a lane restriction implementation occurred, there were negligible changes in operations and safety.

The in-depth analysis by the research team examined traffic composition, traffic flow characteristics, safety, enforcement issues, economic impacts, and pavement deterioration. The analysis revealed no significant operational or safety level increases that could be attributed to the restriction. The safety portion of the analysis did reveal that the number of truck-related crashes for each lane were proportional to the number of trucks traveling in that lane. The Mannering et al. study found that 1) the restriction had no noticeable impact on the distribution of the trucks, 2) the economic impact of the restrictions was minor for motor carriers, and 3) there was only a minimal impact on pavement life. The authors recommended that truck lane restrictions not be implemented in the Puget Sound area *(36)*.

One area of particular concern when implementing truck restrictions on urban freeways is the creation of a "barrier effect" in weaving areas. Weaving areas are segments of freeway formed when diverge areas closely follow merge areas. Operationally, weaving areas are of concern because the "crossing" of vehicles creates turbulence in the traffic streams. When trucks are restricted to the rightmost lanes of a freeway and are of significant numbers, they can form a barrier in the weaving areas. Trucks limit the visibility and maneuverability of smaller vehicles attempting to enter and exit the freeway system. An indication of the barrier effect is an over-involvement of trucks in weaving area crashes, rear-end collisions, and side collisions. Some studies have shown that this problem may be magnified when a differential speed limit is present *(30, 37).*

Garber and Gadiraju *(25)* used a simulation technique to examine the effects of increased truck operations from implementing different strategies on multilane highways. The primary study objective was to provide information about the nature and extent of the impact of specified truck traffic control strategies. The strategies included lane restrictions and differential speed limits. The study found that: 1) the combination of lowering the speed limit for trucks and restricting the trucks to the right lane increased the interaction between cars and trucks and therefore the potential for passenger car/truck crashes; 2) the restriction of trucks to the right lane decreased the vehicular headway in this lane; and 3) the combination of lowering the speed limit for trucks and restricting the trucks to the right lane resulted in a change in the distribution of vehicle spot speeds, and a slight, but not statistically significant, increase of crashes on the right lane.

In 1989 Garber and Joshua *(38)* examined large truck crashes on Interstate highways in Virginia for the period from 1983 to 1985. The following characteristics of truck crashes were documented.

- Thirty-five percent of non-large truck crashes involve one vehicle, while only 22 percent of large truck crashes involve one vehicle.

- Sixty-nine percent of large truck crashes involve two vehicles and 59 percent of non-large truck crashes involve two vehicles.

- Nine percent of large truck crashes involve three or more vehicles and 6 percent of non-large truck crashes involve three or more vehicles.

The authors also found that when a large truck is involved in a two-vehicle crash, non-large trucks were involved 94 percent of the time. There is a temptation to conclude that this over-representation is due to the high percentage of non-large trucks. Therefore, the analysis used a binomial theorem to compare the actual and expected proportions of crashes based on vehicle-miles traveled. The proportion of non-large trucks involved in two vehicle crashes with large trucks was indeed larger than expected, so reducing interaction between the two vehicle types may enhance safety *(38).*

Garber and Joshua also investigated fatal crashes. They found that, for non-large trucks, 68 percent of the fatal crashes were one-vehicle crashes. However, when large trucks were involved in fatal crashes, there were two vehicles involved in the crash 60 percent of the time. In multiple vehicle crashes involving a large truck, fatalities are 40 times more likely than when the crash involves only non-large vehicles. Garber and Joshua concluded that reducing interactions between the two types of vehicles could enhance safety, and the number of fatal crashes could be reduced *(38).*

The New Jersey Turnpike Authority (NJTA) was one of the first jurisdictions to impose lane restrictions for trucks. The dual-dual portion of the turnpike from Interchange 9 to Interchange 14, restricts trucks to the right outer lanes, and buses are allowed to use the left lane. The resulting effect is that the left lane becomes a bus lane with the right lane(s) occupied by trucks. The NJTA rates compliance for truck lane restrictions as high *(39).*

A 1992 study by the Organisation for Economic Co-operation and Development (OECD) regarding truck roads examined operational issues regarding dedicated truck lanes and exclusive truck routes. The authors concluded that truck only lanes appear to be of limited value, because they reduce the operational flexibility of the road. Particular problems may arise when trucks attempt to overtake other trucks or where the road is heavily congested and trucks are traveling faster than vehicles in nonexclusive lanes. Another fear is that designating one lane exclusively for trucks would result in the saturation of that lane by trucks resulting in little to no operational benefit. Conversely, the lane would receive limited use during holidays and weekends when truck traffic is relatively light. A study conducted in the Netherlands found that the designation of a truck lane is feasible only when truck traffic density is in the range of 600 to 1000 trucks per hour. Densities lower than this range would be inefficient lane usage, whereas higher truck traffic densities would result in bottlenecks *(40).*

5.3.1.2 Truck Reserved Capacity Lanes

In 1996, Trowbridge et al. *(41)* considered the impacts that would occur from providing trucks reserved capacity lanes that are in some cases separate from general traffic or allowing trucks access to HOV lanes. The authors reference a 1991 study by BST Associates *(42)* that found that trucks generally make up less than 5 percent of average daily traffic in urban areas, and note that an undue amount of effort is used in devising strategies to restrict and manage this small portion of total traffic. In lieu of strategies restricting truck traffic, the authors proposed providing trucks access to reserve capacity lanes— i.e. high occupancy vehicle lanes— in order to relieve congestion.

The reserve capacity lanes investigated in the study consisted of two options for roadways in the Seattle area. The first option permitted heavy trucks to use existing HOV lanes, while the second option added a lane for the exclusive use of trucks on all facilities that had an existing or planned HOV lane. The authors attempted to determine the impacts of these options on vehicle travel time and vehicle miles traveled for single occupant vehicles (SOVs), HOVs, and trucks. The authors collected traffic data to perform a traffic simulation and an estimate of the economic impacts of this type of strategy *(41).*

5.3.1.3 Truck Preferred and Truck Only Facilities

In cases where the numbers of trucks, high truck-involved crash rates or other factors necessitate more than lane restrictions, truck preferred or truck only facilities offer a solution to mitigate the effects of increasing truck traffic, including exclusive truck lanes. Provision of truck roadways typically creates dual facilities that incorporate an inner and outer roadway in each direction that is physically separated. The best example in the U.S. is the New Jersey Turnpike, where the inner roadway is reserved for light vehicles only, and the outer roadway is a truck preferred scenario, but is open to passenger vehicles as well. The turnpike authority implemented separated facilities, also known as dual-dual segments, to relieve congestion. The turnpike has a 32-mile segment that consists of interior (passenger car) lanes and exterior (truck/bus/car) lanes within the same right-of-way. For 23 miles, the interior and exterior roadways have three lanes in each direction. On the 10-mile section that opened in November 1990, the exterior roadway has two lanes, and the interior roadway has three lanes per direction. Each roadway has 12-foot lanes and shoulders, and the inner and outer roadways are barrier separated by "W-Beam guardrail." The mix of automobile traffic is approximately 60 percent on the inner roadways and 40 percent on the outer roadways *(39)*.

Another planned dual mixed facility is the A86 ring motorway in Paris, France. The A86 is a tollway being built near Paris that will be managed by a private toll entity. The plans for the motorway call for the construction of two separate tunnels to bypass Versailles. The westside tunnel, between Rueil and Bailly, will serve mixed traffic (trucks and cars) and the eastside tunnel, between Rueil and Versailles, will be reserved for light vehicles only. The mixed tunnel will have two lanes, will be slightly shorter than the light vehicle tunnel, and will have standard tunnel dimensions. The cars-only tunnel will consist of two levels (one on top of the other) with three lanes in each direction. According to proposed cross-sections, it will be built with a height of 8 feet 6 inches and lane widths of 10 feet. Construction on the tunnels is underway, but anticipated completion dates were not provided *(43).*

In a 1990 FHWA study, Janson and Rathi *(44)* examined the feasibility of designating exclusive lanes for vehicles by type. This study, which ultimately resulted in a computer program known as exclusive vehicle facilities (EVFS), evaluated exclusive lane use feasibility by utilizing the following lane use possibilities:

- mixed vehicle lanes—lanes utilized by all vehicles;
- light vehicle lanes—lanes utilized only by motorcycles, automobiles, pickup trucks, light vans, buses, and trucks weighing less than 10,000 pounds; and
- heavy vehicle lanes—lanes utilized only by single unit trucks weighing more than 10,000 pounds and all combination vehicles *(44).*

A recent study by Battelle updated the values previously used in the model by Janson and Rathi; Battelle also evaluated the program code and determined that its continued use was appropriate *(45)*. The program can evaluate the economic feasibility of exclusive lanes for specific sites on high-volume, limited access highways in both urban and rural areas. To qualify, a highway must have three or more lanes in each direction. The program allows user to input site-specific information for 57 variables grouped into three categories: 1) traffic characteristics; 2) cost of construction, maintenance, and right-of-way; and 3) crash costs (including lane blockage and time-to-clear data), crash rates by vehicle type, and value of time. Based on either user inputs or default values, the program calculated net present worth, benefit-cost ratio, and other facility performance measures. Janson and Rathi and the Battelle update list and describe the possible options shown below:

- *Case 0:* Base scenario or do-nothing (used for comparing with other scenarios).
- *Case 1:* No change in no. of lanes but redesignate functions.
- *Case 2:* Add mixed lanes (no lane use restrictions).
- *Case 3:* Add non-barrier lanes, designate at least one lane to trucks (no mixed lanes).
- *Case 4:* Add non-barrier lanes, designate at least one lane to trucks (allows both heavy and mixed lanes).
- *Case 5:* Add barrier-separated lane(s) for trucks (exclusive truck lanes [ETL], no mixed lanes).

The Battelle study resulted in some criteria for providing truck facilities based on annual average daily traffic, annual average daily truck traffic, level of service, truck-involved crash rates in million vehicle-miles traveled (MVMT), daily traffic delays, and proximity to freight origin-destination points. Table 34 summarizes the proposed thresholds. This report contains additional information along with a critique of these findings in Chapter 7.

Table 34. Suggested ETL Evaluation of Criteria.

Measure	Suggested Threshold	Remarks
AADT	$\geq$ 100,000 vpd	Use in combination with AADTT percent
AADTT	$\geq$ 25 %	Use in combination with AADT
Level of Service	E or lower – urban hwys F or lower – rural hwys (v/c ratio $\geq$ 1)	To rank potential locations that satisfy traffic criteria
Truck-involved fatal crash rate	$\geq$ national average (2.3 per 100 MVMT, 1999)	To rank potential locations that satisfy traffic criteria
Proximity to intermodal facilities/ processing centers	$\leq$ 2 miles from interstate or X tons of freight or Y TEUs of containers	To be considered with other criteria No data available to determine the values for X or Y

Source: Reference (45).

Wishart and Hoel *(46)* examined problems with mixed vehicle traffic and the four truck traffic strategies described in the original EVFS program. The study considered a number of variables with safety, highway operations, and pavement deterioration being the dominant factors. The authors found that mixed vehicle travel is associated with higher risk, especially for the occupants of smaller or lighter vehicles, and that one contributing factor for crashes is the difference in operating characteristics of trucks and passenger cars. Wishart and Hoel concluded that when properly implemented, adequately publicized, and sufficiently enforced, truck traffic strategies could effectively increase safety, improve traffic operations, and decrease the pavement deterioration rate on Interstate highways.

In 1986, a research study by TTI *(47, 48)* examined the feasibility of an "exclusive truck facility" for a 75-mile segment of I-10 between Houston and Beaumont. The options considered in the study included: the construction of an exclusive truck facility within the existing I-10 right-of-way; construction of an exclusive truck facility immediately adjacent to I-10 outside of the existing right-of-way; or construction of an exclusive facility on, or immediately adjacent to, an existing roadway that parallels I-10 (U.S. 90). The studies concluded that existing and future trends in traffic volumes did not warrant an exclusive facility along the I-10 corridor.

Truck facilities could have positive impacts on noise and air pollution, fuel consumption, and other environmental issues. Creating and maintaining an uninterrupted flow condition for diesel-powered trucks will result in a reduction of emissions and fuel consumption, when compared to congested, stop-and-go conditions. However, the creation of a truck facility may also shift truck traffic from more congested parallel roadways, thereby shifting the environmental impacts. There may also be increases in non-truck traffic on automobile lanes due to latent demand. Feasibility studies for exclusive truck lanes have also been conducted in Virginia, California, United Kingdom, and the Netherlands. However, to date, none of these proposed exclusive facilities have been implemented *(49).*

Planners in the Netherlands are considering a number of strategies in an attempt to relieve severe congestion and ameliorate increasing pollution in the region. One of the strategies being considered is the creation of a truck lane utilizing existing pavement and infrastructure. In areas with severe congestion and bottlenecks, particularly on roads between Randstad (an economic center in the Netherlands), Germany, and Belgium, truck lanes are potentially helpful in combating congestion. Traffic managers are considering utilizing the paved shoulder on the roadway and re-striping the existing roadway to allow four narrow lanes instead of the three existing standard width lanes. Another option being considered is separating through truck traffic from automobile traffic. The truck lanes would be 10.7 ft in width and the car only lanes would be 9.8 ft in width *(40).*

In recent years greater emphasis has been placed on economic aspects of transportation. It has become apparent that transportation facilities must provide acceptable service under the strains of increasing demands while meeting the test of financial prudence and limited funding.

In 1986, Lamkin and McCasland *(48)* studied the economic issues of an exclusive truck facility on the I-10 corridor. The study examined the existing traffic conditions, geometric design, land development and usage, truck services and usage, and pavement structures for the exclusive facility alternatives. Benefits and costs of an exclusive truck facility that were considered during the evaluation included: safety, improved capacity and operations, time travel savings, pavement life, construction costs, right-of-way acquisition, conversion costs, and impact to local environment. The authors concluded that existing and future trends in traffic volumes did not warrant an exclusive facility along the I-10 corridor. Specific conclusions in the analysis included the following:

- The conversion of a non-freeway facility that passes through smaller communities, such as the parallel U.S. 90, to an exclusive truck facility is not feasible. The impact to nonusers could not be offset by the benefits to the users, and the additional travel distance required by the facility would require high speeds to gain travel time savings.

- Only short sections (10 to 12 miles) of existing I-10 right-of-way could geometrically accommodate exclusive facilities without the construction of major structures, such as bridges and flyovers.

- Locations for an exclusive facility outside the right-of-way presented problems in right-of-way acquisition, provision of truck roadside services, local traffic circulation, and freeway to exclusive facility interconnections *(48)*.

When Wishart and Hoel *(46)* investigated exclusive truck facilities in Virginia using EVFS, a list of expected benefits and costs were described. Broad intended benefits of separating truck traffic from automobiles included improved operations, reduced crashes, less severe crashes, and fewer and shorter delays. Other expected benefits are: savings from reduced travel delay; reduced vehicle operation cost; decreased environmental impact from exhaust and fuel consumption; and injury and property damage savings. These benefits are offset by expected costs in engineering, construction, additional right-of-way, signage, enforcement, and maintenance. Although expected costs may outweigh benefits, many of the costs are one-time costs, while the benefits are recurring.

In a 1997 Virginia Transportation Research Council report, Hoel and Vidunas *(50)* examined the economics of exclusive vehicle facilities defined by the EVFS program. The authors found that although no single factor is dominant, there are a number of factors that contribute to the feasibility of exclusive lanes. These factors include: traffic volume, vehicle mix percentage, crash rate, and maintenance and construction costs. Maintenance and construction costs are given more weight in EVFS than other factors.

In an effort to finance the infrastructure used by commercial vehicles, one study recommended truck tollways as an economic method of providing exclusive truck routes. Several feasibility studies have explored this option. One feasibility study of exclusive truck lanes on State Route 60 in California began in 1999. Initial estimates for the preferred design alternative found that user fees would fund only 28 percent of the initial cost of the project *(49)*.

A recent study for the Reason Policy Institute by Samuel et al. *(51)*, proposed that self-financing toll truckways consisting of one or two lanes in each direction be built in the existing right-of-way. These truckways would be barrier separated from existing lanes and have their own ramps. The lanes would be designed specifically for trucks and trucks would have exclusive use of the lanes. Financing for the truckways would be from tolls collected from trucks using the facilities. Trucks using the truckways would be rebated federal and state fuel taxes for the mileage traveled on the truckways. Federal truck size and weight regulations would also be eased for truckway users.

In contrast to the Reason Policy Institute findings, the SR 60 study in California found that tolls would not be sufficient to cover its construction cost. SR 60 is a major east-west freeway connecting downtown Los Angeles with industrial sections of the San Gabriel Valley and the growing warehouse districts south of the Ontario International Airport. It generally has four lanes in each direction and HOV lanes along much of its project length. For trucks, according to Caltrans *(52)* it is one of the most heavily traveled corridors in Southern California with as many as 28,000 trucks each day, which is approximately 15 percent of the total traffic. In 2000, 61 percent of the truck traffic is 5+ axle trucks. There were several scenarios evaluated at differing costs, but the most advantageous of these would raise $1.2 billion of the total construction cost of $4.3 billion. The remaining $3.1 billion would have to be raised through other federal, state, or local sources. Based on historical data, this funding gap would be larger than public funding agencies are willing to cover. The gap is also too risky for significant private investment in project construction. Therefore, the financial consultant concluded that the project was not financially feasible *(49)*.

Evaluation of truck preferred and truck only facilities must also consider effects on the environment. The 1992 study by the OECD *(40)* on cargo routes and truck roads examined the impact of truck facilities and truck lanes on the environment. The environmental issues considered were noise and vibration pollution, fuel consumption, and air pollution. According to this study, the air pollution produced by trucks is quite different from the pollution produced by cars. Trucks are primarily powered by diesel engines that operate with higher air/fuel ratios than the gasoline engines that power most cars. Diesel engines produce less carbon monoxide and unburned hydrocarbons than gasoline engines. However diesel engines produce more smoke and solid particles due to the rich fuel/air mix than automobile engines. Vehicle emissions and energy consumption increase with traffic congestion and speed variations. Speed variations can increase both emissions and fuel consumption by 25 to 40 percent, while traffic congestion can increase emissions and fuel consumption by 50 to 100 percent *(40).*

The European Conference of Ministers of Transport held a special conference on the environment in 1989. The reports presented to the conference discussed various concerns regarding environmental damage caused by traffic and traffic congestion. The conference compared the pollution due to trucks versus automobiles. One conclusion reached was that given the current state of traffic a 10 percent reduction in traffic congestion for trucks would result in a significant decrease in environmental pollution while a 10 percent decrease in traffic congestion for automobiles would be inconsequential *(53).*

The most significant obstacle to exclusive truck facilities may be public opinion. The OECD report on truck roads *(40)* verified that exclusive truck lanes would be unpopular with the general public. Public acceptance of a facility depends on whether individuals find the facility useful. In the case of an exclusive truck road, people living near the facility do not perceive a direct benefit and may oppose the facility. Once again, although public opinion is negative toward exclusive facilities, the public generally favors the restriction of trucks to specific lanes.

5.3.1.4 Bypass Facilities

A bypass facility is a treatment for a specific section or segment of roadway. This management strategy has been successfully used in several areas and often addresses a roadway segment that has the following characteristics: weaving area, a significant grade, high percentage of truck traffic, and/or congestion. Weaving areas are segments of freeway formed when a diverge area closely follows a merge area. Operationally, weaving areas are of concern because the "crossing" of vehicles creates turbulence in the traffic streams. Trucks limit the visibility and maneuverability of smaller vehicles attempting to enter and exit the freeway system. An indication of the barrier effect is an over-involvement of trucks in weaving area crashes, rear-end collisions, and side collisions. Some studies have shown that this problem may be magnified when a differential speed limit is present *(30, 37).*

There are four truck preferred interchange bypass facilities in the Los Angeles area: 1) at I-5/I-405 in Orange County, 2) at I-405/I-110, 3) I-5/I-405 north of Los Angeles in the San Fernando Valley, and 4) a 2.4 mile bypass of I-5 in the vicinity of SR-14 and I-210. All of these bypass facilities separate heavy flows of trucks from other traffic to minimize the impact of grades or other features that would otherwise create operational and safety problems. Although these facilities were built for trucks to bypass interchanges, automobiles and other vehicles also use the lanes in order to avoid the weaving sections *(39).*

Detailed information regarding the construction cost of the bypass lanes was unavailable. However, the reason cited by Caltrans engineers for building the truck bypasses was to reduce weaving problems. The truck bypass lanes have received mixed reviews; many passenger car drivers use them instead of going through the interchange in order to avoid weaving. Truck drivers would prefer to restrict the bypass lanes to trucks only due to differences in vehicle operating characteristics and because of an apparent lack of understanding by auto drivers of truck operating characteristics *(39).*

A truck bypass facility exists on a section of northbound I-5 near Portland, Oregon, at the Tigard Street interchange; it is similar to some of the California facilities. The bypass lane requires trucks to stay in the right lane, exit onto a truck roadway, and re-enter the traffic downstream of the interchange. Passenger cars are also allowed to use the bypass facilities, so this facility fits the description of a truck preferred facility. One reason this facility is needed is a significant grade on the main lanes of I-5. Without the truck roadway, larger vehicles would be forced to climb a grade, and then weave across faster moving traffic that is entering the main lanes from their right. The resulting speed differentials caused by trucks performing these maneuvers created operational as well as safety problems prior to the implementation of the bypass facility. Truck speeds are now typically 50 mph in the merge area; whereas prior to implementation of the bypass lane, truck speeds were 20 to 25 mph. Observations of trucks traveling northbound indicated that nearly every truck uses the truck bypass with little or no need for enforcement *(39)*.

5.4 RESULTS OF FOLLOW-UP CONTACTS

5.4.1 New Jersey Turnpike

The New Jersey Turnpike, the first controlled access toll road to span the entire state, opened in stages as sections were completed (see Figure 27). The first section from Interchange 1 (Deepwater) to Interchange 7 (Bordentown) opened on November 15, 1951 and another 40 miles to Interchange 11 (Woodbridge) opened a few days later that same month on November 30. The 16-mi stretch from Woodbridge to Interchange 14 (Newark) opened on December 13, 1951. The final 9 miles from Newark to Interchange 14 (Ridgefield Park) completed the original turnpike for an initial border-to-border length of 118 mi on January 15, 1952. Traffic volumes grew beyond expectations on this four-lane divided roadway largely because this was the first roadway that allowed motorists to travel non-stop through the state.

The turnpike has been lengthened and widened over the years since its construction; five major improvement projects have both improved safety and increased capacity. The first of these improvements began in 1955, widening an 83-mi stretch from four lanes to six lanes. The second widening project began in 1966 and created the first dual-dual system between Interchanges 10 and 14. In 1973, the New Jersey Turnpike Authority extended the dual-dual roadway southward from Interchange 10 to Interchange 9. An additional expansion of the dual-dual roadway opened in 1990, widening the turnpike from six lanes to 10 lanes between Interchange 8A and Interchange 9 *(54)*. Today, the dual-dual roadway extends from Interchange 8A to Interchange 14, a distance of 32 mi. The inner roadway of the dual-dual system is for cars only, and the outer roadway is for cars, trucks, and buses. Reasons for building the dual-dual roadway were twofold: 1) traffic management had a goal of automating traffic control, and 2) to allow flexibility in closing parts of the roadway for maintenance activities or crashes. Figure 28 shows the general layout of the inner and outer roadways, although some sections have more separation between the inner and outer “barrels.” Figure 29 shows the mainline layout of the dual-dual roadway on a section with three inner lanes and three outer lanes in each direction. As Figure 30 shows, the inner and outer roadways have their own access ramps to/from each interchange. This figure also shows the overhead signs that guide motorists when an incident or major congestion occurs on one or the other roadway.

The proportion of cars on the inner versus the outer roadways varies by turnpike section, but overall about 62 percent of cars take the inner roadway and 38 percent take the outer roadway when no traffic balancing is necessary. Therefore, even with all commercial vehicles restricted to the outer roadways, there are still substantial numbers of cars there as well.

Table 35 indicates 2001 traffic volume according to the following categories: cars, all trucks, and all buses. Appendix D shows a complete list of 2001 traffic volume by vehicle class (as defined by the New Jersey Turnpike Authority).

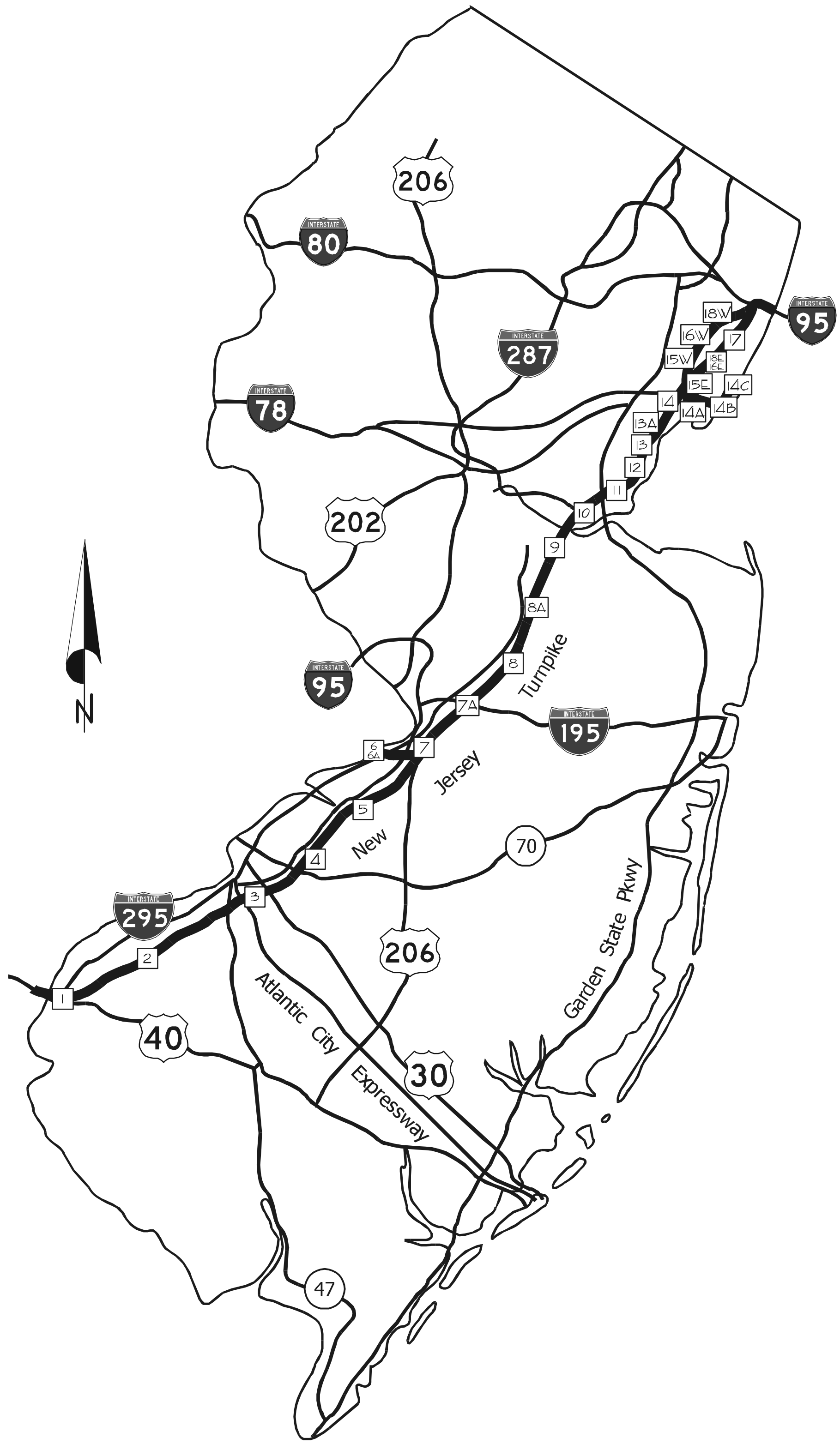


Figure 27. New Jersey Turnpike.

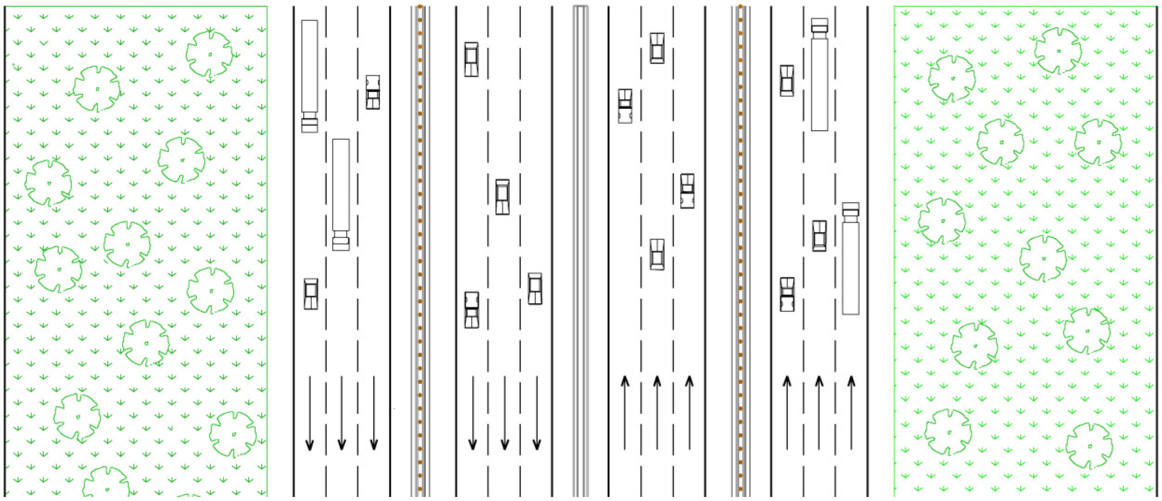


Figure 28. Typical Cross-Section of Dual-Dual Roadway.

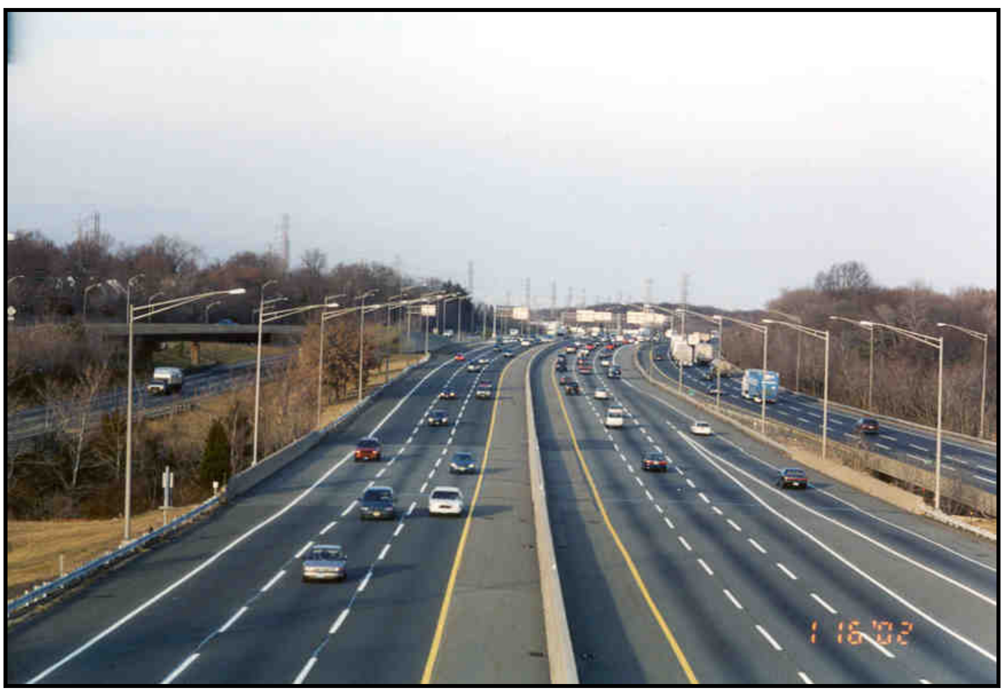


Figure 29. Overhead View of New Jersey Turnpike.

Figure 30. Individual Ramp Access for the Inner and Outer Roadways.

Table 35. 2001 Traffic Volume on the New Jersey Turnpike.

Vehicle Type	Traffic Volume	Percent of Total
Cars	199,466,095	86.9
Trucks	27,649,048	12.1
Buses	2,304,833	1.0
Total	229,419,976	100.0

Data Source: New Jersey Turnpike Authority.

5.4.1.1 Crash Rates

Table 36 shows the number of crashes by vehicle type (described in Table 37). Table 38 provides a comparison of crash rates of the inner roadway versus the outer roadways in 2001. Figures 31 and 32 show injury crash rates and total crash rates, respectively, for 1999, 2000, and 2001. On a comparative basis, one might expect that the non-dual sections and perhaps the outer roadways to have higher crash rates than the inner (car only) roadways. Comparison of both injury and total crash rates indicates that this assumption to be true sometimes but not all the time. Total crash rates were higher in 1999 and 2000 for the outer roadway than for either the inner roadway or the non-dual roadway, but about equal in 2001.

Table 36. Vehicles Involved in Crashes by Class.

Vehicle Class	No. of Crashes
Class 1	9,870
Class 2	441
Class 3	434
Class 4	112
Class 5	2,033
Class 6	11
Buses	139
Total	13,040

Data Source: New Jersey Turnpike Authority.

Table 37. Description of Vehicle Classes.

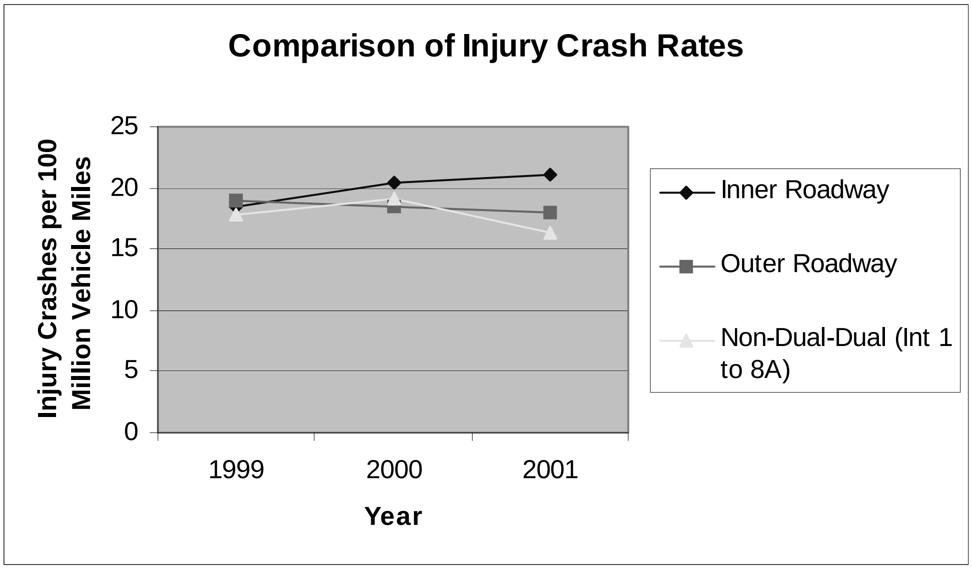
Ticket Class	Type of Vehicles	Number of Axles
1	Passenger car, light truck, taxis & hearses, motorcycles	2
2	Two-axle dual-tire vehicle, two-axle tractor, wide tire	2
3	Passenger car with trailer, two-axle single-tire truck with trailer, three axle single unit truck, three-axle semitrailer combination, two-axle dual-tire truck with single axle trailer	3
4	Any dual-tire truck & trailer with four axles and single unit trucks with four axles, passenger car with two-axle trailer, two cars tandem	4
5	Any truck & trailer with five axles	5
6	Tractor-trailer with six or more axles, three-axle tractors-tandem	6
B-2	Two-axle bus	2
B-3	Three-axle bus	3

Source: New Jersey Turnpike Authority.

Table 38. Crash Rate Comparison on the New Jersey Turnpike in 2001.

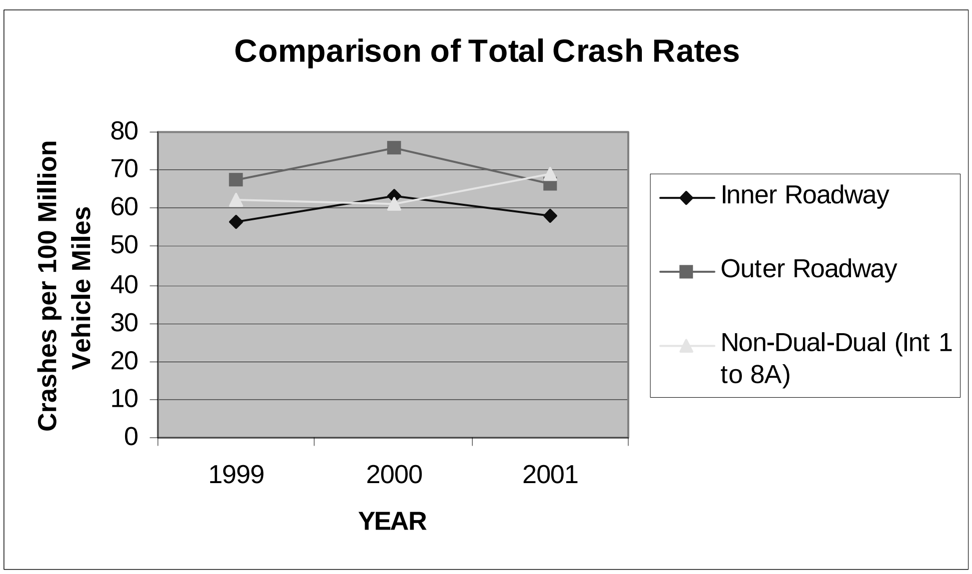
Roadway	Crashes	Mileage	Rate
Outer	627	943,030,720	66.5
Inner	748	1,291,070,473	57.9
Total	1,375	2,234,101,193	61.5

Source: New Jersey Turnpike Authority.



Data Source: New Jersey Turnpike Authority.

Figure 31. Turnpike Injury Crash Rates for 1999, 2000, and 2001.



Data Source: New Jersey Turnpike Authority.

Figure 32. Turnpike Total Crash Rates for 1999, 2000, and 2001.

5.4.1.2 Factors that Affect Crash Rates

The main factors that affect policy-makers' decisions regarding the building of commercial vehicle facilities are: numbers of commercial vehicles, crash rates, cost, driver considerations, and enforcement consideration.

Separating trucks from other traffic on the dual-dual sections of the turnpike are not the only factors that might contribute to crash rates. Other factors include construction or design standards, lane restrictions for commercial vehicles, enforcement level, use of ITS, strategic locations of service plazas, and incident response.

5.4.1.3 Construction or Design Standards

The following information sets forth some of the guidelines used by NJTA in designing its facilities; it includes items like grading criteria and guardrail. Other items are available in NJTA Design Standards sheet number DS-3 (see Appendix E). The intent of the standards is to become a guideline to achieve an economically feasible, safe, and aesthetically pleasing design. Variations are permitted as long as the design adequately complies with the intent of the guidelines. Flat slopes are desirable when possible to eliminate the need for guardrail.

The NJTA uses 12-ft travel lanes throughout on both the inner and outer roadways, but allows lane widths as narrow as 10 ft 6 inches in construction areas. Paved shoulders on the right side of the travel way are 12-ft wide on newer sections of the turnpike, but they are 10 ft on older sections. There are also sections of the turnpike with shoulders even wider than 12 ft as shown by Figure 33. These extra wide shoulders are part of a planned future widening project, which will increase the total number of lanes from 10 to 12. The design speed is 70 mph south of Interchange 13 and 60 mph north of Interchange 13. Design speeds are typically 5 to 10 mph higher than posted speeds. Table 39 summarizes some of the design elements used on the turnpike. Weaving distances for trucks are not a significant factor today because known problems have been corrected. For example, one insufficient weaving area north of Interchange 14, which connected the dual-dual section and the east-west split, was corrected during a widening project which removed the requirement for truck weaving. Although not a conclusive factor in determination of weaving distances, providing adequate distance between interchanges is one element. The only segment considered by turnpike officials to pose a weaving problem today is the one between Interchanges 13 and 13A, which is also the area with the highest traffic volume. Table 40 provides distances between interchanges.

Table 39. New Jersey Turnpike Design Elements.

Design Element	Value Used
Design Speed	70 mph [a]
Lane Width	12 ft
Shoulder Width	12 ft [b]

[a] South of Interchange 13, 60 mph north of Interchange 13.
[b] Used on newer sections, 10 ft on older sections.

Figure 33. Photo of Extra Wide Paved Shoulder.

A section of the standards entitled “Grading in Fill Areas” provides for variable side slopes depending on the height of the fill to be used for all ramps and for existing turnpike roadways. Table 41 shows these values. Both mainline and ramp sections must have a berm width of 6 ft sloping away from the roadway at an 8 percent grade and all roundings must have 5 ft vertical curves. Cut areas must have 2:1 maximum side slopes throughout with berm widths and roundings the same as fill sections.

The standard states that guardrail installation must be evaluated in terms of economic and engineering considerations. For example, flatter slopes should be used in some cases instead of guardrail as dictated by the economics. Guardrail is intended to protect motorists from hazards but care must be exercised in eliminating the hazard when feasible because the guardrail can itself be a hazard.

The NJTA uses guardrail as follows:

- to shield vehicles from piers, abutments, sign bridges, butterfly signs, etc. situated within 30 ft of the edge of pavement;
- on turnpike roadways and ramp fill areas with 2:1 side slopes except where a 30-ft clear zone exists; and
- for continuity to fill in short open areas (short gaps in guardrail).

Table 40. Distances between Interchanges.

Measured from:	Measured to:	Separation (miles)
1 - Delaware Mem. Br.	2 – U.S. 322	11.7
2 – U.S. 322	3 - NJ 168	13.2
3 - NJ 168	4 - NJ 73	8.4
4 - NJ 73	5 - Burlington	9.5
5 - Burlington	6 - Penn. Turnpike	7.0
6 - Penn. Turnpike	6A - Penn. Turnpike	0.0
6A - Penn. Turnpike	7 – U.S. 206	2.3
7 - US 206	7A - I-195, Trenton	6.7
7A - I-195, Trenton	8 - NJ 33 Hightstown	7.6
8 - NJ 33 Hightstown	8A - South Brunswick	6.1
8A - South Brunswick	9 - NJ 18, New Brunswick	9.6
9 - NJ 18, New Brunswick	10 - I-287	4.8
10 - I-287	11 - Garden State P'way	2.5
11 - Garden State P'way	12 - Carteret	5.3
12 - Carteret	13 - I-278, Elizabeth	4.0
13 - I-278, Elizabeth	13A - US 1&9	1.7
13A – U.S. 1&9	14 - Newark Airport	3.1
14 - Newark Airport	14A - Bayonne	3.5
14A - Bayonne	14B - Jersey City	2.0
14B - Jersey City	14C - Jersey City	0.4
14 - Jersey City	15E – U.S. 1&9	2.2
15E – U.S. 1&9	15W - I-280	1.9
15W - I-280	16W - NJ 3, E. Rutherford	3.9
16W - NJ 3, E. Rutherford	17 - NJ 3, Secaucus	0.0
17 - NJ 3, Secaucus	18E – U.S. 46	0.4
18E – U.S. 46	18W – U.S. 46	1.5

Source: New Jersey Turnpike Authority.

Table 41. Side Slopes in Fill Areas. [a]

Fill Height (ft)	Side Slope Required
0 – 5	6:1
5 – 10	4:1
Over 10	2:1 maximum

Source: New Jersey Turnpike Authority.

[a] Another section of the standard provides guardrail requirements based on fill height.

5.4.1.4 Tall 42-Inch Concrete Barrier

The purpose for constructing the New Jersey Turnpike's 42-inch high concrete barrier was to provide a more positive barrier to contain commercial vehicles while not increasing the risk for passenger vehicles impacting the barrier. The turnpike authority first used this barrier in 1984 to separate opposing directions of traffic; it has not used the barrier between parallel roadways where traffic is traveling in the same direction. The authority is now building all median barriers that separate opposing directions of traffic according to this standard. The barrier is not just taller than the standard 32-inch barrier; it is also built to be stronger. It is 12 inches thick at the top instead of the standard 6-inch thickness, it is more heavily reinforced, and it is anchored more securely at the bottom.

Full-scale testing of this barrier by the Texas Transportation Institute in 1983, which yielded acceptable results, helped its acceptance for use by the turnpike authority. In these tests, TTI uniformly loaded a five-axle tractor-semitrailer with sandbags to achieve a gross vehicle weight of 80,180 lb and composite center-of-gravity height of 64 inches and impacted the barrier at a speed of 52 mph. The barrier smoothly redirected the combination vehicle away from the barrier at a 6-degree angle, achieving a maximum roll angle of 52 degrees. The vehicle did not roll over during the test, and there was no measurable deflection of the barrier *(55)*.

According to NJTA personnel, this barrier has performed extremely well in accomplishing the primary objective of containing all vehicles, including large combination vehicles. NJTA operations personnel receive notification each time a commercial vehicle strikes the barrier and blocks traffic lanes, and turnpike personnel respond to the more serious crashes. Determining how many trucks and buses in total have hit the barrier since its initial installation in 1983 or 1984 would be extremely time consuming, but more importantly, turnpike officials are certain that no trucks or buses have penetrated the 42-inch high barrier.

5.4.1.5 Lane Restrictions

NJTA was one of the first agencies to impose lane restrictions for trucks in the 1960s. The restriction does not allow trucks in the left lane of roadways that have three or more lanes by direction. This restriction thus covers much of the turnpike; however, the outer roadway has only two lanes between Interchange 8A and Interchange 9. On the dual-dual portion of the turnpike from Interchange 9 to Interchange 14, buses are allowed in the left lane of the outer roadway. When an incident or maintenance work forces closure of the outer roadway, lane restrictions are still imposed on the inner roadway. Regulatory signs are used with the following message: "NO TRUCKS OR BUSES IN LEFT LANE." Automobiles are also restricted by the following regulatory sign message: "CARS USE LEFT LANE FOR PASSING ONLY." Automobiles also use the outer roadway; the proportions are approximately 60 percent on the inner roadway and 40 percent on the outer roadway. NJTA sources stated that the compliance rate for truck lane restrictions is very high. An HOV lane, which opened in December 1996, also serves three-plus carpools, motorcycles, and buses in the far left lane of the outer roadway between Interchange 11 and Interchange 14. Its hours of operation as an HOV are 6:00 a.m. to 9:00 a.m. northbound and 4:00 p.m. to 7:00 p.m. southbound. At other times, this lane is open to all passenger vehicles. Trucks are not allowed in the left lane of the outer roadways between Exits 11 and 14.

5.4.1.6 Enforcement

The enforcement unit of the New Jersey Police serving the New Jersey Turnpike is known as Troop D. The current level of staffing of State Police assigned to the turnpike is 218, and there are 170 state police cars assigned. This staffing level means that the New Jersey Turnpike employs more state police per lane-mile than other jurisdictions in the New Jersey troop. Besides that distinction, according to NJTA personnel, these troopers make more motor vehicle stops, investigate more crashes, and pick up more disabled vehicles than officers in other jurisdictions. Undoubtedly, this effectiveness in the enforcement arena serves a major role in preventing crashes and enforcing safety regulations. The turnpike authority pays the salaries and operating expenses for Troop D and provides its personnel with extensive continuing education and training programs in traffic safety, advanced crash reconstruction, and construction zone safety.

In recent years, the NJTA concentrated on maintaining safe speeds for commercial vehicles. One of the means of achieving this goal is to compile truck crash data and send the results to the New Jersey Motor Truck (NJMT) Association. The association, in turn, disseminates this information to members.

In order to ensure continued success with enforcement efforts, NJTA traffic engineers and enforcement personnel meet monthly. In these meetings, engineers identify problem areas where they believe additional enforcement will be effective in reducing crash rates and/or compliance with laws. NJTA engineers believe this good working relationship is essential in maintaining the safest possible environment for motorists.

Another activity that undoubtedly contributes to vehicle safety on the turnpike is an activity called “safety breaks.” This is a program where NJTA provides information to motorists, sometimes in the form of a static display at service areas. In one case, in cooperation with the NJMT, it provided a tractor-trailer to allow motorists to climb into the cab. NJMT also displays and demonstrates a seat belt sled (called the “convincer”) to replicate an 8 to 10 mph impact and has shown safety films and distributed brochures. The “safety break” campaign has been well received by the public and supported by service area operators who provided free coffee and donuts. One of the programs the NJTA continues to sponsor is “Sharing the Road with Truckers,” showing the public how difficult it is to control a large combination vehicle and where blind spots exist.

The turnpike authority oversees incident management through its contacts with the state police and contracted towing and emergency response services. It is critical that an adequate number of wreckers, ambulances, and fire fighting equipment and personnel are always available to meet any potential emergency on the turnpike. A hazardous materials specialist is also on call for quick response when needed.

5.4.1.7 Traffic Control and ITS Devices

Highway lane and edge lines exceed federal standards in width and length of painted lines. NJTA uses 6 inch width on lane lines and centerlines, and the lane lines are 25 ft in length with a 25-ft skip. NJTA places guide signs overhead on its dual-dual roadway system in advance of all interchanges over both the inner and outer roadways. As a minimum, guide signs for interchanges begin with a two-mile advance sign placed between the inner and outer roadways, followed by a one-mile sign, then a one-quarter mile sign placed at the start of the one-quarter mile deceleration lane. This signing sequence mounts this latter sign on a sign bridge spanning the roadway and accompanied by a THRU TRAFFIC/NEXT EXIT XX MILES sign, then a cantilevered gore sign over the painted gore.

Guide signs in the non dual-dual turnpike (from Exit 8A to the south) follow the same pattern of 2-mile, 1-mile, one-quarter mile, and gore locations. However, the difference in sign mounting for these non dual-dual sites is that 2-mile and 1-mile signs are ground-mounted signs, with one-quarter mile and gore signs mounted overhead.

The NJTA has variable message signs, drum signs, neon signs, and highway advisory radio (HAR) in addition to fixed signs discussed above. If installed today, the turnpike authority would probably choose the more flexible matrix format due to the larger numbers of messages that can be programmed into the sign system. Drum signs are effective in diverting traffic between inner and outer roadways such as shown in Figure 34. This photo shows the beginning of the northbound dual-dual roadway in the vicinity of Interchange 8A.

Drum signs are effective in diverting traffic away from an incident on the turnpike. Once there is detection and verification of a serious incident or other reasons to do so, traffic can be immediately diverted by operations staff in New Brunswick by changing the message that appears to motorists. Another quick response initiative is changing the speed limit via changeable message signs upon detection of congestion ahead or an incident. These ITS measures undoubtedly reduce crash rates for commercial and all other vehicles on the turnpike.

5.4.1.8 Service Plazas

The turnpike's 12 service plazas offer locations that are strategically placed to provide motorists with convenient places to eat, refuel and receive other vehicle services, and relax. Closely related is the need for truck parking to provide adequate rest and minimize fatigue as well as to meet hours-of-service requirements. Table 42 provides the number of truck parking bays available at each of these locations. State police are required to take enforcement action on illegally parked trucks within service areas. There are no significant indicators or crash records that would suggest that parking in these areas is not sufficient.

Figure 34. Picture of Overhead Rotating Drum Signs.

Table 42. Truck Parking at Service Plazas.

Service Area	Milepoint	Distance	Dir.	Truck Parking Spaces
John Fenwick	5.4	NA	NB	20
James Fenimore Cooper	39.4	34.0	NB	52
Woodrow Wilson	58.7	19.3	NB	41
Joyce Kilmer	78.7	20.0	NB	53
Grover Cleveland	92.8	14.1	NB	46
Vince Lombardi [a]	116.0	23.2	NB	164
Clara Barton	5.4	NA	SB	20
Walt Whitman	30.2	24.8	SB	30
Richard Stockton	58.7	28.5	SB	40
Molly Pitcher	71.7	13.0	SB	84
Thomas Edison	92.9	21.2	SB	50
Alexander Hamilton	111.6E	18.7	SB	33
Vince Lombardi [a]	116.0	4.4	SB	See NB

Source: New Jersey Turnpike Authority.

[a] Serves both directions of travel (one plaza).

5.4.1.9 Construction Cost

The additional construction cost of a dual-dual roadway comes primarily from the cost of the additional right-of-way, the metal beam guardrail, additional pavement (including shoulders), additional length of overhead structures, increased sign costs, and increased interchange costs due to additional ramps.

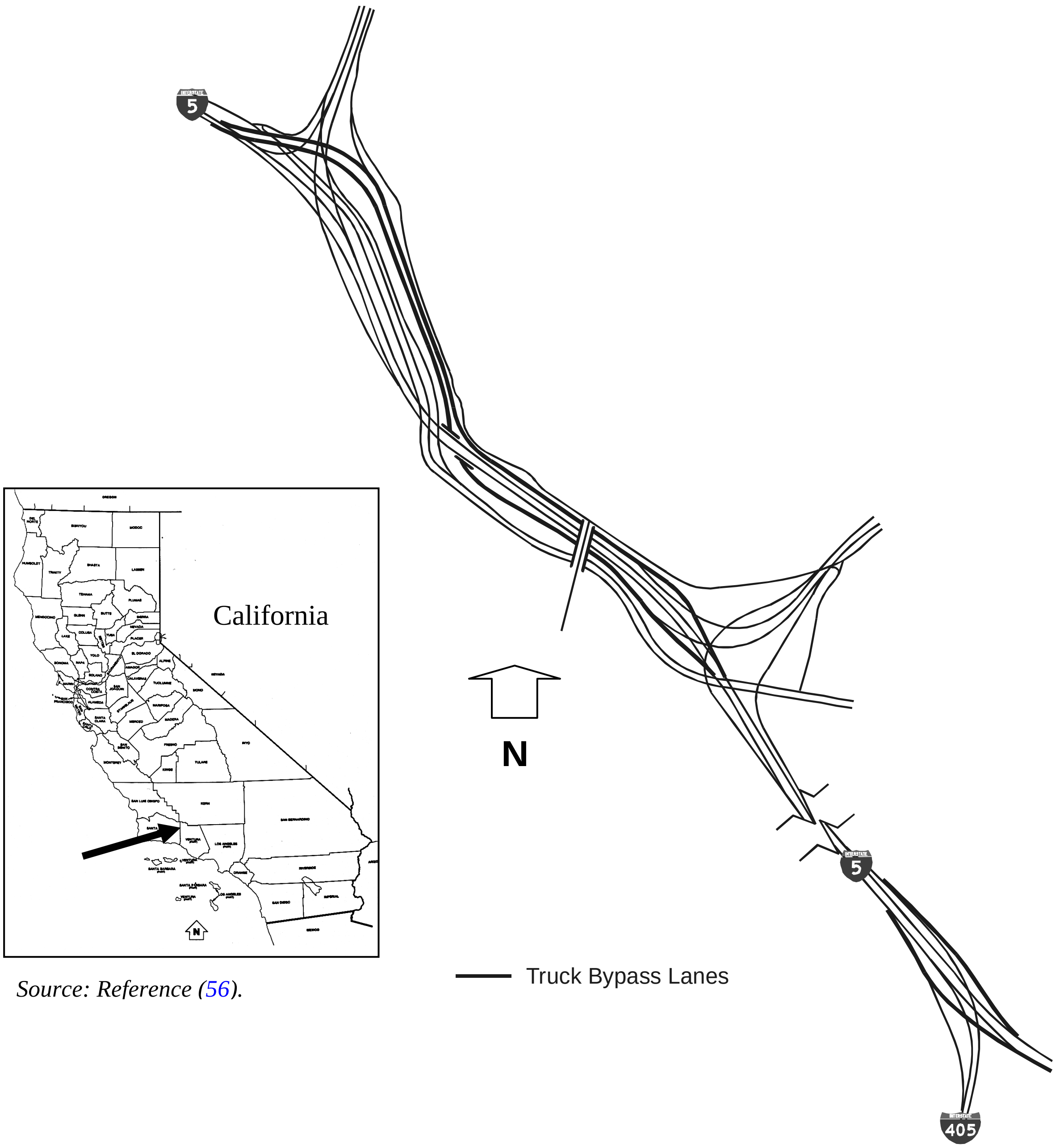
The approximate construction cost of a dual-dual roadway with 12 lanes is $25 to $30 million per mi excluding interchanges. Some of the most recent interchanges in urban and suburban areas cost the turnpike authority over $100 million, including toll plazas and related appurtenances. One fairly recent interchange in a rural area with 11 toll lanes and new inside ramps (used existing outside ramps) cost $45 million. An improvement project completed in the early 1990s, which widened a six-mile segment of non-dualized freeway to a dualized freeway with 10 lanes (2-3-3-2 configuration) and some interchange improvements, cost the authority $300 million.

Rough estimates of non-dualized freeway indicate a cost of approximately $10 million per mile, excluding environmental challenges, which must be addressed. For example, noise barrier is required now, whereas it was not required as much in recent years. In one example, the cost of noise barrier construction and relocation of houses cost $28 million on a 15-mi segment of freeway.

5.4.2 Caltrans Truck Facilities

The California Department of Transportation (Caltrans) has utilized truck bypass lanes at high-volume interchanges and a 2.42-mi truck roadway near the Los Angeles area since the 1970s. For the truck roadway, Caltrans made use of an old roadway alignment parallel to I-5 north of Los Angeles and just north of the I-5/I-405 interchange. Figure 35 shows this alignment of the truck roadway and the truck bypass lanes at the I-405 interchange. Cars can also use all of the truck facilities. The truck roadway is a segment of controlled access facility involving significant grades, so truck speeds are slower than free-flow speeds of passenger cars especially in the northbound (uphill) direction. The truck roadway allows trucks to regain speed at the top of the hill before merging with other traffic. Figure 36 is a photo showing northbound trucks near the base of the grade parallel with I-5 mainline traffic with southbound trucks to the far left on the truck facility.

Lane restrictions on bypass facilities in California require trucks to remain in the right lanes, which means that if trucks exit the main lanes from the right side and reenter from the right there is no weaving required. Bypass lanes are a solution used by Caltrans in locations where safety is a concern due to speed differentials or where weaving capacity is exceeded. The trucks exit the main lanes upstream of the first exit ramp leading to the intersecting roadway and they reenter the main lanes downstream of any entrance ramps from the intersecting roadway.



Source: Reference (56).

Figure 35. Schematic of I-5 Truck Bypass.

Figure 36. I-5 Traffic Lanes and Parallel Truck Facility.

The primary reason for initially building the bypass lanes at interchanges was to reduce weaving problems, which were occurring with all traffic passing through the main lanes at the interchanges. There are three examples in the Los Angeles area of truck bypass lanes at interchanges to reduce or remove weaving for trucks: I-5 at I-405 north of Los Angeles (see Figure 35), I-5 at I-405 in Orange County, and I-405 at I-110/SR-91. Figures 37 and 38 show schematics of two of these facilities and Figure 39 is a photo on I-5 for traffic going northbound approaching the I-5/I-405 interchange north of Los Angeles as trucks enter the bypass. Figure 40 is a downstream view of this same bypass looking north to its merge point with traffic from I-405 to the south and I-5 car traffic that did not exit onto the truck bypass.

5.4.2.1 Crash Rates

The research team requested information from Caltrans to determine the crash history of the truck roadway on I-5 (designated by Caltrans as I-5S) shown in Figures 42 and 43. The analysis of crash rates also used traffic data from the Caltrans web site *(57)*. Appendix F shows the tabulations of data and the resulting crash rates for the truck roadway compared to the main lanes; Table 43 shows the summary results of these analyses. The crash data requested from Caltrans facilitate two possible comparisons of crash rates from 1997 through 2001. The primary comparison is between the truck roadway and segments 10 and 11, which is the section of I-5 parallel to and alongside the truck roadway for non-truck traffic. Its grade and other features make it a more appropriate comparison section than the second one, but its length is the same as I-5S and is relatively short. The secondary comparison utilizes segments 1 through 7, which is a longer section of I-5 just to the south of the truck roadway. Figure 41 is a map of this area showing the segments of I-5 and I-5S included in this evaluation. The reason for choosing the section of I-5 to the south as a secondary comparison was to provide a longer length of freeway for comparison, even though some of the factors that could have affected crash rates are not the same as segments 10 and 11.

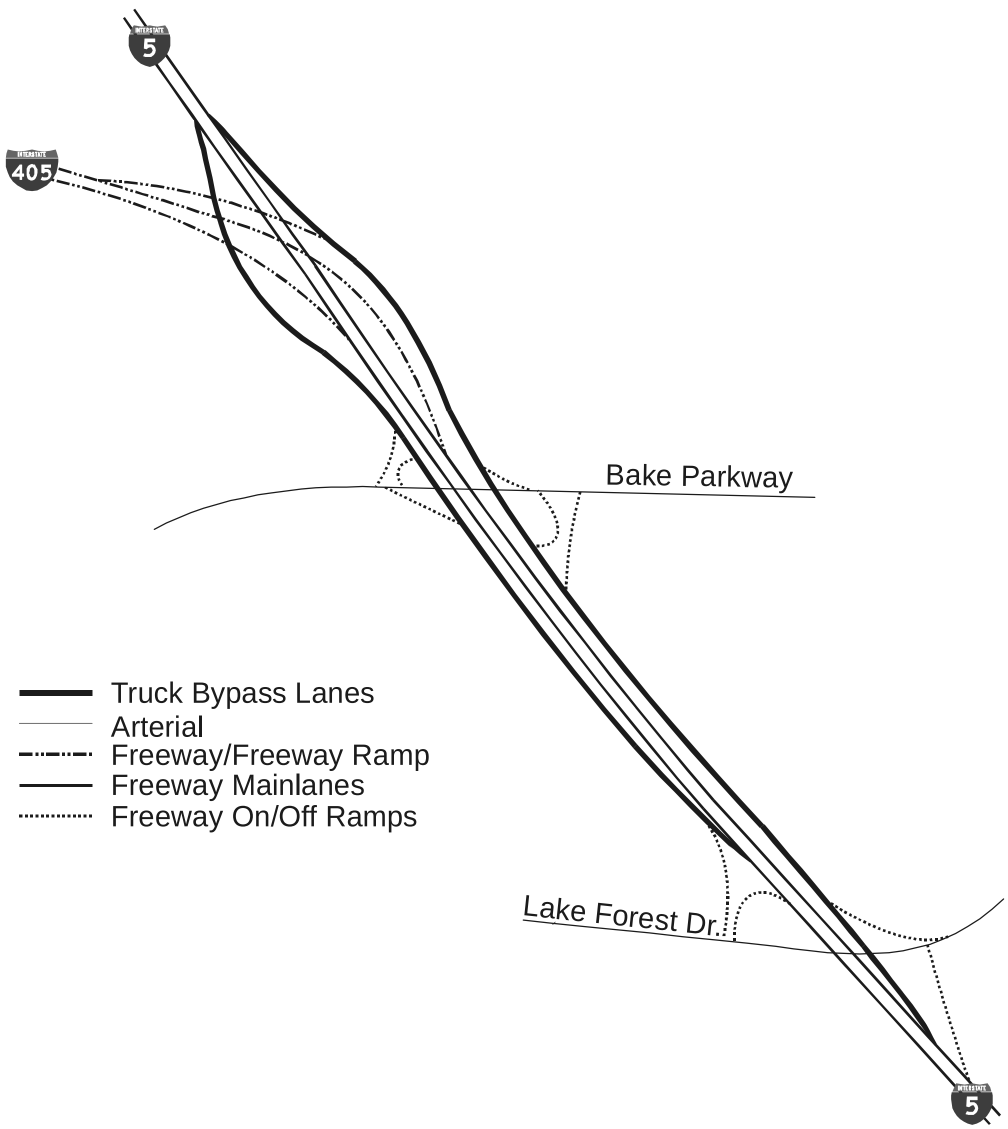


Figure 37. I-5/I-405 North of Los Angeles.

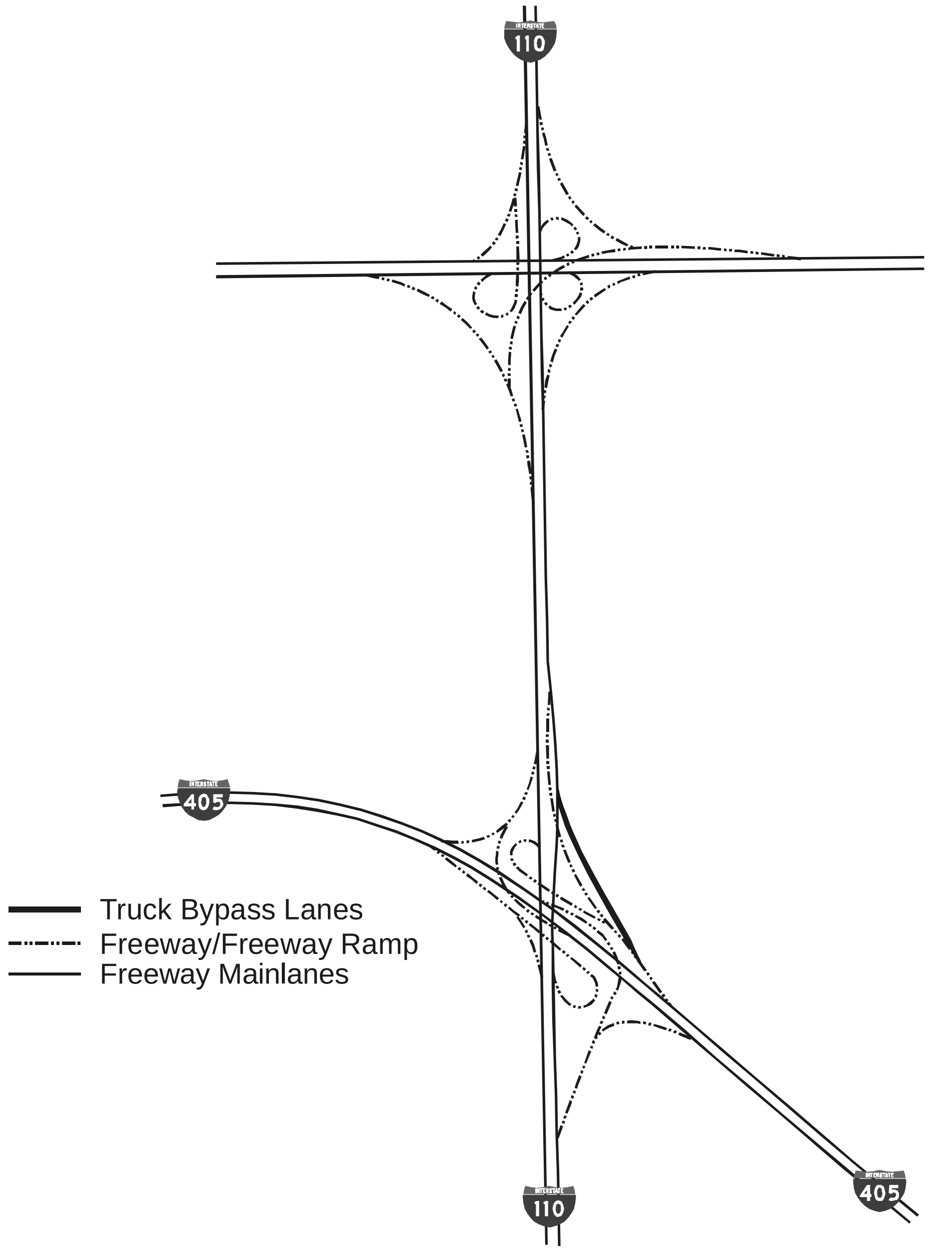


Figure 38. I-405/I-110/SR-91 in Los Angeles.

Figure 39. Northbound I-5 Entering the Truck Bypass at I-405.

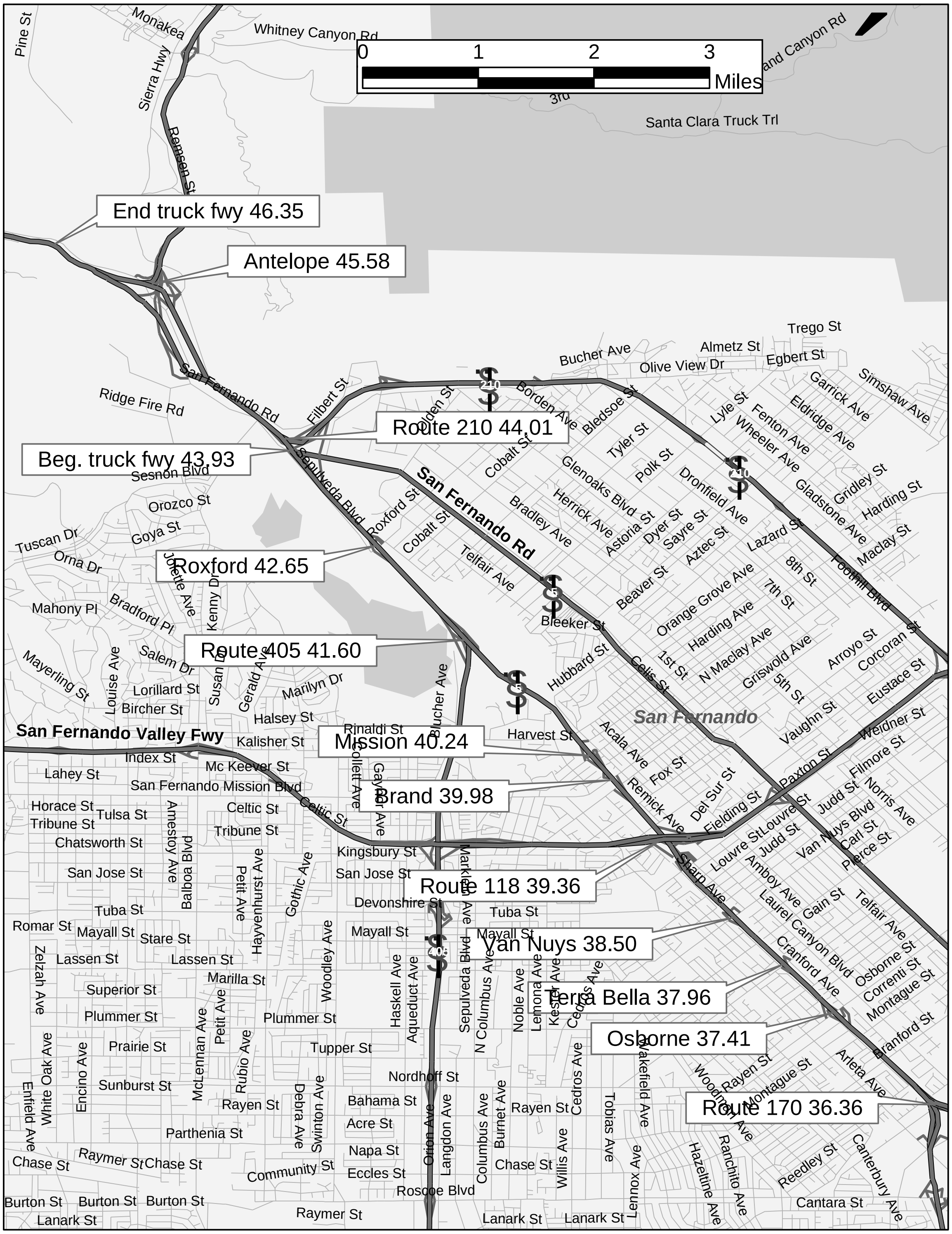
Figure 40. Northbound I-5 Leaving the Truck Bypass at I-405.

Table 43. Crash Rate Summary Comparing I-5 and I-5S.

Year	Route	Segment	Crash	Fatal	Injury	From	To	Length	100 MVM/yr	Rate (per 100 MVM)		
										Crash	Fatal	Injury
1997	5	1-7	209	1	110	36.36	41.26	4.9	3.771	55.42	0.27	29.17
	5	10-11	98	2	66	44.01	46.35	2.34	1.656	59.19	1.21	39.86
	5S	1-3	31	1	12	43.93	46.35	2.42	0.297	104.38	3.37	40.41
1998	5	1-7	245	2	104	36.36	41.26	4.9	3.739	65.53	0.53	27.82
	5	10-11	98	0	46	44.01	46.35	2.34	1.724	56.83	0.00	26.68
	5S	1-3	30	0	12	43.93	46.35	2.42	0.301	99.54	0.00	39.81
1999	5	1-7	245	3	118	36.36	41.26	4.9	3.766	65.06	0.80	31.34
	5	10-11	114	2	61	44.01	46.35	2.34	1.776	64.19	1.13	34.35
	5S	1-3	22	0	3	43.93	46.35	2.42	0.316	69.69	0.00	9.50
2000	5	1-7	260	2	130	36.36	41.26	4.9	3.954	65.75	0.51	32.88
	5	10-11	111	2	41	44.01	46.35	2.34	1.810	61.33	1.11	22.65
	5S	1-3	14	0	6	43.93	46.35	2.42	0.316	44.35	0.00	19.01
2001	5	1-7	244	0	135	36.36	41.26	4.9	4.046	60.31	0.00	33.37
	5	10-11	150	0	63	44.01	46.35	2.34	1.835	81.74	0.00	34.33
	5S	1-3	15	0	8	43.93	46.35	2.42	0.316	47.52	0.00	25.34

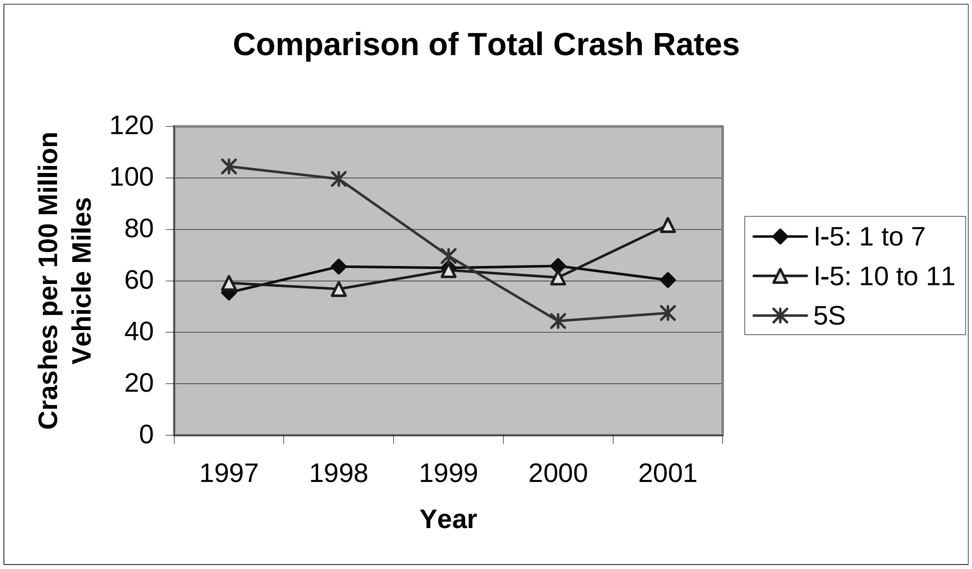
Data Source: Caltrans.

Figures 42 and 43 are plots of the crash rates comparing the truck roadway and the two comparison sections. Analysis of the data plots indicates some interesting findings. The section of I-5 with cars only would be expected to exhibit a lower total crash rate than I-5S since I-5S is mixed flow. Indeed, total crash rates are lower from 1997 through 1999, but they are higher in 2000 and 2001. Similarly, one would expect injury and fatal crash rates to be higher where trucks and cars operate together, and they are, in fact, higher in 1997 and 1998, but not in other years.



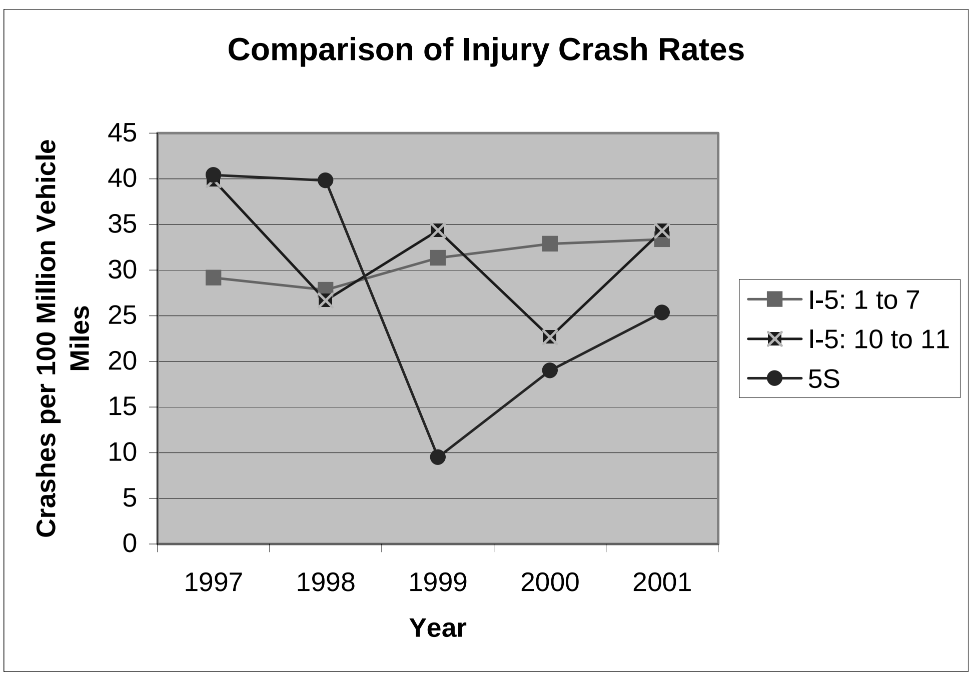
Source: Reference (58).

Figure 41. Map of Truck Roadway and Comparison I-5 Sections.



Data Source: Caltrans.

Figure 42. I-5 and I-5S Total Crash Rates for 1997 through 2001.



Data Source: Caltrans.

Figure 43. I-5 and I-5S Injury Crash Rates for 1997 through 2001.

CHAPTER 6. CRITICAL NON-GEOMETRIC DESIGN ISSUES

6.1 INTRODUCTION

There are many issues beyond design considerations that need to be considered for accommodating trucks. Many of the items discussed in this chapter are closely related to design, and can become equal in importance, especially if not properly dealt with. Other items may include financial issues, environmental issues, political issues, and acceptance by other motorists. This chapter also has a section that discusses applications of Intelligent Transportation Systems and roadside issues that need to be considered.

6.2 METHODOLOGY

Findings for this chapter came primarily from the literature search and from office and phone interviews. Following the literature search and the surveys discussed in earlier chapters, the research team contacted agencies for follow-up visits to supplement initial information.

6.3 CRITICAL NON-GEOMETRIC DESIGN ISSUES

The critical non-design issues relate primarily to lane restrictions or truck roadways and are organized by the following categories:

- Operational, Capacity, and Safety Issues;
- Legal and Policy Issues;
- Social and Public Opinion Issues;
- Compliance and Enforcement Issues;
- Financial and Public Opinion Issues; and
- Environmental Issues.

6.3.1 Operational, Capacity, and Safety Issues

The first issue is to determine whether a lane restriction is justified. A number of studies have attempted to quantify the effects of lane restrictions as summarized below through operational, safety, and other considerations. One consideration is simply the number of trucks using a facility. A study conducted in the Netherlands found that the designation of a truck lane restriction is feasible only when truck traffic density is in the range of 600 to 1000 trucks per hour. Densities lower than this range would result in inefficient lane usage, whereas higher truck traffic densities would result in bottlenecks *(40).*

Results of the recent truck lane restriction demonstration project *(33)* on the I-10 East Freeway in Houston found that compliance rates were high – between 70 and 90 percent – and the highest compliance rate was among local drivers. Vehicle crashes along the freeway main lanes dropped by 68 percent during the 36-week monitoring period, while the operations impact was insignificant. Increased enforcement cannot be ignored as part of the reason for this improvement.

The 1990 study by Zavoina, Urbanik, and Hinshaw found no definitive safety improvements that resulted from the truck restriction. Although the lane distribution of trucks changed significantly due to the restriction, there were no measurable safety effects pertaining to the lane distribution of cars, speeds of either cars or trucks, or the time gaps between vehicles. Even though truck lane restrictions should theoretically improve capacity and safety, the research evidence did not support this assumption *(34).*

Hanscom *(35)* addressed the operational effectiveness of restricting trucks from designated lanes on multilane highways. Reduced speeds of impeded vehicles following trucks were more prominent at the two-lane site. At the three-lane sites, the results of the lane restriction were beneficial traffic flow effects and reduced congestion. No speed changes (between the restricted and adjacent lanes) were observed to indicate an adverse effect of implementing the truck lane restrictions.

The literature review conducted by Mannering, Koehne, and Araucto *(36)* revealed that although a number of states had instituted truck lane restrictions, very few states had documented the effects of the restriction. In nearly every instance where a comprehensive examination of a lane restriction implementation occurred, negligible changes in operations and safety were observed. The in-depth analysis revealed no significant operational or safety level increases that could be attributed to the restriction. The restriction had no noticeable impact on the distribution of the trucks, the economic impact of the restrictions was minor for motor carriers, and there was only a minimal impact on pavement life. The authors recommended against the implementation of truck lane restrictions in the Puget Sound area.

One area of particular concern when implementing truck restrictions on urban freeways is the creation of a "barrier effect" in weaving areas. An indication of the barrier effect is an over-involvement of trucks in weaving area crashes, rear-end collisions, and side collisions. Some studies have shown that this problem may be magnified when a differential speed limit is present *(30, 37).*

Garber and Gadiraju *(25)* used a simulation technique to examine the effects of increased truck operations from implementing different strategies on multilane highways. The study found that:

- the combination of lowering the speed limit for trucks and restricting the trucks to the right lane increased the interaction between cars and trucks and therefore the potential for passenger car/truck crashes;

- the restriction of trucks to the right lane decreased the vehicular headway in this lane, and

- the combination of lowering the speed limit for trucks and restricting the trucks to the right lane resulted in a change in the distribution of vehicle spot speeds, and a slight, but statistically insignificant, increase of crashes on the right lane.

Garber and Joshua *(38)* examined large truck crashes on Interstate highways in Virginia for the period from 1983 to 1985, finding that enhanced safety can result from reducing interactions between large trucks and non-large trucks. Lane restrictions may be one way to at least partially effect this reduction.

Wishart and Hoel found that mixed vehicle travel is associated with higher risk, especially for the occupants of smaller or lighter vehicles, and that one contributing factor for crashes is the difference in operating characteristics of trucks and passenger cars. The authors concluded that when properly implemented, adequately publicized, and sufficiently enforced, truck traffic strategies could effectively increase safety, improve traffic operations, and decrease the pavement deterioration rate on interstate highways *(46)*.

The four truck interchange bypass facilities in the Los Angeles area have all improved vehicle operations, although their effects have not been well documented. In an informal sense, the truck bypass lanes have received mixed reviews; many passenger car drivers use them instead of going through the interchange in order to avoid weaving. Truck drivers would prefer to restrict the bypass lanes to trucks only due to differences in vehicle operating characteristics and because of an apparent lack of understanding by auto drivers of truck operating characteristics *(39)*.

The truck bypass facility on northbound I-5 near Portland, Oregon at the Tigard Street interchange is similar to some of the California facilities. With the truck bypass roadway, truck speeds are now typically 50 mph in the merge area, whereas prior to implementation of the bypass lane, truck speeds were 20 to 25 mph *(39)*.

6.3.2 Legal and Policy Issues

State transportation officials usually have the authority to implement lane restrictions, but in many instances, local jurisdictions have the authority through existing legislation to implement restrictions on state highways. The Surface Transportation Assistance Act in 1982 and Tandem Truck Safety Act in 1984 established a national network of highways as a designated large truck network. The law is insistent that state regulations should not interfere with interstate truck movements, as long as the trucks conform to size and weight limits established by STAA and TTSA *(23)*.

An issue exists for non-urban areas such as I-35 north of Waco where TxDOT officials are considering lane restrictions but the current legislation passed in May 1997 by the 75th Texas Legislature requires that a local municipality initiate the action to request lane restrictions within the municipality's jurisdiction. Even though TxDOT must approve the request, a municipality must currently initiate it *(23)*.

6.3.3 Social and Public Opinion Issues

The response by the general public to the Trowbridge et al. *(41)* study indicated considerable resistance to any strategy that was perceived as a special benefit to truck traffic. However, the general public favored truck lane restrictions. Nineteen percent of individual comments stated that trucks were unable to maintain constant speed or traveled at different speeds, while 13 percent viewed trucks as dangerous or unsafe. Both the OECD study *(40)* and public input on the Capital Beltway truck lane restrictions supported the notion of lane restrictions. In the beltway case, public opinion was so favorable that lane restrictions were maintained even though there was no indication of improved traffic operations or a reduction of crashes *(59, 60).*

6.3.4 Compliance and Enforcement Issues

In order for an enforcement program to be successful, a number of components must be present. These components include legal authority, fines and citations, enforcement strategies, enforcement techniques, funding, and communication. The Mannering, Koehne, and Araucto study in the Puget Sound region addressed enforcement issues in terms of violation rates. Researchers found that the violation rate for trucks during the restriction was 2.1 percent, which was the same as the proportion of trucks in that lane prior to the restriction. Increased enforcement did not alter the percentage *(36).*

6.3.5 Financial and Public Opinion Issues

A recent study for the Reason Policy Institute by Samuel et al. proposed self-financing toll truckways consisting of one or two lanes in each direction be built in the existing right-of-way. Financing for the truckways would be from tolls collected from trucks using the facilities. Trucks using the truckways would be rebated federal and state fuel taxes for the mileage traveled on the truckways. Federal truck size and weight regulations would also be eased for truckway users *(51).* Even with heavy truck size and weight incentives, the use of single lanes with apparently no opportunities for overtaking slower trucks is perceived as a critical flaw of this analysis.

In contrast to the Reason Policy Institute findings, the S.R. 60 Truck Facility Project in California was not anticipated to raise sufficient revenues by toll collection to cover its construction cost. There were several scenarios evaluated at differing costs, but the most advantageous of these would raise $1.2 billion of the total construction cost of $4.3 billion. The remaining $3.1 billion would have to be raised through other federal, state, or local sources. Based on historical data, this funding gap would be larger than public funding agencies would be willing to cover. The gap is also too risky for significant private investment in project construction. Therefore, the financial consultant concluded that the project was not financially feasible *(49)*.

In a 1990 FHWA study, Janson and Rathi *(44)* designed an analysis format that could evaluate the economic feasibility of exclusive lanes for specific sites on high-volume, limited access highways in both urban and rural areas. Battelle *(45)* updated the model parameters, finding an attractive benefit/cost relationship on facilities with at least four lanes in each direction when the total traffic volume reaches 100,000 vehicles per day with at least 25 percent trucks. The model also considers level-of-service, truck-involved crash rates, and other criteria.

Trowbridge et al. investigated the benefits and costs of using reserved capacity lanes as exclusive truck lanes in the Seattle area. The economic analysis reflected increased pavement deterioration in the reserved capacity lane and decreased pavement deterioration in other lanes. The net effect would be a modest overall increase in cost due to pavement deterioration and the consequent increased maintenance. In the reserved capacity feasibility study by Trowbridge et al., an attitudinal study of motorists and the general public examined opinions regarding the use of HOV lanes by trucks. The response by the general public indicated considerable resistance to any strategy that was perceived as a special benefit to truck traffic *(37)*.

When Wishart and Hoel *(46)* investigated exclusive truck facilities in Virginia using EVFS, they developed a list of expected benefits and costs. Expected benefits are offset by expected costs in engineering, construction, additional right-of-way, signage, enforcement, and maintenance. Although expected costs may outweigh benefits, many of the costs are one-time costs, while the benefits are recurring.

In a 1997 report, Hoel and Vidunas *(50)* examined the economics of exclusive vehicle facilities defined by the EVFS program. The authors found that although no single factor is dominant, there are a number of factors that contribute to the feasibility of exclusive lanes. These factors include: traffic volume, vehicle mix percentage, crash rate, and maintenance and construction costs. Maintenance and construction costs are given more weight in EVFS than other factors.

A significant obstacle to exclusive truck facilities is public opinion. The OECD report on truck roads verified that exclusive truck facilities would be unpopular with the general public. People living near an exclusive truck facility would not perceive a direct benefit and may oppose the facility. Once again, although public opinion is negative toward exclusive facilities, the public generally favors the restriction of trucks to specific lanes *(40)*.

6.3.6 Environmental Issues

The 1992 study by the OECD on cargo routes and truck roads noted that vehicle emissions and energy consumption increase with traffic congestion and speed variations. Speed variations can increase both emissions and fuel consumption by 25 to 40 percent, while traffic congestion can increase emissions and fuel consumption by 50 to 100 percent *(40)*.

The European Conference of Ministers of Transport held a special conference on the environment in 1989. Based upon the current state of traffic, a 10 percent reduction in traffic congestion for trucks would result in a significant decrease in environmental pollution while a 10 percent decrease in traffic congestion for automobiles would be inconsequential *(53)*.

6.4 ITS AND ROADSIDE PARKING

This section encompasses elements such as Intelligent Transportation System treatments for trucks and roadside parking for commercial vehicles. The text that follows discusses a few of the more pertinent applications that have been documented in the literature or that research staff discovered through interviews.

6.4.1 Intelligent Transportation Systems

Some of the elements that qualify as Intelligent Transportation Systems for trucks can also serve passenger car needs. Included are variable message signs (VMS), automated traveler information systems (ATIS), in-vehicle devices, and transponders. Devices that detect the size, speed, and weight of trucks require special roadway sensors. For applications where truck drivers are unable to perceive potential hazards in design features, warning systems can be effective in measuring truck height, speed, and weight and determining if the truck is too large or traveling too fast for the conditions ahead. Examples of roadway geometric features that may present problems are limited overhead clearance, sharp curves on freeway connectors or on the mainline, and long downgrades. Curves are more hazardous for large trucks than passenger cars due to the higher propensity of rollover in large trucks. The discussion that follows begins with more general applications for all vehicles followed by that specifically for trucks.

6.4.1.1 Smart Signs

Variable message signs are a consideration for controlling traffic on each roadway where there is one roadway for cars and another for trucks. These signs can facilitate diverting traffic from one roadway to another if an incident occurs. Planners should assess the need for traffic monitoring systems versus relying on 911 cell phone calls to detect problems such as incidents. These signs will also be useful in displaying information pertaining to traffic congestion or other problems downstream of the actual sign location. The initial planning for truck facilities, whether exclusive to trucks or not, should also include communication for video and data to urban traffic management centers such as in Austin, San Antonio, and Houston.

6.4.1.2 Truck Rollover Warning Systems

Although rollover crashes are not the most common type of crash involving large commercial vehicles, they are often catastrophic. The higher eye height advantage of truck drivers is not always sufficient to provide the driver an adequate view of roadway geometrics, so ITS elements can fulfill a need by supplementing other more typical roadway information. One of the ITS safety systems that has been successfully deployed in a few locations is rollover warning systems. Until recently, these systems were completely outside the vehicle and provided driver input through a roadside warning device. At least one device has also been introduced as an available option from one large truck manufacturer to be installed on the vehicle to provide an in-cab warning. The University of Michigan Transportation Research Institute *(61)* recently evaluated this system.

Most recently, Georgia DOT contracted the installation of six truck rollover warning systems near Atlanta. The purpose of these warning systems is to reduce crashes on hazardous highway curves. The systems measure weight, height, and speed while a truck is traveling at highway speeds, and utilize this information to warn a driver of unsafe conditions. The six sites in Georgia are located at the highly congested intersections of Interstates I-20, I-75 and I-85 with I-285 surrounding the city of Atlanta *(62)*.

Newer intelligent rollover systems can incorporate several vehicle parameters to help determine the safe speed for that vehicle. The most sophisticated systems can utilize speed, weight, live load, non-live load, vehicle height, and vehicle configuration function as vehicle descriptors in estimating the safe speed for each truck approaching a downstream horizontal curve or other potential hazard. However, there is still the need to input the characteristics of the load as it largely determines the rollover propensity. At some future date, there will probably be on-board components, in addition to the increasing numbers of on-board computers, that communicate composite (load plus vehicle) center-of-gravity information to a roadside system, which can more accurately determine the vehicle's safe speed. Accuracy is critical in rollover warning systems because repeated false alarms tend to reduce system effectiveness. Therefore, adding weigh-in-motion (WIM) improves results, and adding a high-end WIM improves results even more. Upon determining the safe speed for a vehicle, the warning system sends a signal to an active message element that informs the driver to reduce speed to a displayed value *(62)*.

One application of a relatively high-end truck rollover system was on the Capital Beltway near Washington D.C.; it utilized a speed warning system on a freeway ramp that had a history of truck rollovers. This system, installed at the northbound (I-495 exit to Route 123 North in McLean, Virginia, utilized two WIM systems upstream of the curve to calculate the weight, speed, height, vehicle configuration, and deceleration to determine the need to activate the warning sign. Baker et al. concluded that adding vehicle weight as one of the measured parameters reduced the number of false alarms compared to the speed-based system by approximately 44 to 49 percent (depending on the accuracy of the WIM system selected) *(62)*.

Relatively simple speed warning systems detect all vehicles exceeding a preset length plus a preset speed. If both thresholds are exceeded, the warning system sends a signal to activate a visible element in front of the driver to recommend actions to reduce speed. Texas, California, Washington, and Colorado have installed rollover systems that have incorporated speed (and at least in some cases, vehicle length) into an intelligent rollover system. Virginia, Maryland, and Pennsylvania have all installed systems that utilize speed, deceleration, and weight *(62)*.

Middleton *(63)* tested the effects of active and passive signs on truck speeds on a Houston freeway connector (I-610 and U.S. 59 north) that had a history of truck crashes due primarily to two 12-degree horizontal curves and high approach speeds. The baseline signing consisted of a black-on-yellow RAMP 40 MPH sign on the right side near the gore and a set of black-on-yellow curve warning signs (right side only) with advisory speeds upstream of each curve. The study designated the baseline condition as Test Condition 1 (TC 1), and the other conditions as TC 2 (static truck tipping signs), TC 3 (truck tipping signs with advisory plates), TC 4 (large overhead truck tipping sign), and TC 5 (an "active" flashing light system mounted on the truck tipping signs). The active light system only flashed when trucks exceeded a predetermined safe speed. Once the baseline condition (TC 1) was removed, warning devices were additive. For example, TC 2 remained with TC 3, TC 2 and TC 3 remained for TC 4, and so forth. Also, the research measured the speeds near the gore (point “A”), then at the beginning of the first horizontal curve (point “B”), and finally at the beginning of the second curve (point “C”).

The Analysis of Variance result indicated that, in the models tested, TC 5 (active flasher) and TC 2 (adding ground-mounted truck tipping signs) were usually the most effective treatments (exhibited the highest speed reductions), although these two TCs were not always statistically different from each other or from TC 3 and TC 4. In the pure comparison of the active system (TC 5), in which lights came on in one data set and did not in the other, speed reductions were significant in AC and BC data sets, but not in AB data sets, suggesting that truck driver response to the lights occurred downstream of location B. While not intended to show statistical significance, cumulative speed distributions at Location C indicated modest reductions in truck speeds as a result of treatments. At locations B and C, the critical trucks (85th and 95th percentile groups) exhibited decreases of 2 to 3 mph.

Study findings reinforce the need to calculate an accurate safe speed for every individual truck in order to reduce false alarms and improve driver compliance with the displayed safe speed. However, determining an accurate speed requires knowing a center of gravity (c.g.) height for each truck. Most systems assume this parameter based on general characteristics of the truck population since it is difficult to measure at highway speed. However, measuring the weight of the vehicle is one step closer than simply measuring the vehicle footprint. Only a few systems installed to date have used vehicle weight as an input by installing weigh-in-motion systems upstream of a hazardous curve. Even though WIM has accuracy issues, determining whether the vehicle is loaded or unloaded is helpful in measuring c.g. height.

Lee et al. *(64)* reported on a two-year study of a truck warning system at the I-610 and S.H. 225 interchange in Houston. The project focused on freeway-to-freeway connectors at interchanges because of the traffic congestion and safety issues surrounding these facilities. The main project objectives included preparing, installing, operating, and evaluating a system called the Traffic Data Acquisition (TDA3), which was equipped to monitor and warn truck traffic. The system’s safety parameters were set for trucks 16-feet long at a height of 7 feet above the road surface and that were traveling at or above a speed of 56 miles per hour on the straight tapered section of the exit ramp terminal. If these conditions were met, the system initiated flashing lights that warned drivers of the speed violation. The study found:

- Violating trucks in the higher initial speed range of 62 to 70 miles per hour reduced their speed on average by 8 to 10 miles per hour, while those in the lower speed range of 56 to 62 miles per hour reduced their speed by 6 to 8 miles per hour.

- The additional average speed reduction for all violating trucks attributable to the effect of the flashers being activated was 2 miles per hour.

- When speed reduction data were grouped according to time headway between pairs of violating trucks, trucks operating at a headway greater than 6 seconds responded to the warning flashers by reducing speed by an additional 2 miles per hour, on average, more than when the flashers were not activated.

- Trucks operating at a headway equal to or less than 6 seconds also responded to the warning flashers by reducing speed, on average, an additional 2 miles per hour more than when the flashers were not activated.

The Houston District has installed several of these speed warning devices for trucks since the first evaluation of the active warning system.

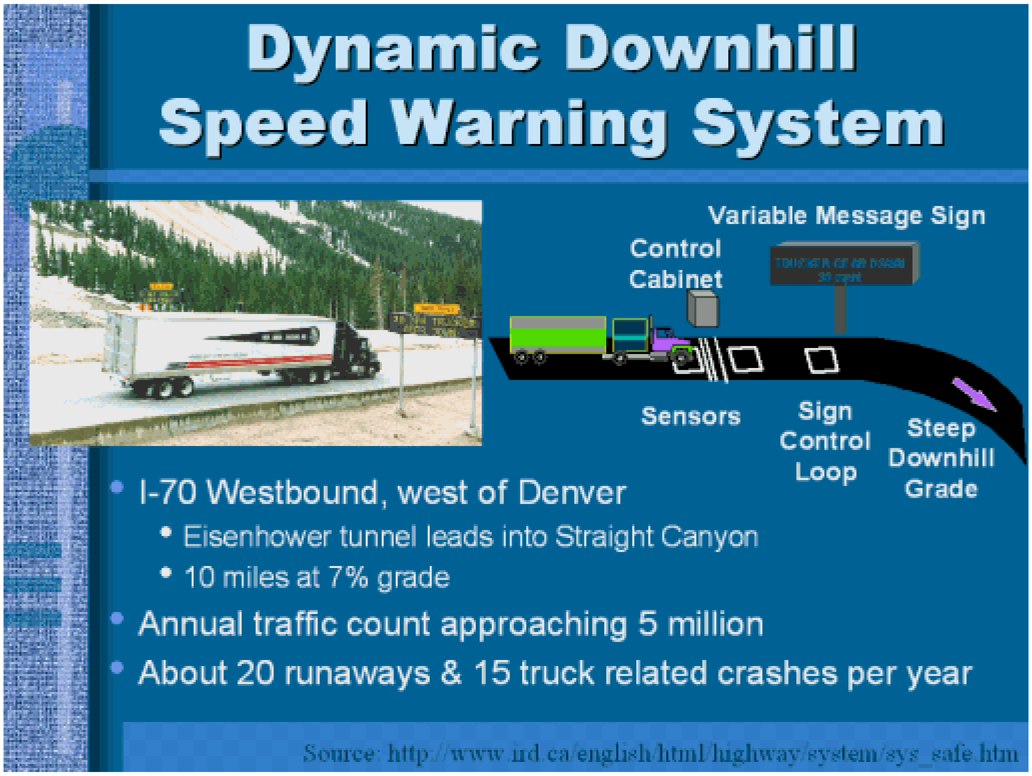
6.4.1.3 I-70 Downhill Truck Warning System

For the period from 1989 to 1991, the six most heavily used downgrades in Colorado experienced 156 crashes, of which four were fatal, 58 were injury crashes, and there was much resulting property damage *(65)*. The Colorado Department of Transportation (CDOT) decided to supplement passive advisory signing and runaway truck ramps with an automated Downhill Speed Warning System. This truck warning system is located on I-70 in the westbound direction west of Denver about one-quarter mile west of the Eisenhower tunnel. It precedes a 10-mile downgrade of 7 percent where truck drivers have not always made adequate preparation at the top of the long grade. Trucks, especially loaded ones, must approach a downgrade of this magnitude and length in a low gear in order to avoid overheating and subsequently losing brakes.

Figure 44 depicts the speed warning system and some of its components. This equipment includes a weigh-in-motion system in the pavement, a variable message sign, a sign control loop, and a microprocessor that communicates with roadway sensors and the VMS. The WIM system determines the classification and weight of each truck, then the warning system processor determines the safe speed for that vehicle by its weight. The VMS displays the safe speed for each truck as it approaches the beginning of the downgrade. Previous research sponsored by the Federal Highway Administration developed algorithms that determined safe speed based on the operating temperature of brakes and overheating characteristics based on the size and weight of the vehicle and the geometrics of the grade. Preliminary evaluation of the effectiveness of this system indicates that overall use of the truck runaway ramps farther down the grade was down by 24 percent compared to its expected use, and crashes resulting from excessive truck speed were down by 13 percent.

6.4.1.4 Overheight Vehicle Detection and Warning System

The Michigan Department of Transportation (MDOT) contracted with a consultant to evaluate the use of an overheight vehicle detection and warning system at a site in Oakland County at the western fringe of the metropolitan Detroit urban area. Three companies that offer such equipment are: Trigg Industries; ASTI Transportation Systems, Inc; and International Road Dynamics. Trigg Industries claims to have provided systems to 26 Departments of Transportation. Its system consists of a transmitter, a receiver, and warning indication components. The transmitter emits two infrared beams across the roadway, which allow the system to distinguish the height and direction of travel. Trigg claims that its system can detect heights at speeds between 1 and 100 mph and that weather conditions such as rain, fog, and snow do not interfere with its operation *(66)*.



Source: Reference (65).

Figure 44. Downhill Speed Warning System.

As part of its contract with MDOT, the consultant prepared and sent out a survey form to determine additional information on the use of overheight detection and warning systems. In general, the agencies felt that the systems were advantageous. Favorable opinions were twice as frequent as unfavorable comments. Mississippi and North Carolina both had long-term experience (over 10 years) with such systems, with Mississippi reporting no additional hits following installation, but North Carolina still recorded hits following installation.

The estimated cost of the active detection and warning system MDOT installed along I-96 near Detroit was $110,000, but its estimated three-year benefit ranged from $609,000 to $674,000. Actual benefits and costs elsewhere would be site-specific, but at this site the installation was economically feasible with a benefit/cost of much greater than 1.0. Also, it provides better protection of a height obstruction than two less expensive alternatives – a passive warning sign and a “sacrificial structure” that is the same height as the obstruction and placed upstream of the obstruction. The consultant recommended to MDOT that it install the active detection and warning system *(66)*.

6.4.2 Commercial Vehicle Parking

Section 4027 of the Transportation Equity Act for the 21st Century (TEA-21) required that a study be conducted to determine the location and quantity of parking facilities in 49 states (Hawaii excluded) at commercial truck stops and public rest areas that could be used by motor carriers to comply with federal hours-of-service rules. The two-step approach used by the FHWA first hired a contractor to clarify truck driver parking-related needs and decision-making. This step included a nationwide sample of truck drivers at commercial truck stops and travel plazas, resulting in a total of 2046 completed surveys. In the second step, the FHWA encouraged the formation of partnerships of public and private sector stakeholders to inventory current facilities serving the National Highway System (NHS) and determine current and projected shortages. This second stage also developed plans for action to meet the identified needs *(67)*.

The consultant determined the peak hour demand for commercial truck parking by developing a model to estimate the demand based on total truck hours of travel and the time and duration of the stops. The model includes the effects of the federal hours-of-service rules on parking demand.

The inventory of public rest areas and private truck stops utilized information from state departments of transportation and a proprietary database developed by Interstate America to determine existing parking availability at public and private facilities, respectively. There are an estimated 315,850 parking spaces at all facilities combined that are serving the needs of Interstate highways and other NHS routes carrying more than 1000 trucks per day. Approximately 10 percent of these spaces are in public rest areas, while 90 percent are in commercial truck stops. Truck drivers value public rest areas primarily for their convenience and commercial truck stops for their amenities *(67)*.

Texas is first among the states with the highest demand for truck parking, followed by California, then midwestern states of Indiana, Illinois, and Ohio. The ratio of public parking versus truck stop parking was based on the national driver survey, which indicated that 23 percent of the demand is at public rest areas and 77 percent is at commercial truck stops. The year 2000 peak hour parking demand in Texas was 8305 spaces in public rest areas and 27,797 spaces in commercial truck stops, with a 20-year forecasted annual increase in parking demand of 2.7 percent.

A total of 105 public rest area facilities (654 spaces) in Texas provide 3 percent of the available parking, whereas 284 truck stops and travel plazas (23,525 spaces) provide 97 percent of the current supply along Interstate and NHS routes with more than 1000 trucks per day. The proportion of total parking supply provided by public rest areas needs to be increased substantially to meet the needs as expressed in the national driver survey *(67)*.

The analysis for overcrowding compared the demand and supply results by examining the ratio of estimated parking space demand (from the demand model) and parking space supply (from the supply survey). A value near 1.0 indicates supply approximately equal to demand, and a value significantly greater than 1.0 indicates a shortage. The demand-supply ratio for Texas for public spaces was a value of 12.70, which was the second worst ratio of all the states. However, for commercial space, the value was 1.18, indicating a shortage but not nearly as severe as for public parking spaces. Current and future actions planned by TxDOT to improve the demand/supply value include expanding public facilities. Other actions planned or suggested by some states include: expanding or improving commercial truck stops, encouraging the formation of public-private partnerships, educating or informing drivers about available spaces, changing parking enforcement rules, and conducting additional studies *(67)*.

CHAPTER 7. TRUCK DESIGN THRESHOLDS

7.1 INTRODUCTION

Based on public hearings pertaining to the I-69 corridor project through TxDOT's Houston District, one public desire was separating trucks from passenger cars by barriers. Recently, the Research and Technology Implementation Office of TxDOT conducted a survey of districts to determine: 1) actions currently being taken to mitigate the impacts of increasing truck traffic levels on the Texas highway system, and 2) actions suggested by survey respondents to mitigate truck impacts *(3)*. One-third of all responses indicated a need for managed lanes along freeways, especially through urban and metropolitan areas. Responses were divided as to the best way to separate truck traffic from smaller vehicles. Suggestions include "preferred truck lanes," "designated truck lanes," "truck only lanes," and "truck-excluded lanes." The next issue pertains to the conditions for considering these measures.

7.2 METHODOLOGY

This chapter makes use mostly of previously gathered information to determine appropriate thresholds for truck design treatments. There is limited information in the literature from other facilities in California and New Jersey that accommodated trucks on separate roadways. However, these facilities also allow smaller vehicles to operate on the truck facilities. There are no controlled access high-speed facilities in the U.S. that allow only trucks, so this discussion builds on the California and New Jersey experience and utilizes the experience of the research staff to develop meaningful design thresholds.

7.3 STRATEGIES/REASONS FOR SEPARATING TRUCKS

Large trucks operating together on the same lanes and separated from cars operating on their own lanes forms two more homogeneous blends of vehicles with similar operating characteristics when compared to a single mixed traffic stream. Acceleration rates, stopping distances, weaving capabilities, and roll stability are but a few of the operational characteristics that make trucks different. Driver knowledge and expectations are factors in this environment as well because many car drivers behave as if they expect trucks to operate like passenger cars. Even these operational features alone are not sufficient justification to build expensive truck roadways, but as overall congestion increases and the numbers of trucks increase and trucks are involved in incidents, the result is often much more catastrophic than if only cars are involved. Crash severity generally increases where trucks are involved, resulting in greater damage to smaller vehicles and their occupants and to roadway appurtenances. It is easy to understand why safety is the most prominent argument used to support the concept of separating trucks although lack of supporting safety documentation for full separation of trucks leaves uncertainty regarding the full safety implications. Another supporting reason for separating trucks is being able to design truck roadways with thicker pavement for heavier truckloads while designing car lanes with thinner pavement (or realistically for smaller or fewer trucks).

Separating trucks from other traffic can occur either spatially or by time of day. Spatial separation can be accomplished to some degree by designated routing or by placing trucks in their own lanes along the same routes with passenger vehicles. Certain commodities such as hazardous materials need the maximum practicable separation from other traffic and population centers, so some cities have designated non-radioactive hazardous material routes for the through movement of these vehicles. Truck lane restrictions may only apply to certain hours of the day or certain traffic conditions or both. In Texas, the I-10 lane restriction in Houston was limited to weekdays and daylight hours when traffic was heaviest. Cities often pass ordinances to establish truck routes whose purpose is to keep trucks on routes that best accommodate them geometrically and structurally, and minimize their impact by separation from population centers or other environmentally sensitive areas. Cities with alternative or bypass routes sometimes restrict long-haul trucks from using interior, non-bypass routes, but enforcement of these bans is difficult.

Based on preliminary information gathered in this research and documented in Chapter 4, there are at least two levels of truck treatment that designers should consider. The process used today utilizes a "design vehicle" and ensures that it can negotiate any geometric feature with relative ease. Perhaps for all design, but more importantly, as truck intensity increases, design should be *truck friendly.* This concept means overall consideration of accommodating large vehicles without consideration of any particular class of large vehicle. It includes the idea of a "forgiving roadway environment" that, for example accommodates the greater off-tracking demands of long vehicles without causing damage to either highway appurtenances or to the large vehicle or unduly infringing on other traffic streams while maneuvering.

This report considers three possible scenarios for trucks, with the status quo being no specific treatment for trucks and allowing them to operate as part of the mixed flow of traffic. Even in this scenario, there will be a need to consider trucks in design. Then, there are two levels of separated operations for trucks. One is normally referred to as lane restrictions or lane designations for trucks. It allows trucks to remain in the mixed traffic stream but restricts them to or from certain lanes, allowing at least one lane to be free of trucks. Truck lane restrictions can occur on facilities with at least three travel lanes in each direction, and they normally either restrict trucks from the left lane or to the right two lanes. The second level of separated operations is a truck roadway, typically barrier-separated from other traffic flows and where no cars are permitted.

General findings from the literature pertaining to lane restrictions include *(68)*:

- Trucks should only be restricted on roadways with three or more lanes by direction.
- Trucks should not be restricted to a single lane.

- Perceptions of automobile drivers are positive, while perceptions of truck drivers are generally negative.
- Lane restrictions generally improve traffic operations by reducing potential auto-truck conflicts and by eliminating slower-moving vehicles from certain lanes, but safety improvements are not as obvious.
- Trucks should either be restricted from the left lane or to the right two lanes.
- Trucks should not be restricted in such a way as to make use of entrance and exit ramps difficult.
- Restricting trucks to or from certain lanes may equalize pavement wear by redistributing trucks.

The text that follows summarizes some of the more pertinent examples of attempts to establish thresholds that indicate when special truck treatments are warranted.

7.3.1 Thresholds for Truck Accommodation

The following development of thresholds begins with criteria developed by Battelle *(45)* and Douglas *(68)*, from truck facilities outside of Texas and current or projected truck demand in Texas. Results of both studies are in daily volumes, so the discussion of Texas volumes begins with daily volume then progresses to a more refined evaluation of hourly truck flows by direction. Researchers present this information as information that contributes to development of thresholds, and not necessarily as an endorsement of either study.

7.3.1.1 Battelle Study

A recent study by Battelle sponsored by the U.S. Department of Transportation *(45)* modified and updated a benefit-cost (B/C) model that was developed in 1990 for evaluating the feasibility of exclusive truck facilities. Variables considered by the model include: traffic characteristics, construction costs, units of pavement damage by vehicle type, and costs associated with crashes. The model considers the many inputs and calculates the costs, benefits, Net Present Value (NPV), and B/C ratios for different alternatives of potential exclusive truck facilities (ETF). Table 44 groups these alternatives into five scenarios plus the base case or "do nothing" alternative. Below the list is a more detailed description of each scenario. Because the Battelle study was released so near the end of Project 0-4364, its results need further review and evaluation in future research. Section 7.3.1.2 provides a preliminary discussion of some of its findings.

The Battelle report offers three case studies to indicate the utility of the program and suggests thresholds for certain truck improvements. The first example is a 3.5-mile urban section of I-10 in Alameda County in California with five lanes in each direction and one interchange. The 1999 traffic volume on this freeway was 155,500 vehicles per day in each direction with a truck percentage of 6 percent. The most promising options were Case 5 with a B/C ratio of 7.0 and Case 2 with a B/C ratio of 5.3. The only other option with a B/C greater than 1.0 was Case 3 with a B/C ratio of 1.1.

The second example was a 2.6-mile section of urban I-275 in Cincinnati, Ohio, with four lanes in each direction with no interchanges. Traffic volumes on this highway averaged 104,000 vehicles per day in each direction (1999) with a truck percentage of 16 percent. Output from the program indicated that the most promising options were Case 2 with a B/C ratio of 17.2 and Case 5 with a B/C ratio of 5.0. No other options yielded a B/C greater than 1.0.

Table 44. Options Used by the Battelle Model.

Case	Description
Case 0	Do nothing. There is no change to the highway facilities.
Case 1	Add no new lanes but designate existing lanes for mixed, light, and heavy vehicles.
Case 2	Increase the number of mixed-vehicle lanes (no lane use restrictions).
Case 3	Add non-barrier separated lanes and designate at least one lane for the exclusive use of a certain vehicle class.
Case 4	Add non-barrier separated lanes and designate at least one lane for the exclusive use of a certain vehicle class. The difference in Case 4 and Case 3 is that in Case 4 trucks are allowed to use mixed lanes when the capacity of the designated lane is exceeded.
Case 5	Add barrier-separated lanes and designate new and existing lanes for light and heavy vehicles. The additional exclusive lane is barrier-separated from the existing lanes and trucks are restricted to use this facility only. The use of barrier separation is the major difference between this alternative and Cases 3 and 4.

Source: Reference (45).

The third example was a 2.8-mile urban section of I-294 in Chicago, Illinois with four lanes in each direction with one interchange. Traffic volume on this section of freeway averaged 59,000 vehicles per day in each direction (1999) with 26 percent trucks. The result in this case indicated that none of the five cases resulted in a B/C greater than 1.0. The closest was Case 5 with a B/C of 0.9. Table 45 summarizes these results.

Table 45. Battelle Case Study Summary.

Case Study	Facility	No. Lanes by Direction	AADT (vpd)	% T	Case				
					1	2	3	4	5
1	I-10	5	155,500	6%	-	5.3	1.1	-	7.0
2	I-275	4	104,000	16%	-	17.2	-	-	5.0
3	I-294	4	59,000	26%	-	-	-	-	-

Source: Reference (45).

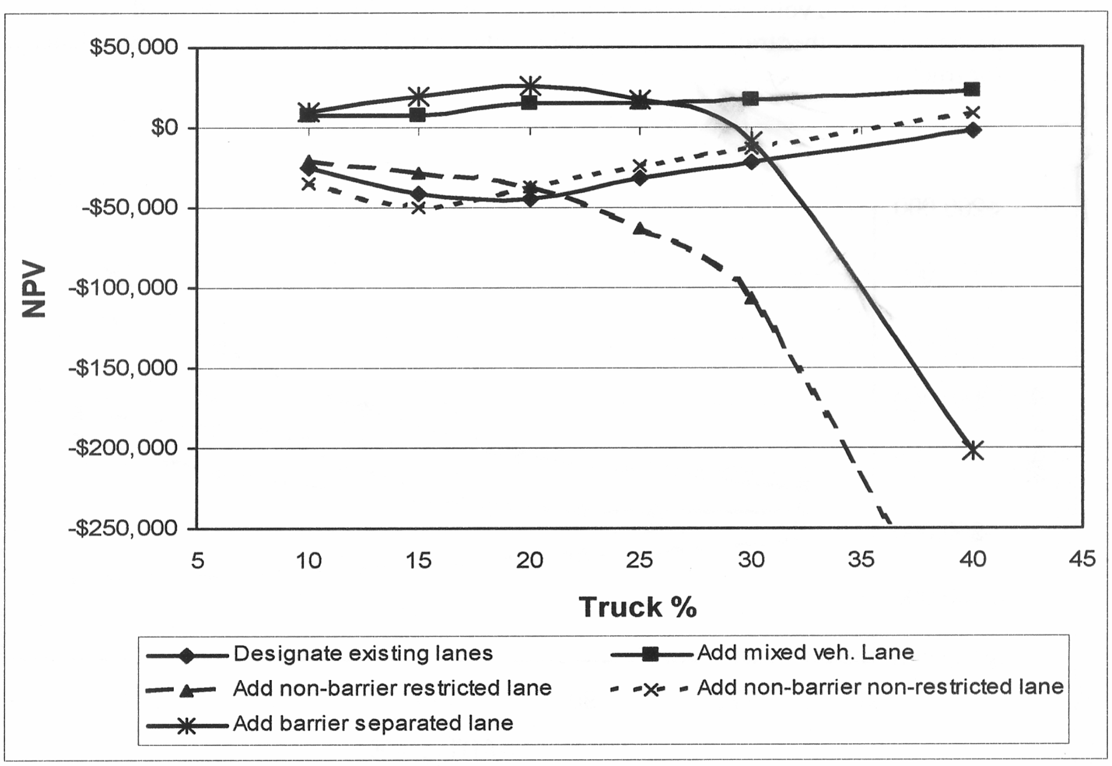
Another evaluation using this updated model involved a sensitivity analysis to determine the range of truck percentages, total traffic volume, and crash rates where certain treatments for trucks might be viable. In the first case, total traffic was arbitrarily fixed at 100,000 vehicles per day and the truck percentage was varied from 10 to 50 percent. Figure 45 from the Battelle report shows the result. The following observations come from this analysis:

- Only two scenarios have positive net present values: 1) adding a mixed vehicle lane, and 2) adding a barrier separated designated truck lane for truck percent less than 30 percent.

- The scenario of adding a barrier separated designated truck lane is most cost-effective at around 25 percent trucks. The results suggest that a truck percent of 25 percent can be a threshold value for all scenarios.

- Adding a non-barrier separated designated truck lane does not appear to be cost-effective as measured by the NPV.

- The NPVs for the scenarios of designating an existing lane (Case 1) or adding a lane but with mixed and designated lanes (Case 4) suggest that these options are only cost-effective for truck percentages greater than 35 percent.

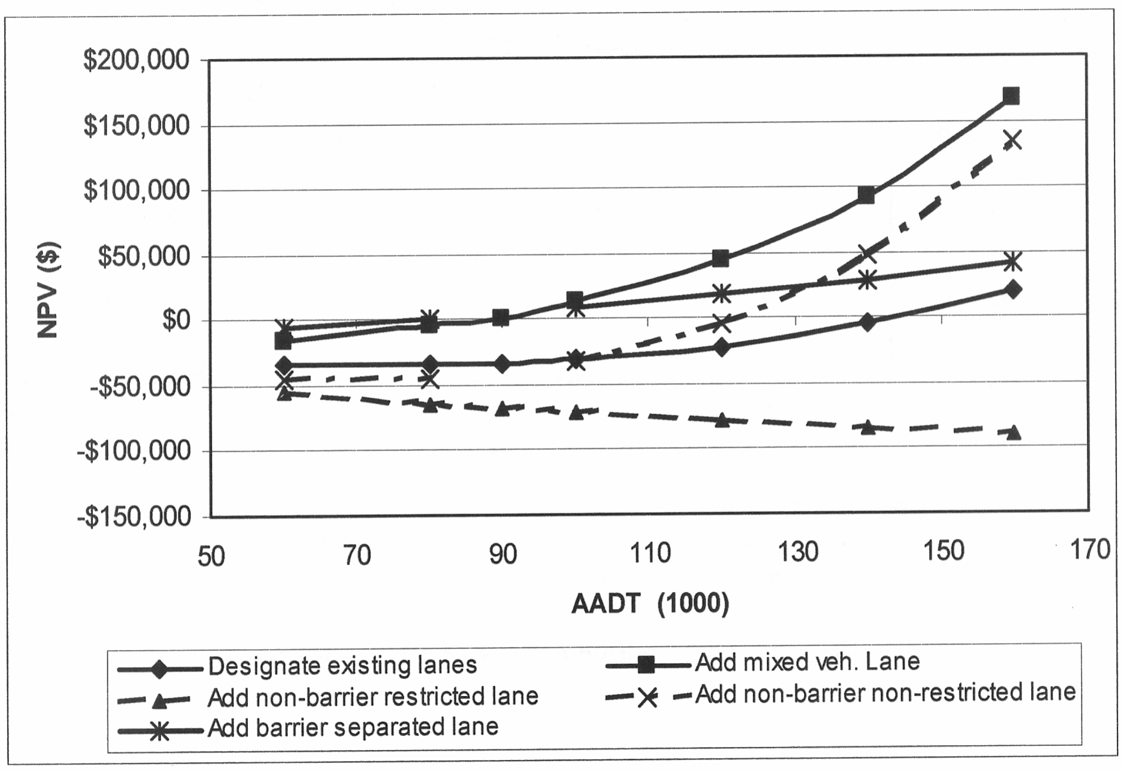


Source: Reference (45).

Figure 45. Sensitivity of Net Present Value to Truck Percent.

The second analysis held the truck percentage fixed at 25 percent and varied the traffic volume from 60,000 vpd to 160,000 vpd in increments of 10,000 vpd. Figure 46 shows the resulting net present values (NPVs). These results indicate the following:

- NPV increases with increasing traffic except for Case 3, adding a non-barrier separated designated truck lane (no mixed lane).
- It is not cost effective to add a non-barrier separated lane and restrict trucks to the designated lane, irrespective of traffic volume.
- Adding a mixed lane is the most cost effective for traffic volumes greater than 100,000 vpd and truck percent around 20 percent.
- Adding a barrier separated designated truck lane is the most cost-effective of all alternatives for traffic volumes between 80,000 and 100,000 vpd.

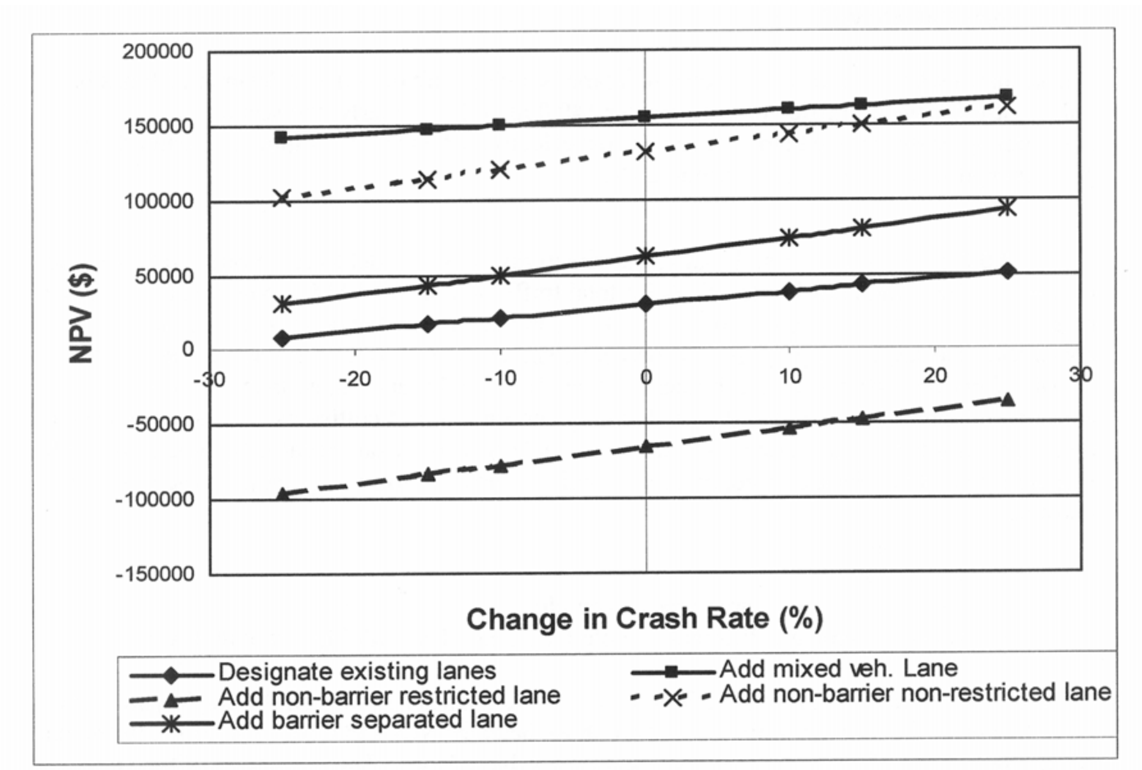


Source: Reference (45).

Figure 46. Sensitivity of Net Present Value to AADT.

The third analysis examines the effect on cost of varying the crash rates for total traffic volume of 100,000 vpd and truck percent of 25 percent. The crash rate was varied by plus-or-minus 10, 15, and 25 percent from the default values. Figure 47 shows how the NPVs vary with percent change in crash rates for each scenario. The following are major indications from the results:

- For all alternatives, the NPVs increase linearly with increasing crash rates. Adding a barrier separated designated truck lane shows the greatest rate of change and is therefore most sensitive to the crash rate.
- Adding a mixed lane is the most cost-effective alternative, followed by adding a barrier separated designated truck lane.
- The alternative of adding a non-barrier separated truck designated lane and restricting trucks to that lane is not economically cost-effective.



Source: Reference (45).

Figure 47. Sensitivity of Net Present Value to Crash Rate.

Table 34 on page 101 summarizes the criteria used by Battelle. One of these factors not discussed already is level of service (LOS). The LOS of a highway segment is a reflection of the volume-to-capacity (v/c) ratio, and it uses categories "A" through "F." LOS A is free-flow with LOS B through E representing increasing levels of congestion and their associated effect on speeds and other factors. Removal of significant numbers of trucks from a mixed traffic stream improves operating conditions and level of service by reducing the volume-to-capacity ratio.

7.3.1.2 Discussion of Battelle Results

Some of the model results need further evaluation, although extensive analysis is beyond the scope of this project. For example, Case 0 (do nothing) has costs and benefits. One would expect that the base case would have costs and benefits of "zero" to facilitate comparisons of alternative cases. The Battelle model computes NPVs, so this may be a non-issue; however, for the sensitivity analysis, it could play a role. Also, the "Add Barrier-Separated Lane" option has a positive NPV (Figure 45) for percent trucks less than 30 percent, but then the NPV becomes negative for percent trucks over 30 percent. One would anticipate that the larger the percent trucks (if it translates to number of trucks), the more beneficial a barrier separated facility would be. Figure 46 also indicates findings that are contrary to expectations in that a mixed vehicle lane is better than a barrier separated lane at AADT values above 100,000 vpd. The model apparently allows Case 5 (barrier separated truck roadway) to occur on only one lane. As noted elsewhere in this report, a single lane barrier-separated truck roadway is not viable. Finally, there is apparently no consideration given to terrain in the model. In rolling terrain, there would appear to be a greater incentive to separate trucks because of their poorer climbing abilities compared to smaller vehicles. Speed differential is a contributing factor to crashes.

7.3.1.3 Other Evidence of Threshold Values

Truck and total vehicular volume are the most likely criteria for establishing thresholds, even though other criteria should be considered too. Measuring and predicting vehicular volume is reasonably accurate, so it appears to be a strongly viable candidate. The driving factor for designation of trucks to certain lanes is usually more than just vehicular volumes. Therefore, establishing a firm threshold pertaining to truck and total volume for this treatment might not be appropriate. Instead, where enough lanes exist, maintaining one or more lanes that are free of trucks seems to be the appropriate objective to optimize traffic operations. The factors noted in Section 7.3 are also important.

One could utilize the implicit and explicit factors surrounding existing facilities in the U.S. that have incorporated special treatments for trucks to suggest evidence supporting the need for such facilities elsewhere. The New Jersey Turnpike, I-5S north of Los Angeles, and S.R. 60 near Los Angeles are examples that generate this type of information. The general useful information gleaned from these facilities, based on information from Douglas *(68)*, pertains primarily to vehicular volumes as follows.

The total two-way daily volume of heavy (class 5+ in Texas 6 Scheme, 3+ axles) trucks should exceed 20,000. Experience has indicated that beyond 20,000 heavy trucks per day the volume of trucks alone can seriously reduce the operational characteristics of the roadway. S.R. 60 in California and the New Jersey Turnpike are examples where heavy truck demand already exists at this level and measures have either been taken or are being planned for preferential truck facilities. In the case of S.R. 60, one scenario under study was a two-lane exclusive truck facility. Douglas concluded that truck demand less than 20,000 heavy trucks per day would not fully utilize a (two-lane) facility *(68)*.

The total daily volume of heavy trucks should exceed 20,000 for a distance of 10 miles, or there should be major sources of truck traffic near the termini of the proposed truck facility. As an example, the initial segment of the New Jersey Turnpike using the dual-dual roadway concept was just over 15 miles in length. Distances shorter than 10 miles might still be justified in special cases near high truck traffic generators such as truck terminals, major warehousing districts, intermodal facilities, and ports *(68)*.

The existing or planned highway should have at least four travel lanes in each direction. Two of these lanes would be general purpose lanes to primarily serve light duty vehicles and two would serve trucks. It is conceivable that a few large trucks might still need to use the general purpose lanes if the ETF does not have as many access points as needed for local delivery or for access to certain services.

The total two-way daily volume of all vehicles on the highway should exceed 120,000. If the daily volume is under 120,000 on an eight-lane highway (assumed freeway), the highway is not operating near its capacity, so even a truck volume exceeding 20,000 tpd would not impede the highway's operation enough to justify an ETF. If the truck demand does not meet its design horizon for several years, the operating agency might consider allowing smaller vehicles on the truck facility for a time in order to reduce congestion on general purpose lanes, and perhaps improve public opinion by fuller utilization of the truck facility *(68)*.

Truck and total vehicular volumes are appropriate criteria for establishing thresholds that identify the need for truck roadways. Both Battelle and Douglas established traffic volume criteria, although it should be noted that the definition of a truck was different between the two studies. This difference could be quite significant. Douglas considered only "heavy trucks" with 3+ axles (Class 5 and above in the Texas 6 Scheme), whereas the Battelle study considered trucks as vehicles heavier than 10,000 lb GVW. To summarize, the two traffic volume criteria for exclusive truck facilities are as follows:

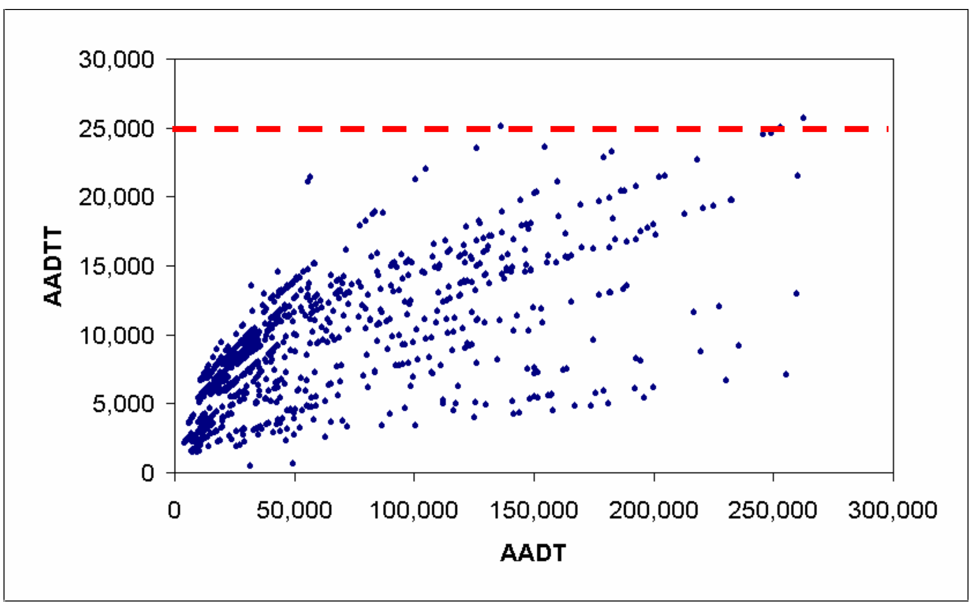
- The Battelle criterion for traffic volume is an AADT of at least 100,000 vpd and 25 percent trucks on a facility with four or more lanes in each direction.
- The Douglas criterion for traffic volume is an AADT of at least 120,000 vpd and 20,000 (large) trucks per day where there are at least four lanes in each direction and the traffic demand occurs over at least a 10-mile length or has a large truck traffic generator at one terminus.

Based on these two studies, the selected AADTT in Texas should be close to 20,000 large tpd (3+ axles) or 25,000 total tpd (over 10,000 lb GVW). Figures 48 through 52 utilize TxDOT data for all trucks above 10,000 lb GVW. The influence of the smaller two-axle trucks varies, with greater influence in and near urban areas. Converting the available TxDOT data to eliminate the smaller trucks varies by location, so an across-the-board conversion would not be appropriate. Based on TxDOT data, the number of Class 3 plus 4 vehicles seems to most highly correlate with urban vs. rural areas and time of day. There are more of these smaller trucks (and buses) in and near urban areas and during daylight hours. There is more discussion below concerning the differences in truck demand by size. The figures show that, on an AADTT basis, only a few locations have the level of truck activity suggested by Battelle and Douglas. Following this discussion of daily demand is a more detailed analysis based on hourly demand.

Other factors suggested in the two studies merit further consideration as well. As always, safety is an important consideration and can be factored into the decision process more effectively when safety aspects of truck roadways are better understood. Also, the LOS is a useful measure of quality of traffic flow where all the traffic and roadway characteristics are known or can be accurately predicted.

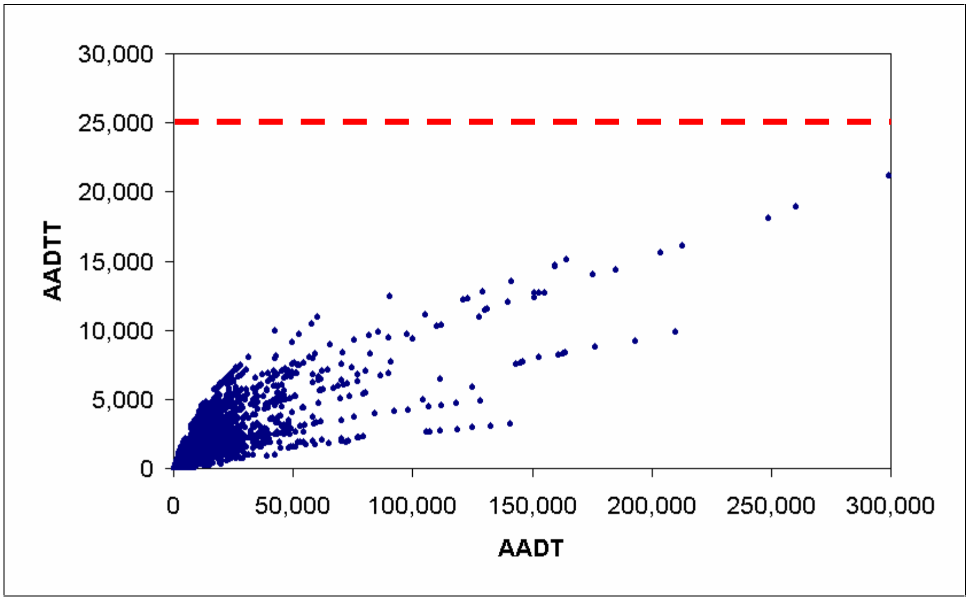
7.3.1.4 Evidence Based on Texas Truck Demand

Figures 48, 49, and 50 indicate the relationship between AADTT and AADT for Texas Interstate highways, U.S. highways, and state highways, respectively. Clearly, IH class roadways serve the largest portion of the high truck demand, followed by U.S. highways. Comparing these volumes of trucks and other traffic with the Battelle and Douglas volumes, one can establish an approximate level of demand where truck treatments should be considered.



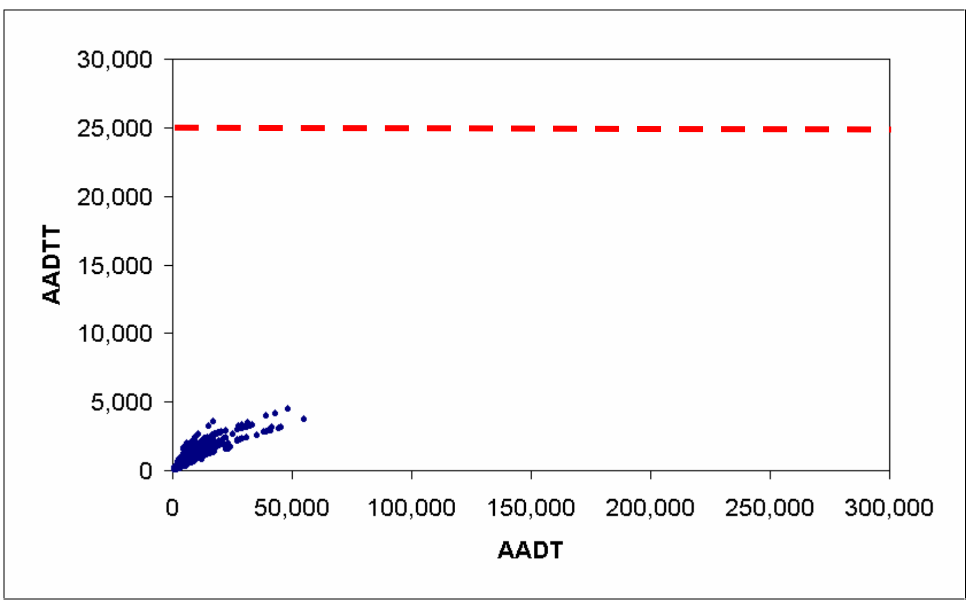
Data Source: TxDOT.

Figure 48. Correlation between AADT and AADTT (IH Road Class).



Data Source: TxDOT.

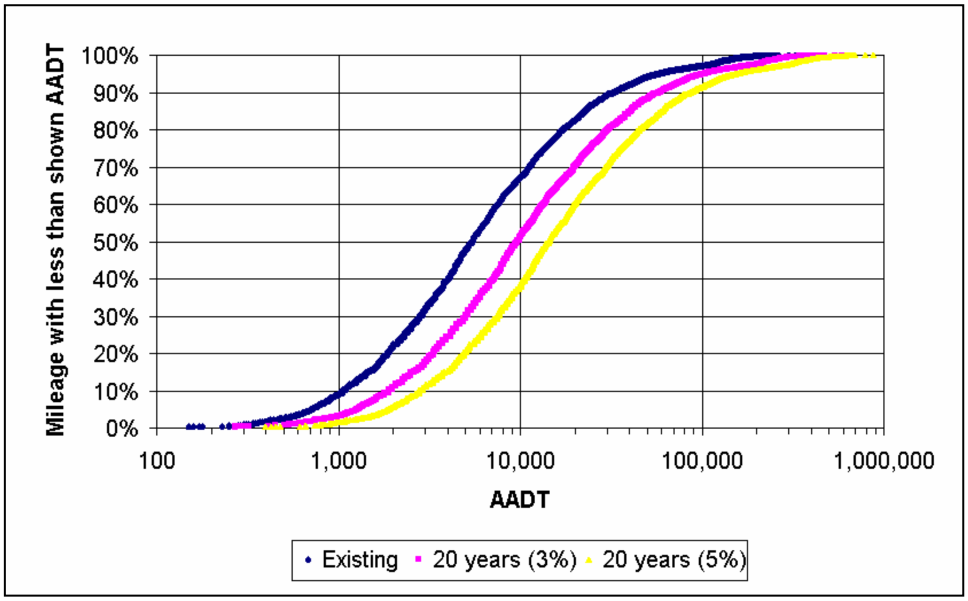
Figure 49. Correlation between AADT and AADTT (U.S. Road Class).



Data Source: TxDOT.

Figure 50. Correlation between AADT and AADTT (S.H. Road Class).

There must be sufficient truck demand to justify each level of truck treatment. In Texas, the interstate system handles the heaviest truck traffic, supplemented by some U.S. highways and even fewer state routes. Chapter 4 developed the basic truck system of roadways with the highest demand and it also developed growth factors that represented most of the high-growth corridors. In general, truck growth is expected to range from 3 percent to 5 percent per year over the next 20 years. Figures 51 and 52 represent cumulative distributions of AADT and AADTT, respectively, over the next 20 years using growth rates of 3 percent and 5 percent. The discussion that follows utilizes this type of data to consider thresholds for truck treatments.

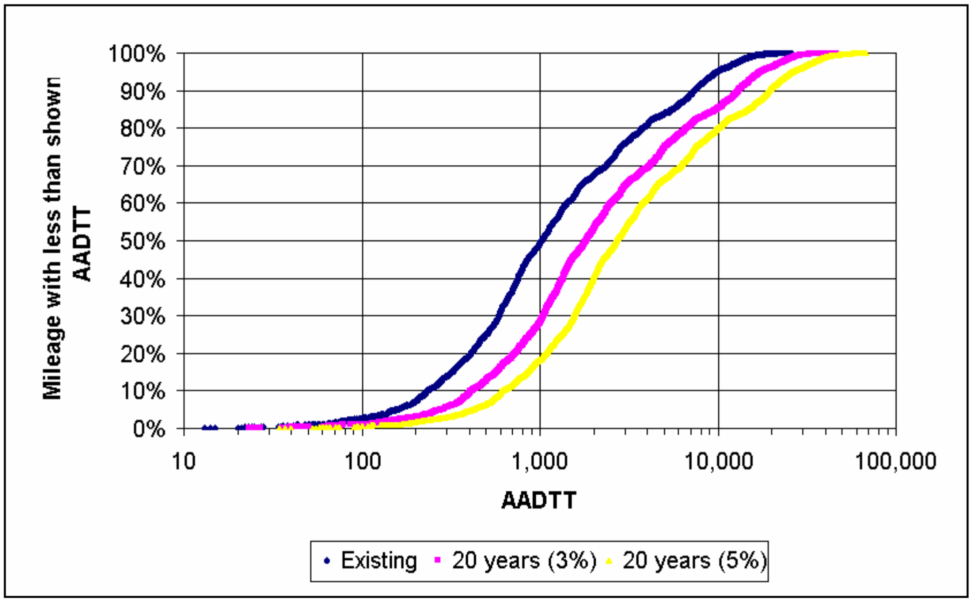


Data Source: TxDOT.

Figure 51. Cumulative Frequency Distribution for AADT.

TTI's operational analysis on S.R. 60 in California used a combination of CORSIM runs and the Highway Capacity Software (HCS) to determine the capacity of a separate truck roadway and LOS based on predicted truck flows. HCS runs required selection of appropriate values for *k*-factor, directional flows, peak-hour factor (PHF), terrain factor (level, rolling, or specific grades), number of other large vehicles besides trucks, driver population factor, free flow speed, lane width, right shoulder lateral clearance, and design LOS. The results indicated that the capacity (LOS E) of a two-lane truck facility was approximately 1600 trucks per lane per hour in flat terrain and 800 trucks per lane per hour in rolling terrain *(49)*. The TTI analysis also utilized factors for specific grades based on the characteristics of each. By comparison, the passenger car capacity (LOS E) for basic freeway segments in the 2000 *Highway Capacity Manual* (HCM) at free-flow speeds at or greater than 70 mph is 2400 passenger cars per hour per lane *(69)*.

Translating from AADTT to hourly truck flows requires knowledge of large truck peaking characteristics. This analysis uses typical vehicle classification data from Texas



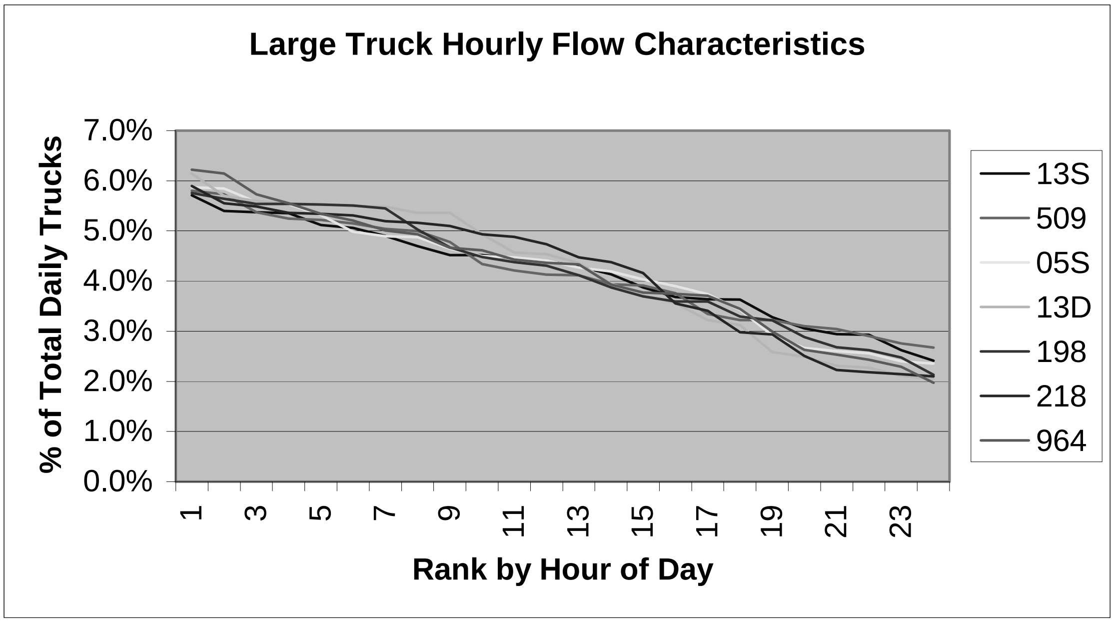
Data Source: TxDOT.

Figure 52. Cumulative Frequency Distribution for AADTT.

sites to determine threshold information. Appendix G contains graphics based on directional hourly traffic demand for seven selected relatively high-volume sites (minimum of 5000 trucks per day) segregated by Class 5 and above (large trucks) and other vehicles. Figure 53 graphically depicts the hourly percent of total daily (AADTT) values for these seven sites arranged from high to low. The first six of the sites listed in Figure 53 (Stations 13S to 218) fall into the AADTT range of 5760 to 11,520 trucks per day, whereas the final one, Station 964, falls in the range of 11,520 to 23,040 trucks per day (see ranges established in Chapter 4). Figure 53 indicates a very consistent pattern for percentages by ranked hour of day for all sites represented. The consistency of these data suggests the use of these sites to represent other relatively high-volume sites throughout the state. Unfortunately, these data may not represent an entire year, so the user must still be cautious. However, for this analysis, a "typical" peak hourly bi-directional truck demand can be taken as about 6 percent of the AADTT. Table 45 also indicates the hourly directional splits for each of these sites along with hourly percentages.

Design for mixed traffic on a given facility where traffic volume is more precisely known typically uses the 30th highest hour in the year. The design value for truck facilities must also consider the appropriate design period (e.g., 20 years) for determining the desired demand volume of trucks. Therefore, the analysis should apply appropriate truck growth factors as discussed in Chapter 4, likely in the range of 3 to 5 percent growth per year.

Table 46 summarizes the means, minimums, and maximums for these seven sites to provide information on the variability in hourly truck flows grouped by Class 5 and above, then by Class 3 and above. For purposes of this study, the focus is on larger trucks, but Class 3 and 4 vehicles may also need to utilize truck roadways or be segregated in truck lanes if lane restrictions are imposed. From a capacity standpoint, Class 3 and 4 vehicles should probably be included, although it is also anticipated that a limited number of trucks may still need to use mixed flow lanes. This discussion assumes that all Class 3 and up vehicles need to be accommodated.



Data Source: TxDOT.

Figure 53. Bi-Directional Hourly Truck Percentages at Seven High-Volume Sites.

It is readily apparent from Appendix G, Figure 51, and Table 47 values that truck demand for highway facilities has different peaking characteristics than cars. The Appendix G graphical representations of hourly flows of large trucks over an entire day show this difference between trucks and cars. Large truck demand is spread over the entire day more uniformly than cars, resulting in a “flatter” histogram of volume than that for smaller vehicles. Peak hour volumes for smaller vehicles might be in the range of 10 to 12 percent of daily values, but truck volumes, as indicated above, are in the range of 5 to 6 percent. This difference will result in better utilization of exclusive truck facilities in that trucks operate around the clock to a greater extent than cars. Therefore, in a 24-hour period, a facility built just for trucks will experience a more uniform flow than a facility serving only or mostly cars. This fact also has implications on the number of trucks that would be needed to warrant an exclusive truck facility.

For preliminary analysis, an exclusive truck roadway should have a minimum of two lanes in each direction in order to accommodate passing maneuvers of faster trucks overtaking slower trucks. One of the early lessons learned from motor carriers, and especially truck drivers in TTI studies conducted in the 1980s, was that there must be passing opportunities (i.e., two or more lanes by direction). Otherwise, truck drivers will not use these facilities unless there are absolutely no viable alternatives.

Table 46. Hourly and Directional Distribution of Trucks (Class 5 and Above).

Hour	Station (Year)													
	13S (00)		509 (00)		05S (00)		13D (00)		198 (00)		218 (99)		964 (00)	
	Hrly %	Dir	Hrly %	Dir	Hrly %	Dir	Hrly %	Dir	Hrly %	Dir	Hrly %	Dir	Hrly %	Dir
0	3.6	47%	3.0	43%	2.7	49%	2.6	47%	3.6	54%	2.9	48%	2.4	53%
1	2.4	40%	2.7	43%	2.6	44%	2.3	45%	3.2	51%	2.2	50%	2.6	50%
2	2.6	44%	3.2	37%	2.6	54%	2.3	46%	2.9	56%	2.1	49%	2.5	56%
3	2.9	40%	2.9	45%	2.4	50%	2.0	44%	2.1	46%	2.1	43%	2.0	50%
4	2.9	34%	2.8	38%	2.4	46%	2.1	40%	2.6	49%	2.2	44%	2.3	43%
5	3.1	38%	3.3	44%	2.9	51%	2.5	48%	3.6	46%	2.5	50%	3.0	48%
6	3.3	43%	3.1	51%	3.4	53%	3.1	49%	3.3	46%	3.0	53%	3.4	46%
7	3.9	44%	3.9	42%	4.2	47%	3.6	46%	4.3	52%	4.4	45%	3.7	50%
8	4.1	43%	3.9	42%	4.4	50%	3.7	48%	4.5	46%	4.7	43%	4.4	49%
9	5.1	43%	5.0	47%	4.3	50%	4.4	45%	5.5	54%	4.9	46%	4.6	45%
10	5.4	46%	5.2	56%	4.5	55%	4.9	45%	5.5	51%	5.1	49%	4.9	52%
11	5.1	51%	5.2	51%	4.9	48%	5.7	50%	5.0	56%	5.2	53%	5.7	56%
12	5.4	51%	5.8	59%	4.9	49%	5.6	45%	5.5	54%	5.3	52%	5.3	53%
13	5.7	52%	5.7	58%	5.5	51%	5.4	51%	5.5	56%	5.5	45%	5.6	48%
14	4.9	57%	5.0	49%	5.6	40%	5.5	55%	5.8	56%	5.3	48%	6.2	57%
15	4.7	52%	5.4	55%	5.3	50%	5.5	52%	5.6	55%	5.6	51%	5.2	58%
16	5.4	44%	5.2	52%	5.9	53%	5.5	56%	5.5	53%	5.9	47%	6.1	51%
17	4.5	52%	4.8	49%	5.8	55%	6.1	53%	4.7	54%	5.4	46%	5.0	49%
18	4.4	42%	4.2	48%	5.0	54%	5.5	56%	4.4	58%	4.9	48%	4.4	56%
19	4.3	48%	4.3	50%	4.5	48%	5.4	53%	4.1	62%	5.2	50%	4.7	49%
20	3.7	47%	4.1	52%	4.6	45%	4.6	57%	3.9	51%	4.5	49%	4.3	52%
21	4.5	43%	3.8	43%	3.9	46%	3.9	53%	3.7	49%	4.2	51%	3.9	56%
22	4.5	43%	4.1	44%	3.7	49%	4.5	51%	2.7	61%	3.6	53%	3.7	54%
23	3.6	37%	3.2	44%	4.0	48%	3.2	61%	2.5	56%	3.4	53%	3.8	56%

Data Source: TxDOT.

Table 47. Summary of AVC Station Statistics.

Site	Direction	No. of Class 5 and Above			No. of Class 3 and Above		
		Mean	Min.	Max.	Mean	Min.	Max.
13S	3	169	86	266	214	92	337
	7	201	128	270	248	140	369
509	3	183	53	323	258	58	464
	7	181	129	250	261	133	410
05S	3	191	100	295	280	117	478
	7	194	108	308	297	113	465
13D	3	169	68	262	190	74	298
	7	165	92	246	187	95	277
198	3	153	67	221	178	68	269
	7	134	72	188	159	83	234
218	3	123	55	173	208	70	337
	7	131	67	192	210	79	387
964	3	223	101	365	373	109	655
	7	207	103	310	356	119	636

Data Source: TxDOT.

Pursuing this analysis further and considering the terrain that might be encountered in the various large urban areas that serve the highest truck volume indicates that some of central Texas (e.g., the "hill country") would qualify as "rolling terrain" and the lower value of 800 trucks per lane per hour would apply. However, a large proportion of Texas freeways would fit the category of flat terrain where the capacity would be 1600 trucks per lane per hour. This higher capacity would apply to most freeways in and around large areas such as Houston, Dallas, Ft. Worth, El Paso, and portions of other urban areas.

The authors developed Figures 54, 55, and 56 from AADTT data by the following highway types: IH, U.S., and S.H., respectively. Again, the designer typically uses the 30th highest hour volume, but TxDOT does not have sufficient hourly truck classification data to calculate this value; it only has 24- or 48-hour classification counts at a few sites. The procedure to calculate truck directional design hour volume (DDHV) was as follows:

$$\text{Truck DDHV} = \text{AADTT} * K * D * F$$

Where:

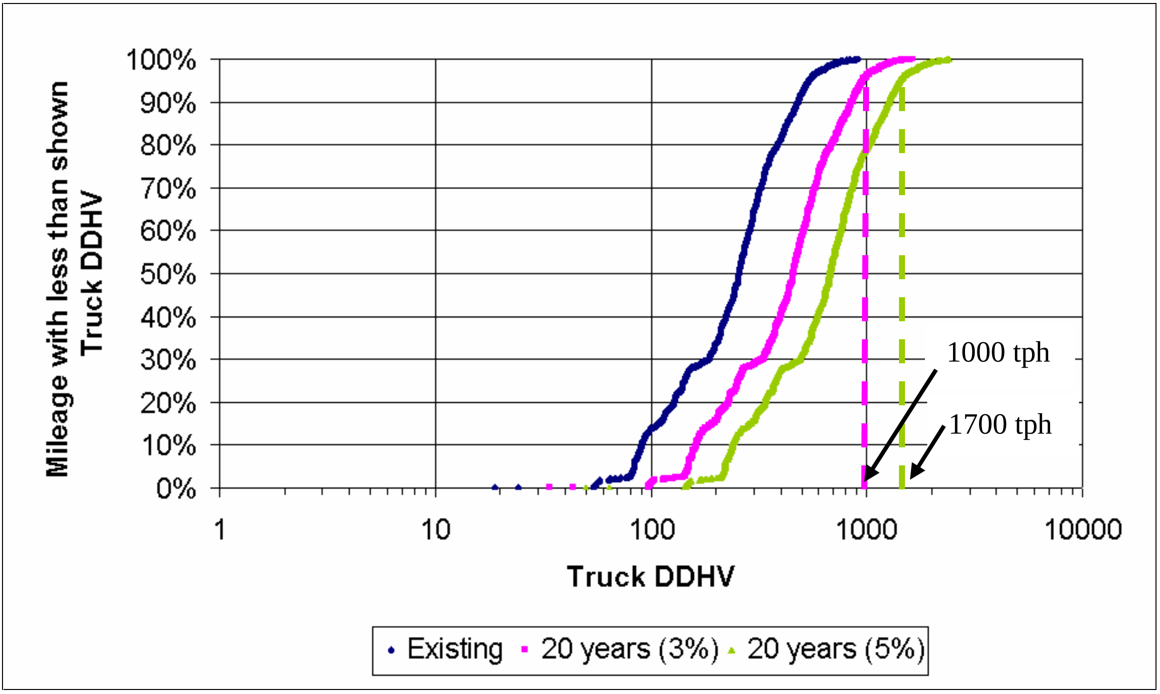
- Truck DDHV = Truck directional design hour volume (vph),
- AADTT = average annual daily truck traffic (vpd) from TxDOT data,

- K = proportion of AADTT occurring in the peak hour (assumed 6 percent based on average from data from seven stations),

- D = proportion of peak hour truck traffic occurring in the peak direction (assumed 0.59 based on average from seven stations), and

- F = factor to convert 2000 data to 2020 data (1.806 and 2.653 for 3 percent and 5 percent annual growth rate, respectively).

Interstate values of truck directional design hour volume are most appropriate for this analysis because most of the heavy flows of trucks occur on IH road types. Figure 54 shows the growth in DDHV that is expected over the next 20 years at the two growth rates. Paying close attention to the slopes of the lines plotted in Figure 54 indicates a fairly constant slope from near zero to around the 95th percentile value. The sharp bend in the line at 95 percent suggests that the demand is increasing at a slower rate above that value and the resulting return on investment on a per-unit basis would be less than below 95 percent.



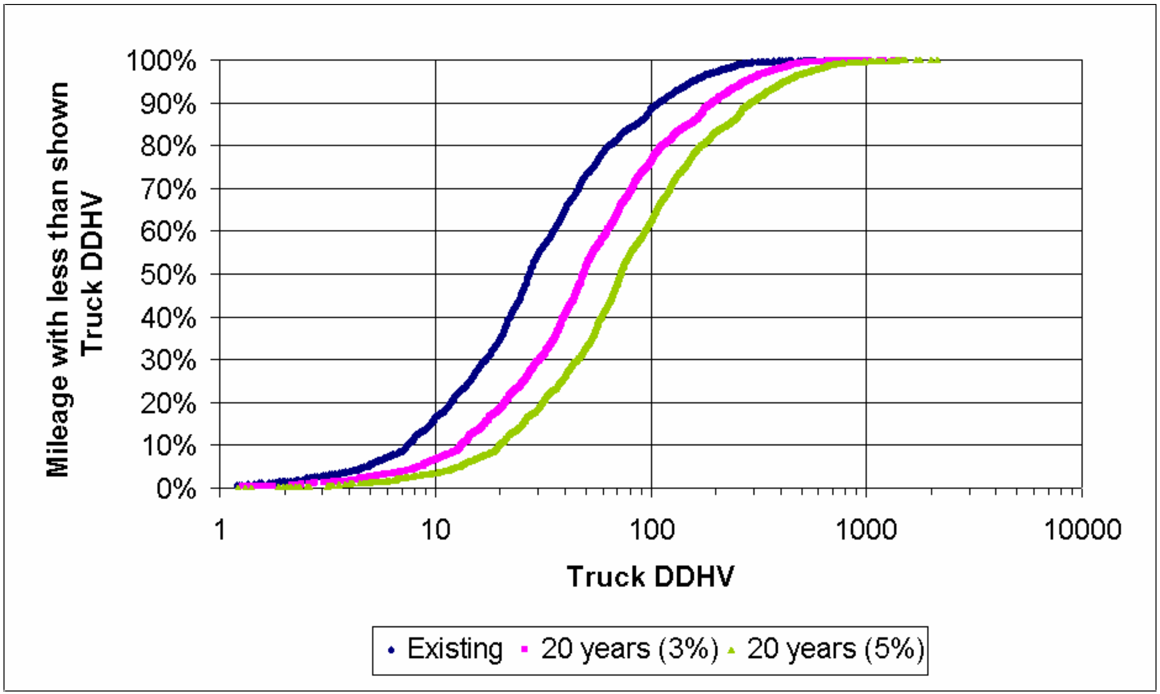
Data Source: TxDOT.

Figure 54. Cumulative Frequency Distribution for Peak-Hour Truck Traffic on IH Highways (3235 miles).

As shown in Figure 54, the 95th percentile hourly design volume for a 20-year design on Interstate highways would be between 1000 tph and 1700 tph (100th percentile shows 2000 tph at 3 percent per year growth and 2500 tph at 5 percent growth). Based on capacity values cited earlier and 5 percent growth per year, the graphic indicates that, in

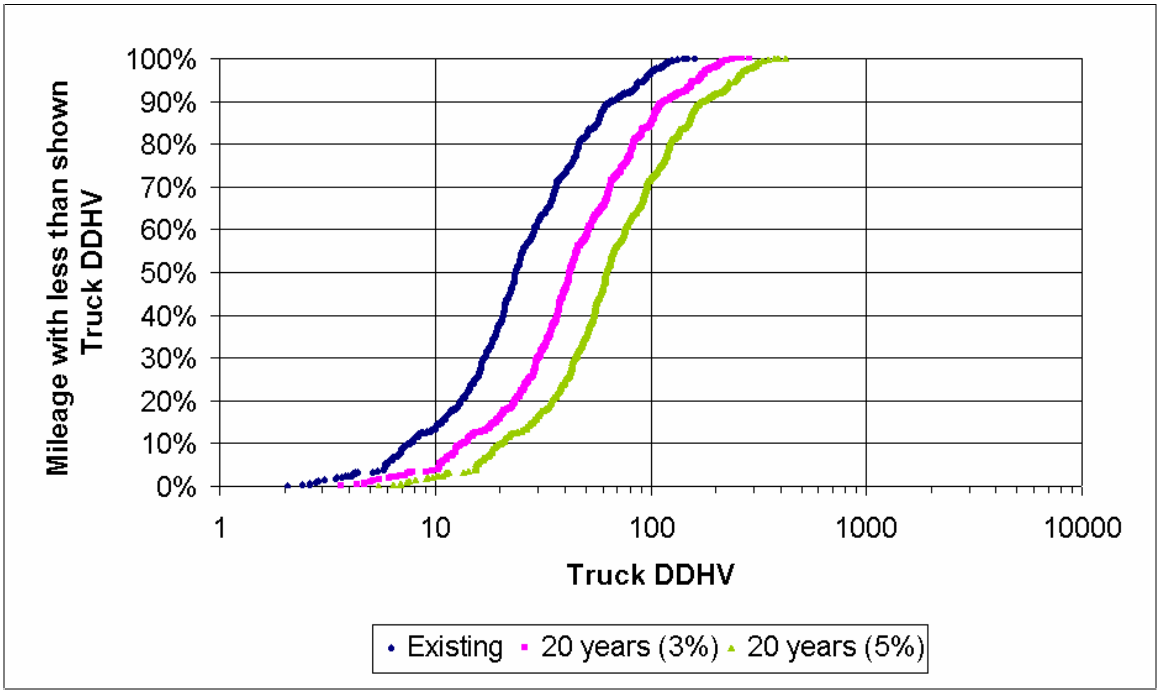
20 years, truck demand levels will exceed by a small amount the capacity of a two-lane truck roadway in rolling terrain and a single lane roadway on flat terrain (if a single lane truck facility were viable). If truck growth is closer to 3 percent per year, the 95th percentile truck volume would still require two lanes in rolling terrain and one lane in flat terrain (again strictly from a capacity standpoint).

One further consideration that is worth considering concerns the attractiveness of a truck facility or incentives to using the facility by motor carriers throughout its design life. Designing a truck facility for the usual 30th highest hour (approximated in this case by 95th percentile hourly flows) may not be adequate, especially if the roadway becomes a toll facility and viable non-toll alternatives exist. Designing for a high LOS for all design hours instead of the 95th percentile may be necessary to ensure success. If so, Figure 54 indicates that the truck roadway capacity would need to be increased even more. Three percent and 5 percent growth rates would result in a demand of as much as 1800 and 2600 trucks per hour, respectively, a few hours each year.



Data Source: TxDOT.

Figure 55. Cumulative Frequency Distribution for Peak-Hour Truck Traffic on U.S. Highways (12,000 miles).



Data Source: TxDOT.

Figure 56. Cumulative Frequency Distribution for Peak-Hour Truck Traffic on State Highways (1614 miles).

7.3.2 Summary

Even though this chapter has emphasized truck volumes, designers must continue to design for trucks even at relatively low truck volumes. The concept of truck friendly design has to be considered at some relatively low volume levels, especially if truck growth rates are expected to be high. Based on data presented in Chapter 4, 85 percent of the truck-miles of travel in Texas occur on roadways where the AADTT is at least 1000 trucks per day. Table 48 summarizes data from Chapter 4 to help visualize breakpoints in truck activity. Based upon this information, designers should utilize truck-friendly design when the AADTT within the design period is expected to reach 1000 or more trucks (Class 3 and above) per day.

Table 48. Summary of Route-Miles and Annual TMT.

AADTT	Route-Miles	Annual TMT
960 – 2880	22%	21%
2880 – 5760	6%	15%
5760 – 11,520	6%	31%
11,520 – 23,040	2%	18%
SUM	36%	85%

Data Source: TxDOT.

This document has considered special treatments for trucks as two basic concepts: 1) lane designations or lane restrictions and 2) truck roadways. Previous TxDOT research has not established the criteria for lane restrictions. For other states, the factors that seem to have driven the establishment of lane restrictions included operational and safety concerns. They have not historically been connected to a particular truck volume level or to total traffic volume. Therefore, establishing guidance for designers is more establishing a rational approach than evaluating what others have done. Based upon engineering judgment from the foregoing analysis, a reasonable criterion to begin considering special truck treatments is 5000 trucks per day.

One of the questions that needs to be answered in this discussion pertains to how much of the Texas highway mileage could justify building truck roadways in the next 20 years. Assuming that the capacity of a two-lane truck roadway in flat terrain is 1600 trucks per lane per hour (cited above from the S.R. 60 study), one could calculate representative corresponding AADTT values to determine how many miles of Texas roadways might warrant such facilities (AADTT values are more readily available than peak hour truck volumes). If 6 percent of the AADTT occurs during the peak hour, the corresponding maximum AADTT value that could be accommodated by a four-lane separate truck roadway (two lanes in each direction) would be over 100,000 trucks per day. According to Figure 52, 100 percent of the highway mileage in Texas will have a demand less than this magnitude in 20 years even at a high growth rate. This finding suggests that truck roadways built in the near future will operate well below capacity unless smaller vehicles were also allowed to use the truck roadways. In rolling terrain (e.g., the "Hill Country"), the capacity is approximately 800 trucks per lane per hour (cited above from S.R. 60 study), resulting in a corresponding AADTT value of just over 53,000 trucks per day. On the basis of AADTT, Figure 52 predicts that 92 percent of the high-growth corridor mileage with two dedicated exclusive truck lanes in each direction will experience a demand at or lower than this value in 20 years.

The traffic volume criteria that would warrant a truck roadway should be related to the capacity of a separate two-or-more-lane (barrier separated) roadway. Since the analysis of future Texas truck volume suggests that none of the high volume mileage in flat terrain would be sufficient to justify building the minimum two lanes, designers must look at two options. These two options appear to be: 1) allow only trucks and let the facility operate at a LOS much lower than its capacity during the early years of its use, or 2) allow passenger vehicles to share the "truck facility." The first option will probably result in negative public relations, but would be the preferred option by truck drivers. It might also attract trucks from other parallel corridors and experience an even higher than expected growth in trucks. Building such a facility is perhaps the only way to determine if such a facility is really safer than a mixed flow facility. The second option (allowing passenger cars) assures better utilization of the facility but is probably no safer for passenger car occupants than other mixed flows of large and small vehicles.

CHAPTER 8. DESIGN GUIDELINES

8.1 INTRODUCTION

The TTI research team developed a set of guidelines for the accommodation of trucks in geometric design. The basic documents used in the development of these guidelines were the AASHTO *Green Book (1)* and the TxDOT *Roadway Design Manual* (TRDM) *(2)*. Recent research supplemented these two documents and provided guidance on whether current design is sensitive to the operating characteristics of large trucks. The primary definition of trucks used in the design process is Class 5 and above in the Texas 6 Vehicle Classification Scheme or Class 6 and above in the FHWA Vehicle Classification Scheme. The general methodology used was to check values in the *Green Book*, then determine if the TxDOT *Roadway Design Manual* adequately reflects those values.

8.2 METHODOLOGY

TTI produced a preliminary list of design elements early in the project to use in developing guidelines; Table 49 shows the list of elements along with page numbers where the element can be found in the TxDOT *Roadway Design Manual*. Most of these elements relate to geometric design, although some pertain to roadside hardware and to Intelligent Transportation Systems elements. Chapter 6 has information on ITS elements, but this chapter addresses other elements listed in the table. To adequately design roadways for large trucks, one must first know the size and operational characteristics of the design vehicle population. Chapter 3 provides some information on these vehicle characteristics, and a parallel research project sponsored by the National Cooperative Highway Research Program *(7)* conducted a survey of current vehicle characteristics. Some of the data collection for this NCHRP study actually occurred in Texas, providing input to indicate whether truck operational characteristics are changing.

8.3 DESIGN ELEMENTS

Design elements in this chapter track the following categories: sight distance, horizontal alignment, vertical alignment, and cross-section elements. Each of these categories has multiple sub-elements addressing more specific areas of design or operations.

8.3.1 Sight Distance

Sight distance is the length of roadway ahead of the driver that is visible to the driver. The minimum amount of sight distance provided for drivers should be sufficient for a vehicle traveling at the design speed to stop before reaching a stationary object in its path. This *stopping sight distance* is the basis for design for crest vertical curve length and minimum offsets to horizontal sight obstructions. Stopping sight distance must be available at every point on the roadway.

Table 49. Design Factors Potentially Affected by Truck Characteristics.

Element for Consideration	Specific Focus Area	Page No. in the TRDM
Sight Distance	Stopping Sight Distance Decision Sight Distance Passing Sight Distance RR-Highway Grade Crossing Sight Dist. Intersection Sight Distance	2-8 to 2-9 2-10 2-11; 3-30 to 3-31 Omitted 2-11
Horizontal Alignment	Curve Radius Superelevation Intersection and Channelization Pavement Widening	2-13 to 2-15 2-16 to 2-31 3-13; 7-14 to 7-25 Omitted
Vertical Alignment	Critical Length of Grade Downgrades	2-35 to 2-38 Omitted
Cross-Section Elements	Lane Width Shoulder Width and Composition Sideslopes and Drainage Features Pavement Cross-Slope Breaks Vertical Clearance Traffic Barrier Passive Signs Curbs Acceleration Lanes	2-54; 3-69 to 3-70; 3-75 2-54; 3-70; 3-72; 3-75 2-51 to 2-52; 2-65 to 2-74 2-50 3-73 to 3-74 7-3 to 7-5; App. A Omitted 2-61; 3-75 3-38; 3-95 to 3-108
Intelligent Transportation Systems	Smart Signs Roadway Sensors	N/A

8.3.1.1 Stopping Sight Distance

The recommended stopping sight distances in the *Green Book* are based on passenger cars and do not explicitly consider trucks. As a general rule, large trucks need longer stopping distances from a given speed than cars. However, one factor that tends to compensate for longer truck stopping distances is the driver eye height advantage. In the *Green Book*, the eye height for passenger cars is 3.5 ft and that for trucks is 8.0 ft. Separate stopping sight distances for trucks and cars, therefore, are not generally used in highway design.

The stopping sight distance consists of two distances, the brake reaction distance and the braking distance. The brake reaction time in the 2001 *Green Book* equals 2.5 seconds and is assumed to be applicable to truck drivers as well as passenger car drivers. Brake application time for air brake systems used by large trucks is approximately 0.5

seconds, but professional truck drivers may have shorter brake reaction times and their higher eye height advantage in most cases offsets the brake application delay.

The deceleration rate in the 2001 *Green Book* is set at 11.2 ft/s^2, which is a comfortable value for controlled braking by a passenger car driver. Trucks equipped with antilock brakes can achieve deceleration rates in controlled braking approximating distances required by passenger cars as shown in the *Green Book*. NCHRP Synthesis 241 *(70)* noted that braking distances for cars and trucks are very similar on wet pavements, which are the critical condition for stopping sight distance. Differences are greater between cars and trucks on dry pavement.

There is one situation noted in the *Green Book* to which designers should pay close attention because the truck driver eye height advantage may not apply. It is where horizontal sight obstructions occur on downgrades, and particularly on long downgrades where truck speeds may exceed that of car speeds. The *Green Book* states that it is desirable to provide stopping sight distance greater than tabulated or computed values for design.

The TRDM does not provide stopping sight distance corrections for grade (although it does refer designers to the *Green Book*), nor does it provide the caution noted above for designers regarding trucks on downgrades where horizontal sight obstructions can reduce the sight distance for truck drivers to equal that of passenger car drivers. The values it does provide are exactly the same as those provided in the *Green Book*. In some cases, this finding could represent a critical weakness in the TRDM.

Recommendation: The authors recommend that a statement of caution regarding horizontal curves at the end of long downgrades be added to the TRDM for truck roadway design. Wording similar to that contained in the *Green Book* would be appropriate.

8.3.1.2 Decision Sight Distance

The 1984 *Green Book* first introduced the concept of decision sight distance based on research by McGee et al *(71)*. Originally, decision sight distance only considered a single maneuver, a lane change to avoid an obstacle. This maneuver might have been necessary to avoid an obstacle in the roadway ahead or vehicles stopped due to an incident. The 1990 *Green Book* changed decision sight distance to include multiple scenarios that might be encountered by a driver. The criteria now defined in five avoidance maneuvers are as follows:

- Avoidance Maneuver A – Stop on rural road,
- Avoidance Maneuver B – Stop on urban road,
- Avoidance Maneuver C – Speed/path/direction change on rural road,

- Avoidance Maneuver D – Speed/path/direction change on suburban road, and
- Avoidance Maneuver E – Speed/path/direction change on urban road.

Distances required for avoidance maneuvers A and B are calculated the same as for stopping sight distance, but the first term (the pre-maneuver time) is longer because of the more complex nature of the decision. Distances for C, D, and E use the same equation as the perception-reaction portion of the stopping distance equation ($d = 1.47Vt$) where V is speed in mph and *t* represents the total pre-maneuver and maneuver time. The total pre-maneuver plus maneuver time, *t*, varies between 10.2 and 11.2 seconds for rural roads, between 12.1 and 12.9 seconds for suburban roads, and between 14.0 and 14.5 seconds for urban roads, with lower values used at higher speeds.

The *Green Book* criteria for decision sight distance do not explicitly consider trucks. The FHWA *Truck Characteristics* study *(72, 73)* included a cost-effectiveness analysis of potential changes to the decision sight distance policy in the 1984 *Green Book* to better accommodate trucks. This analysis concluded that such changes would not be cost-effective. The TRDM provides Table 2-2, which is a duplication of Exhibit 3-3 in the *Green Book*.

Recommendation: Based upon recommendations of the FHWA *Truck Characteristics* report, the authors recommend no changes pertaining to decision sight distance.

8.3.1.3 Passing Sight Distance

The primary focus of this research is on high-type controlled access facilities, so passing sight distance does not apply. It is anticipated that truck roadways will have a minimum of two lanes in each direction, so the passing sight distance criteria should not be necessary.

8.3.1.4 Railroad-Highway Grade Crossing Sight Distance

The criteria in the 2001 *Green Book* reflect the latest stopping sight distance criteria. Reference *(7)* reports on a sensitivity analysis comparing the sight distance requirements of the 2001 *Green Book* and sight distances derived for trucks with anti-lock braking systems. The analysis only considered sight distance for a moving vehicle approaching the grade crossing on the highway ("Case A" in the *Green Book*). The analysis found that current sight distance criteria for railroad-highway grade crossings appear to sufficiently accommodate trucks. The TRDM omits railroad-highway grade crossing sight distance.

Recommendation: The authors recommend no change in railroad-highway grade crossing sight distance.

8.3.1.5 Intersection Sight Distance

The intersection sight distance criteria in the 2001 *Green Book* are based on relatively recent research that explicitly considered the sight distance needs of trucks. Therefore, there is no need to change these criteria for roadways serving heavy truck flows or for truck roadways.

<u>Recommendation:</u> The authors recommend no change.

8.3.2 Horizontal Alignment

In the design of highway alignment, it is important to establish the proper relation between design speed and curvature. The two basic elements of horizontal curves are curve radius and superelevation.

8.3.2.1 Curve Radius and Superelevation

The AASHTO *Green Book* develops horizontal curve criteria by representing the vehicle as a point mass moving at constant speed on a circular path. The unbalanced portion of the lateral acceleration not accommodated by superelevation is a measure of the forces acting on the vehicle that make it skid or overturn. The tendency of the vehicle to skid must be resisted by the tire/pavement friction and the tendency of the vehicle to overturn must be resisted by its roll stability. The vehicle will begin to skid unless the tire/pavement friction coefficient exceeds the side friction demand, and it will rollover unless the rollover threshold of the vehicle exceeds the unbalanced lateral acceleration.

To understand safety aspects of trucks on curves, it is helpful to know the margins of safety against skidding or rollover. Some limited data from a NHTSA study *(74)* indicated that trucks sometimes generate lateral accelerations above 0.30 g, with a few as high as 0.40 g. NCHRP Report 15-21 cited recent research that determined rollover thresholds of most trucks to be greater than or equal 0.35 g. Tables 50 and 51 provide margins of safety for trucks (cars are different) against rollover and skidding, respectively. Comparison of the values in each table indicates that the margin of safety for a truck with rollover threshold of 0.35 g ranges from 0.18 to 0.27 g. This margin of safety is adequate to prevent rollover for trucks traveling at or below the design speed. The margin of safety against skidding on wet pavement varies from 0.15 to 0.22 g, which is also adequate as long as truck speeds do not significantly exceed the design speed.

Since the TRDM uses the same values for curve radius and superelevation as the *Green Book*, there appears to be no need to make changes to Texas practice. One apparent erratum (although on the conservative side) is the TRDM radius of 600 ft for a design speed of 45 mph instead of the *Green Book* value of 500 ft.

<u>Recommendation:</u> The authors recommend no changes (other than a correction of the noted erratum).

Table 50. Margins of Safety against Truck Rollover on Horizontal Curves.

Design speed (mph)	Maximum e	Maximum tolerable lateral acceleration	Minimum radius (ft)	Rollover margin of safety	
				RT=0.35g	RT=0.40g
20	6.0	0.17	116	0.18	0.23
30	6.0	0.16	273	0.19	0.24
40	6.0	0.15	508	0.20	0.25
50	6.0	0.14	833	0.21	0.26
60	6.0	0.12	1333	0.23	0.28
70	6.0	0.10	2042	0.25	0.30
80	6.0	0.08	3048	0.27	0.32
20	8.0	0.17	107	0.18	0.23
30	8.0	0.16	250	0.19	0.24
40	8.0	0.15	464	0.20	0.25
50	8.0	0.14	758	0.21	0.26
60	8.0	0.12	1200	0.23	0.28
70	8.0	0.10	1815	0.25	0.30
80	8.0	0.08	2667	0.27	0.32
20	10.0	0.17	99	0.18	0.23
30	10.0	0.16	231	0.19	0.24
40	10.0	0.15	427	0.20	0.25
50	10.0	0.14	694	0.21	0.26
60	10.0	0.12	1091	0.23	0.28
70	10.0	0.10	1633	0.25	0.30
80	10.0	0.08	2330	0.27	0.32
20	12.0	0.17	92	0.18	0.23
30	12.0	0.16	214	0.19	0.24
40	12.0	0.15	395	0.20	0.25
50	12.0	0.14	641	0.21	0.26
60	12.0	0.12	1000	0.23	0.28
70	12.0	0.10	1485	0.25	0.30
80	12.0	0.08	2133	0.27	0.32

Source: Adapted from Reference (7).

Table 51. Margins of Safety against Trucks Skidding on Horizontal Curves.

Design speed (mph)	Maximum e	Maximum tolerable lateral acceleration (g)	Minimum radius (ft)	Maximum demand f	Available f (wet)	Margin of safety (wet)	Margin of safety (dry)
20	6.0	0.17	116	0.19	0.41	0.22	0.47
30	6.0	0.16	273	0.18	0.36	0.18	0.48
40	6.0	0.15	508	0.17	0.32	0.16	0.50
50	6.0	0.14	833	0.15	0.30	0.15	0.51
60	6.0	0.12	1333	0.13	0.29	0.16	0.53
70	6.0	0.10	2042	0.11	0.29	0.18	0.55
80	6.0	0.08	3048	0.09	0.28	0.19	0.57
20	8.0	0.17	107	0.19	0.41	0.22	0.47
30	8.0	0.16	250	0.18	0.36	0.18	0.48
40	8.0	0.15	464	0.17	0.32	0.16	0.50
50	8.0	0.14	758	0.15	0.30	0.15	0.51
60	8.0	0.12	1200	0.13	0.29	0.16	0.53
70	8.0	0.10	1815	0.11	0.29	0.18	0.55
80	8.0	0.08	2667	0.09	0.28	0.19	0.57
20	10.0	0.17	99	0.19	0.41	0.22	0.47
30	10.0	0.16	231	0.18	0.36	0.18	0.48
40	10.0	0.15	427	0.17	0.32	0.16	0.50
50	10.0	0.14	694	0.15	0.30	0.15	0.51
60	10.0	0.12	1091	0.13	0.29	0.16	0.53
70	10.0	0.10	1633	0.11	0.29	0.18	0.55
80	10.0	0.08	2330	0.09	0.28	0.19	0.57
20	12.0	0.17	92	0.19	0.41	0.22	0.47
30	12.0	0.16	214	0.18	0.36	0.18	0.48
40	12.0	0.15	395	0.17	0.32	0.16	0.50
50	12.0	0.14	641	0.15	0.30	0.15	0.51
60	12.0	0.12	1000	0.13	0.29	0.16	0.53
70	12.0	0.10	1485	0.11	0.29	0.18	0.55
80	12.0	0.08	2133	0.09	0.28	0.19	0.57

Source: Adapted from Reference (7).

8.3.2.2 Intersection and Channelization Geometrics

Selection of the appropriate design vehicle is critical in properly designing intersection and channelization geometrics. Districts use a software program such as AutoTurn or templates to establish turning characteristics of the design vehicle. For today's high volume roadways, the most common large truck is a WB-65, a tractor-semitrailer combination vehicle with a 53-ft semitrailer. Future truck roadways may allow larger vehicles, so the designer must continue to monitor trends in vehicle characteristics. It should be noted that NCHRP 15-21 recommends dropping the WB-50 design vehicle.

The TxDOT *Roadway Design Manual* is somewhat deficient in the area of intersection and channelization geometrics since its turning templates in Chapter 7, Section 7, do not show a WB-65. There is a WB-67D, but the more common WB-65 has somewhat more demanding off-tracking characteristics than the WB-67D. There may be other forthcoming vehicle changes to the AASHTO *Green Book* resulting from the NCHRP 15-21 study that need to be monitored and incorporated as necessary.

Recommendation: The authors recommend adding the WB-65 design vehicle to the TRDM for truck facilities, along with accompanying text to support its selection for many design features. Also, there should be appropriate language cautioning designers that design tools like AutoTurn do not consider driver input and the variability introduced by drivers. AutoTurn or templates give one solution for a selected design vehicle.

8.3.2.3 Pavement Widening

It is not anticipated that pavement widening will be an issue with mainline roadways because design speeds will be high and curves will be flat. As an example, for roadway widths of 24 ft and design speed of 60 mph (maximum in *Green Book* Exhibit 3-51), the widening for a curve of radius 1000 ft is only 1.1 ft. This value would be adjusted upward to 1.6 ft for the more appropriate WB-65 design vehicle. Typically, values less than 2.0 ft would be disregarded anyway.

Recommendation: The authors do not recommend changes pertaining to pavement widening for design speeds of 60 mph or higher.

8.3.3 Vertical Alignment

8.3.3.1 Critical Length of Grade

The *Green Book* provides the warrant for a truck climbing lane in terms of the critical length of grade. A climbing lane is warranted only if the grade exceeds this critical length. The critical length is dependent upon: 1) the power-to-weight ratio of the representative truck, 2) the expected speed of the truck entering the critical length portion of the grade, and 3) the minimum speed on the grade below which interference to following vehicles is unreasonable. Based on these factors, the *Green Book* defines the critical length of grade as the length of grade that would produce a speed reduction of 10 mph for a 200 lb/hp truck. Recent studies indicate that the 85^{th} percentile truck weight-to-power ratios range from 170 to 210 lb/hp for the truck population on freeways and 180 to 280 lb/hp on two-lane roadways. Therefore, values used in the *Green Book* for computing critical length of grade are reasonable.

Recommendation: The TRDM uses the same plots of speed reduction and percent grade as Exhibit 3-63 in the *Green Book*, and it assumes a 200 lb/hp truck and entering speed of 70 mph as the *Green Book*. Therefore, the authors recommend no changes to the TxDOT procedure.

8.3.3.2 Downgrades

The major concern with trucks on long downgrades, usually in mountainous areas, is loss of braking capability. Freeway grades that are long enough and steep enough to be a problem in Texas are practically nonexistent, so this topic is not a major concern. Section 6.4.1.3 in this report on Intelligent Transportation Systems contains information on a downhill warning system for truck drivers.

Recommendation: The authors recommend no changes.

8.3.4 Cross-Section Elements

8.3.4.1 Lane Width

The lane width criteria in the AASHTO *Green Book* apparently have no reference to any explicit vehicle width specification. However, implicit in the criteria for 11- and 12-ft lanes is that these lane widths consider truck width. The Surface Transportation Assistance Act of 1982 mandated that states allow 8 ft-6 inch (102-inch) vehicle widths on a national network. Even with the widespread use of 102-inch trailers today, lane widths remain at 12 feet on freeways. Mason et al. *(31)* proposed the following formula for establishing the lane width where trucks are adjacent to existing travel lanes:

$$W = W_v + 4.5 \text{ ft}$$

where:

W = Width of one lane, ft
W_v = Width of the vehicle, ft

Given that the dominant vehicle width on truck roadways will be at least 8 ft-6 inches, the design engineer should use 13-ft lanes, which is the lane width resulting from the Mason et al. formula. Truck roadways will also need to accommodate occasional permitted overwidth loads rather than having them use a parallel mixed flow facility. Proposed lane widths for truck lanes on the Trans Texas Corridor are 13 ft.

For mixed flow lanes, the 8 ft-6 inch vehicles still have ample width on 12 ft lanes, but designers should consider the probability of the roadway becoming an exclusive truck roadway. Two older studies addressed the operational effects of cars operating beside 8.0 ft and 8.5 ft buses on two-lane, four-lane, six-lane, and eight-lane highways *(73, 74)*. The research found that the lateral position of cars beside buses shifted, but the magnitude of the shift was the same for 8.5 ft buses as for 8.0 ft buses.

Recommendation: The TRDM recommends using a minimum lane width of 12 ft for high-speed facilities such as all freeways and most rural arterials. The authors recommend increasing the lane width from 12 ft to 13 ft for exclusive truck facilities and staying with 12 ft lanes where trucks remain in the mixed flow or are restricted to specific lanes.

8.3.4.2 Shoulder Width and Composition

The AASHTO *Green Book* recommends that on high-speed, heavily traveled highways and highways with large numbers of trucks, shoulders should have a usable width of 10 ft and preferably 12 ft. Where roadside barriers, walls, or other vertical elements are present, it is desirable that the vertical elements be offset a minimum of 2 ft from the outer edge of the usable shoulder.

It is also important on high-volume truck routes that the shoulder be paved. To ensure that the shoulder has adequate structural strength and to simplify construction, it is desirable that the shoulder be designed with the same depth and composition as the mainlanes.

The TRDM recommends minimum shoulder widths of 10 ft on the outside and 4 ft on the inside (median side) of freeways with two lanes in each direction. For freeways with three lanes in each direction, the inside shoulder should be increased to 10 ft along with the 10 ft outside shoulder.

Recommendation: The authors recommend increasing the outside shoulder width to 12 ft along truck roadways and mixed flow roadways predicted to reach an AADTT of at least 5000 trucks per day during the design period. The design should also offset vertical elements (e.g., barrier) a minimum of 2 ft from the outer edge of the usable shoulder.

8.3.4.3 Sideslopes and Drainage Features

The literature search revealed no research pertaining to trucks negotiating sideslopes or impacting drainage structure end treatment and that also considered the additional cost that would be incurred to design for trucks. The current design philosophy assumes that the cost of protecting these facilities from an impact by a truck would be much more than the costs of these appurtenances today. Also, trucks could probably handle roadside obstacles as well as cars, so the benefits gained from designing for trucks would probably not adequately reflect the significant additional cost.

Recommendation: Until further research clarifies the justification for different design for trucks, the authors recommend no changes.

8.3.4.4 Pavement Cross-Slope Breaks

The *Green Book* criteria state that the cross-slope at the edge of the paved surface is limited to a maximum of approximately 8 percent. To alleviate severe cross-slope breaks, it also provides for using a continuously rounded shoulder on the outside of superelevated pavements. A study conducted by FHWA on the dynamic effects of centerline crowns *(75)* included both loaded and empty tractor-semitrailer combinations and single-unit trucks. Truck related findings implied that cross-slope design should be kept to a minimum on high-speed facilities. The primary reason is that the simulation of passing behavior produced vehicle dynamic responses ranging from 0.28 to 0.34 g for cross-slopes of 2 percent for all vehicle types.

The TRDM (p. 2-50) covers pavement cross-slope and only has minimal information on cross-slope breaks. The related requirement is that the algebraic difference between the traveled way and the shoulder should not exceed 6 to 7 percent.

Recommendation: The authors recommend no changes.

8.3.4.5 Vertical Clearance

The Green Book criteria for vertical clearance are generally 16 ft on arterials and freeways. Design vehicles in the *Green Book* have a maximum height of 13.5 ft. Even though Texas allows a height of up to 14.0 ft, almost all trucks are 13.5 ft in order to operate in other states and because the cost of the more common 13.5-ft equipment is more reasonable.

The TRDM stipulates that all controlled access facilities should provide 16.5 ft minimum vertical clearance over the usable roadway. It provides for exceptions for controlled access roadways within urban areas where a bypass exists with the full 16.5 ft clearance. Exceptions for rural interstates and single priority defense interstate routes require approvals.

Recommendation: The authors recommend no changes.

8.3.4.6 Traffic Barrier and Crash Cushions

Concrete barriers are effective safety devices; their purpose is to redirect a vehicle and prevent it from entering the path of oncoming traffic while keeping the vehicle upright. In order for this to occur, the barrier must stop the roll motion of the vehicle and allows it to “slide” along the top of the barrier until it rights itself.

NCHRP 22-12 *(78)* is underway at the University of Nebraska, with one of its goals being to develop guidelines or warrants for different test levels pertaining to barriers. For example, longitudinal barriers fall into five test levels. Four of these test levels are described below:

- Test Level 3 (TL-3) is the basic level for the National Highway System and uses vehicles up through a three-quarter ton truck.

- Test Level 4 (TL-4) still has some smaller vehicles but now includes an 18,000 lb box van.

- Test Level 5 (TL-5) now includes tractor-semitrailers up to 80,000 lb with a box van trailer.

- Test Level 6 (TL-6) is the highest level and uses an 80,000 lb tractor-semitrailer with a tanker trailer.

The standard TL-4 barrier is the New Jersey shape concrete barrier, which is 32 inches tall. It can contain a box van under some conditions but not all. A TL-5 barrier is 42-in tall and is better for containing trucks without being significantly more expensive to build. Past crash testing suggests that this taller barrier will contain most, but not all large trucks, depending on the actual impact conditions, center of gravity height of the payload, and connection of the trailer to the tandems. In truck collisions, the primary load path is vertical because the load is transferred from the underside of the trailer or truck bed to the top of the concrete barrier. In research sponsored by the New Jersey Turnpike Authority, TTI developed and successfully crash-tested a 42-inch concrete median barrier that could safely contain and redirect tractor-trailers to an upright position. This heavily reinforced barrier is made with the New Jersey shape forms and is basically an F-shaped barrier that does not have a vertical reveal. This barrier was different from the current TxDOT 42-inch constant slope barrier, both in shape and in the amount of reinforcing steel used *(79)*.

The Texas 42-inch barrier has a constant slope face, which makes an angle of 10.8 degrees with respect to vertical. Its originally intended use was as a temporary concrete barrier; however, its subsequent use has been for permanent concrete median barrier. TxDOT has not full-scale tested this 42-inch single slope barrier to Test Level 5 standards. It has tested a 32-inch version to TL-4 with an 18,000 lb single unit truck at 50 mph and 15 degree angle of impact. Another tall barrier, in addition to the New Jersey barrier and the Texas constant slope barrier, is the California Type 60 barrier. The California barrier with a constant-slope profile makes an angle of 9.1 degrees with respect to vertical. This is closer to the 6-degree slope on the upper faces of the New Jersey shape and the F shape. California has used this constant-slope profile for its 42-inch Type 60 roadside barrier and for its Type 70 bridge rail *(79)*.

There have been at least three successful TL-5 tests on 42-inch barriers; two were New Jersey safety shape barriers, and one was a vertical wall. Based on this testing, the barrier shape/profile and height of the TxDOT 42-inch single slope barrier is probably adequate for TL-5. However, verification would require a strength analysis to prove that the reinforcing is adequate in the current barrier design to accommodate TL-5 impact loads. The New Jersey 42-inch barrier has more steel to anchor it below the roadway surface as well as above the roadway compared to most others. Another variable that would affect performance besides height, shape, and amount of reinforcing steel is the barrier thickness. Also, its width at the top is 12 inches, whereas the Texas single slope barrier Type 2 (Standard Sheet SSCB[2] – 00A) is 8 inches wide at the top.

Future efforts should consider conducting an analytical strength analysis (or actual field test) on the 42-inch TxDOT barrier. If the current level of reinforcement is not sufficient to accommodate TL-5 impact loads, TxDOT could modify the amount of reinforcement. If the strength can be demonstrated analytically, it is likely that the TxDOT 42-inch barrier would meet TL-5 requirements without additional crash testing. This prediction is based in part on the previous TL-5 testing of the New Jersey-shape 42-inch barriers. The New Jersey profile is more critical than the F-shape or single-slope profile with respect to the geometric interaction with the vehicle. Therefore, given that the New Jersey profile has been successfully tested, the single-slope profile should also be adequate for the same height (given that the strength has been checked). Again, the 42-inch height is considered a minimum for containing tractor-trailers, depending on the actual impact conditions. It is possible that the box trailer (but typically not the tractor) could overturn across the barrier. Even under these circumstances, the consequences may not be severe if there is a wide shoulder (e.g., 10 to 12 ft) to provide a buffer zone from the opposite direction traffic. A taller barrier (e.g., 54 inches) would provide even greater containment capacity.

The concrete barrier is the most effective barrier type for containing trucks, although states have installed other types with some success. A company in Italy also marketed a barrier system in the U.S. under the name Fricasso, more generically known as the "3N barrier," that was approved for TL-5 applications. Even cable systems have become more popular recently and have effectively contained trucks. However, they require more room (behind the barrier) and the cable 30 inches high does not always catch the appropriate part of the truck that would contain and redirect it. Some W-beam median barriers are 27 to 30 inches tall but it would not be effective for trucks. In the final analysis, most states currently use engineering judgment to determine the appropriate level for design. In summary, the most appropriate roadside design where heavy truck flows exist would focus on bridge rail and median barrier, using the 42-inch TL-5 barrier.

Crash cushions are currently designed only for passenger vehicles, not for trucks. Design for trucks would require either a stiffer design or a longer overall crash cushion. The principle of designing crash cushions today is to contain vehicles in the weight range from 1800 lb up to about 5000 lb. To design for trucks and continue using today's design stiffness would require significant additional space, and many gore areas would not be large enough. Another way to design crash cushions for trucks in a mixed traffic stream would be to have multiple stages, the first being the softest to contain the smallest cars. The first stage might stop an 1800 lb car in 12 ft. The second stage might be stiffer than stage one but would contain some larger vehicles. Heavy trucks would require a third stage, which would not be needed for impacts of smaller vehicles. Design for trucks only could use a single stiffer unit.

Recommendation: The authors recommend an evaluation of the results of NCHRP 22-12 when completed to determine their application to Texas roadways in general and to truck roadways in particular. As a preliminary statement, the longitudinal barrier associated with truck roadways or high flows of trucks should always be 42 inches in height and structurally sufficient for trucks, meeting the TL-5 barrier requirements.

8.3.4.7 Passive Signs

With the possibility of trucks following other trucks at fairly close spacings, there exists the potential of signs being visually blocked by a vehicle ahead. There must be consideration given to sign placement to ensure adequate visibility for all motorists. The engineer might consider oversize signs, overhead signs, and sign redundancy to convey the appropriate information to motorists. An example of sign placement that seems to work well occurs on the dual-dual roadway of the New Jersey Turnpike. The NJTA places guide signs overhead on its dual-dual roadway system in advance of all interchanges over both the inner and outer roadways. As a minimum, guide signs for interchanges begin with a two-mile advance sign placed between the inner and outer roadways, followed by a one-mile sign, then a one-quarter mile sign placed at the start of the one-quarter mile deceleration lane.

The TRDM does not cover this subject, but the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) *(80)* does. It provides the following information regarding sign placement for interchanges. In Section 2E.30 entitled “Advance Guide Signs,” the TMUTCD recommends that two and preferably three advance guide signs be used for major and intermediate interchanges. The TMUTCD defines a minor interchange as one where the sum of exit volumes is lower than 100 vehicles per day in the design year. For truck roadways, it is anticipated that exit volumes will far exceed this threshold, so this discussion pertains to intermediate and major interchanges as defined by Section 2E.29 of the TMUTCD. The manual also stipulates that “… signs at interchanges and on their approaches shall include Advance Guide signs and Exit Direction signs.” At minor interchanges, the TMUTCD recommends using only one advance guide sign as opposed to two or three for intermediate and major interchanges.

Mounting locations for guide signs at each of these distances in the TMUTCD depends upon the type of interchange. For freeway-to-freeway interchanges, the manual states that “overhead signs shall be used at a distance of 1 mi and at the theoretical gore of each connecting ramp.” As an option, overhead signs “may also be used at the 0.5 mi and 2 mi points.” For cloverleaf interchanges, the manual requires an overhead guide sign to be placed at the theoretical gore point of the first exit ramp, with a second overhead sign over the second exit placed over the auxiliary lane for each direction. For partial cloverleaf interchanges where the crossing roadway is above the mainline, the manual indicates the use of an overhead sign on the structure (near the gore) and states that “a ground-mounted exit sign shall also be installed in the ramp gore. For a diamond interchange, the manual covers “typical diamond interchange guide signs” and “typical urban diamond interchange guide signs.” In both cases, the manual shows ground-mounted guide signs at distances of 0.5 mile and 1 mile in advance of the interchange and a ground-mounted Exit Direction sign in advance of the gore area. For more details on the placement of these and other signs, see the TMUTCD.

Recommendation: For truck roadways, it is anticipated that diamond interchanges will be very common, so the authors recommend the use of overhead signs instead of ground-mounted signs approaching diamond interchanges. There should be two advance signs in addition to the Exit Direction sign mounted in advance of the gore. The advance signs should be located upstream of the interchange at 1 mile and 2 miles in rural areas and at 0.5 mile and 1 mile in urban areas. Since the manual already stipulates that other signs be mounted primarily overhead, no change is recommended pertaining to other types of interchanges. The authors also recommend the use of overhead signs for mixed flow roadways where the number of trucks predicted during the design period exceeds 5000 tpd.

8.3.4.8 Curbs

In past years, some freeway ramps have utilized 6-inch barrier curb for drainage purposes or simply for delineation. However, research by Ervin *(81)* discovered that curbs on the outside of ramp curves could be a contributing factor to truck rollover. While trailer offtracking at low speeds is inside of the tractor path, at higher speeds it can be outboard of the tractor path. As a combination vehicle negotiates a relatively sharp ramp curve and high-speed offtracking forces the trailer tires to contact the curb, a “tripping” action can occur, with subsequent rollover. Future design should eliminate these curbs on the outside of ramp curves.

The TRDM states that curbs should not be used in connection with the through, high-speed traffic lanes or ramp areas except at the outer edge of the shoulder where needed for drainage. If used, they should be the sloping type and not the vertical type.

Recommendation: The authors recommend no changes.

8.3.4.9 Acceleration Lanes

Acceleration lanes are speed-change lanes that provide adequate distance for vehicles to accelerate to near highway speeds before entering the through lanes of a highway. The *Green Book* states that to assist truck acceleration, high-speed entrance ramps should desirably be located on descending grades and that longer acceleration lanes should be provided on elevated freeways where entrance ramps must necessarily incorporate upgrades.

Findings of NCHRP Project 15-21 provide the latest and most up-to-date information on truck power-to-weight ratios for evaluating the current criteria in the

Green Book and TxDOT's *Roadway Design Manual*. According to that information, The 85th percentile weight/power ratios of trucks in the current truck fleet range from 170 to 210 lb/hp for the truck populations using freeways and from 180 to 280 lb/hp for the truck population using two-lane highways *(7)*. The report establishes the minimum acceleration lengths for a 180 lb/hp truck as shown in Table 52. These minimum acceleration lengths are, on average, about 1.8 times greater than the minimum acceleration lengths given in the *Green Book*.

Recommendation: The authors recommend increasing acceleration lane lengths on roadways with AADTT predicted to reach at least 5000 tpd during the design period to reflect the requirements of today's trucks.

Table 52. Minimum Acceleration Lengths for 180 lb/hp Trucks.

Acceleration length, L(ft), necessary for entrance curve to enable a 180 lb/hp truck to reach V_a given V'_a for a 0 percent grade										
Highway		Stop condition	15	20	25	30	35	40	45	50
Design speed V (mph)	Speed reached V_a (mph)	And initial speed, V'_a (mph)								
		0	14	18	22	26	30	36	40	44
30	23	275	160	-	-	-	-	-	-	-
35	27	400	300	230	-	-	-	-	-	-
40	31	590	475	400	310	170	-	-	-	-
45	35	800	700	630	540	400	240	-	-	-
50	39	1100	1020	950	850	720	560	200	-	-
55	43	1510	1400	1330	1230	1100	920	580	240	-
60	47	2000	1900	1830	1740	1600	1430	1070	760	330
65	50	2490	2380	2280	2230	2090	1920	1560	1220	800
70	53	3060	2960	2900	2800	2670	2510	2140	1810	1260
75	55	3520	3430	3360	3260	3130	2960	2590	2290	1850

Source: Reference (7).

8.3.5 Summary

The overall finding of this chapter is that current TxDOT design practice in many respects already reflects the needs of large trucks as well as large numbers of trucks. However, there are some important deficiencies that need to be addressed, not only for future considerations of truck roadways but for mixed flows of trucks as well.

Under the category of sight distance, TTI recommends that a statement of caution pertaining to stopping sight distance for horizontal curves at the end of long downgrades be added to the TRDM for truck roadway design. Where horizontal sight obstructions occur on downgrades, particularly at the ends of long downgrades, the greater eye height of truck drivers is of little value. The *Green Book* states that it is desirable under such conditions to provide stopping sight distance that exceeds the values in its Exhibit 3-1.

Under the category of horizontal alignment, TTI recommends changes related to curve radius and superelevation, and intersection and channelization geometrics. One apparent erratum (although on the conservative side) is the TRDM radius of 600 ft for a design speed of 45 mph instead of the *Green Book* value of 500 ft. The authors recommend adding the WB-65 design vehicle to the TRDM for truck facilities, along with accompanying text to support its selection for many design features. Also, there should be appropriate language cautioning designers that design tools like AutoTurn do not consider driver input and the variability introduced by drivers. AutoTurn or templates give one solution for a selected design vehicle.

Under the category of vertical alignment, TTI researchers recommend no changes to current practice. For the category of cross-section elements TxDOT design needs to change pavement width, shoulder width, sideslope and drainage features, and passive signs. TTI recommends increasing the lane width from 12 ft to 13 ft for exclusive truck facilities and staying with 12 ft lanes where trucks remain in the mixed flow or are restricted to specific lanes. The authors recommend increasing the outside shoulder width to 12 ft along truck roadways and mixed flow roadways predicted to reach an AADTT of at least 5000 trucks per day during the design period. The design should also offset vertical elements a minimum of 2 ft from the outer edge of the usable shoulder.

There is a need for additional research pertaining to trucks negotiating sideslopes and drainage features, but until that happens, the authors recommend no changes in design practice. In that regard, the authors recommend an evaluation of the results of NCHRP 22-12 when completed to determine applicability to Texas roadways in general and to truck roadways in particular. As a preliminary statement, the longitudinal barrier associated with truck roadways or high flows of trucks should always be 42 inches in height and structurally sufficient for trucks, meeting the TL-5 barrier requirements.

Based on a review of guide sign requirements in the *Texas Manual on Uniform Traffic Control Devices*, anticipated heavy flows of large trucks approaching interchanges should prompt the use of overhead signs instead of ground-mounted signs. For most interchange types covered in the manual, the signs are already overhead and located appropriately. Since the vast majority of interchanges in Texas are currently diamond interchanges and these interchanges will probably continue to be used on truck roadways and in mixed flows, there is a need to reevaluate the location of advance signs. The authors recommend the use of overhead signs instead of ground-mounted signs approaching diamond interchanges. There should be two advance signs in addition to the Exit Direction sign mounted in advance of the gore. The advance signs should be located upstream of the interchange at 1 mile and 2 miles in rural areas and at 0.5 mile and 1 mile in urban areas. No change is recommended pertaining to other types of interchanges. The authors also recommend the use of overhead signs for mixed flow roadways where the number of trucks predicted during the design period exceeds 5000 tpd.

The minimum acceleration lengths needed for large trucks are, on average, about 1.8 times greater than the minimum acceleration lengths given in the *Green Book* and the TRDM. The authors recommend increasing acceleration lane lengths on roadways with

AADTT predicted to reach at least 5000 tpd during the design period to reflect the requirements of today's trucks. A final consideration is that there may be other forthcoming vehicle changes to the AASHTO *Green Book* resulting from the NCHRP 15-21 study that need to be monitored and incorporated into Texas design practice.

Table 53 summarizes the findings of both the design parameters identified early in this research and the recommendations of the TTI research team for change and the truck activity level at which the change should occur (Chapter 7 values). Since the emphasis of the research moved to controlled-access facilities, some of these parameters originally selected did not apply. Much of TxDOT's current design practice already reflects the unique characteristics of large commercial vehicles, so the authors are recommending no change to several design parameters.

Table 53. Design Thresholds.

Design Element	Design Year AADTT		
	1000 to 5000	5001 to 25,000	Over 25,000
Sight Distance			
Stopping Sight Distance	NC [a]	NC [a]	NC [a]
Decision Sight Distance	NC	NC	NC
Passing Sight Distance	NA	NA	NA
RR-Hwy Sight Distance	NA	NA	NA
Intersection Sight Distance	NC	NC	NC
Horizontal Alignment			
Curve Radius and Superelev.	NC	NC	NC
Intersection & Channelization	NC	*	*
Pavement Widening	NC [b]	NC [b]	NC [b]
Vertical Alignment			
Critical Length of Grade	NC	NC	NC
Downgrades	NC	NC	NC
Cross-Section Elements			
Lane Width	NC	NC	*
Shldr. Width & Composition	NC	*	*
Sideslopes & Drainage	NC [c]	NC [c]	NC [c]
Pavement X-Slope Breaks	NC	NC	NC
Vertical Clearance	NC	NC	NC
Traffic Barrier	NC	* [c]	* [c]
Passive Signs	NC	* [d]	* [d]
Curbs	NC	NC	NC
Acceleration Lanes	NC	*	*

* Change required from current TxDOT practice to design specifically for trucks.
NA: Not applicable to high-volume, controlled-access roadways for trucks.
NC: No change from current design practice.
[a] Needs a change in wording in the *TxDOT Roadway Design Manual*.
[b] For design speeds over 60 mph.
[c] Apply findings of NCHRP 22-12 as appropriate to Texas roadways.
[d] For diamond interchanges use overhead signs instead of ground-mounted at 0.5 mi and 1 mi in urban areas and 1 mi and 2 mi in rural areas.

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APPENDIX A

TTI SURVEY FORM SENT TO TXDOT DISTRICTS

SURVEY: TRUCKS AND RELATED DESIGN ISSUES

TxDOT Research Project 0-4364, "Truck Accommodation Design Guidance," will determine design characteristics that are appropriate for roadways that are increasingly dominated by truck traffic. This survey is intended to identify districts that have already taken steps to design features into roadways to accommodate the unique characteristics of commercial vehicles, and what the steps are.

Regulatory Issues

1. Do you have any designated NAFTA corridors or candidate truck corridors in your district? Please identify:

____

2. Do you have any *local* restrictions for truck usage? Please list:

____

3. Do you have any designated truck lanes or separate truck facilities in your district? Please identify:

____

4. Does your district grant route specific (or other) exceptions to "normal" size/weight rules? (beyond Motor Carrier Division oversize/overweight and 2060 permits)? Please list:

____

Design Issues

5. What are the district's busiest truck routes and what are their daily or yearly truck volumes?

____

6. Do these truck volumes vary by season? YES ___ NO ____

If yes, by approximately what percent? <5%: ___ 5% to 10%: __ 11% to 15%: __ >15%: ___

7. Do you give special consideration to geometric issues for trucks? YES ___ NO ____
If yes, please check all that apply.

Acceleration (intersect.)		Decision sight distance		Off-tracking characteristics	
Acceleration (grades)		Driver eye height		Operating characteristics on grades	
Alignment (horizontal)		Intersection design		Ramp design	
Alignment (vertical)		ITS (e.g., active warning on curves)		Roadside hardware (e.g., signs, barrier)	
Braking characteristics		Left-turn lanes		Side slopes	
Bridge issues		Lighting		Stopping sight distance	
Capacity considerations		Minimum design for sharpest turn		Signing (passive)	
Climbing lanes		Passing sight distance		Weaving distances	
Deceleration on grades		Pavement issues		Other (specify below)	

Other: ____

Suggestions

8. Do you have any suggestions or success stories regarding planning and designing for heavy truck volumes or truck routes?

____

Thank you for completing this survey!

If you have any questions, please call:
Dan Middleton, Ph.D., P.E.
Texas Transportation Institute
Telephone: 979-845-7196
E-mail: d-middleton@tamu.edu

APPENDIX B

DPS SURVEY FORM

DPS Survey

TTI sent out a survey through the Austin headquarters of the Department of Public Safety's License and Weight (L&W) Service. Headquarters forwarded the survey to all six DPS regions for completion by both Highway Patrol and L&W troopers who were familiar with roadways in their area. The list below provided guidance to troopers regarding the type of information needed.

<u>Specific deficiencies noted in survey results include</u>:

1. Insufficient parking for trucks ______________________________

2. Shoulders too narrow for truck emergency parking ______________________________

3. Inadequate acceleration or deceleration lane lengths______________________________

4. Intersection design inadequate for large trucks ______________________________

<u>Specific:</u>

1. Sharp turns or curves - Tight ramp or mainline geometrics causing rollovers ________

2. Inadequate distance between entry and exit ramps for weaving ____________________

3. Two lane roadways that need climbing lanes ______________________________

4. Specific locations with big parking problems ______________________________

<u>Additional:</u>

Trends in vehicles noted on the survey:

1. More long semitrailers: Yes____________________ No: _______________________

2. Different vehicle types: ______________________________

3. Other trends: ______________________________

APPENDIX C

MONTHLY TRUCK BORDER CROSSING ACTIVITY
CLASS 7 AND UP

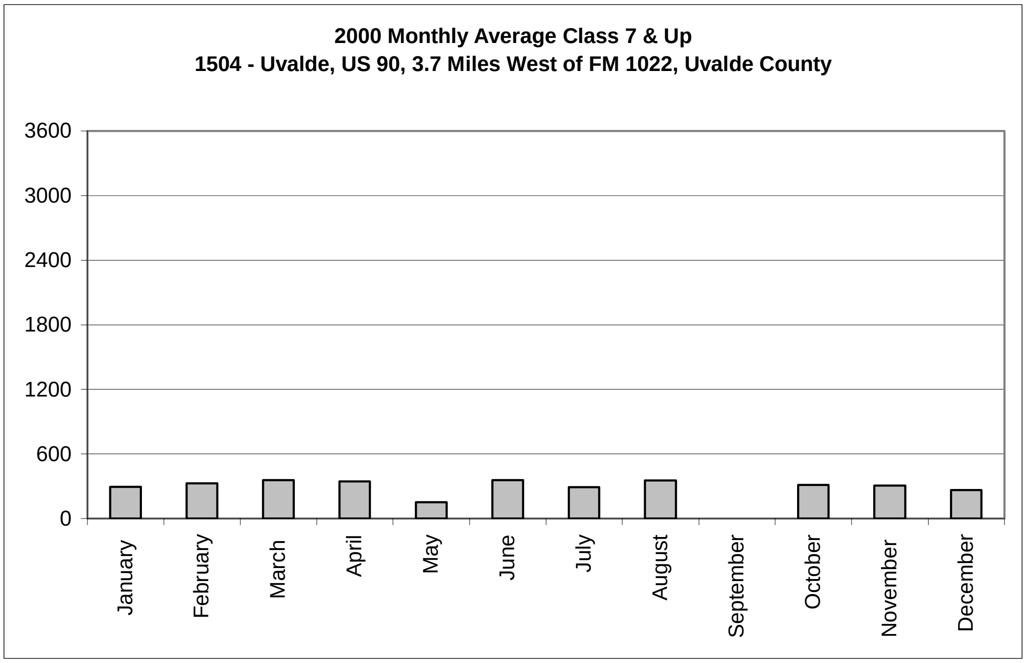


Figure 57. 2000 Monthly Average Count for Class 7 and Up at Station 1504.

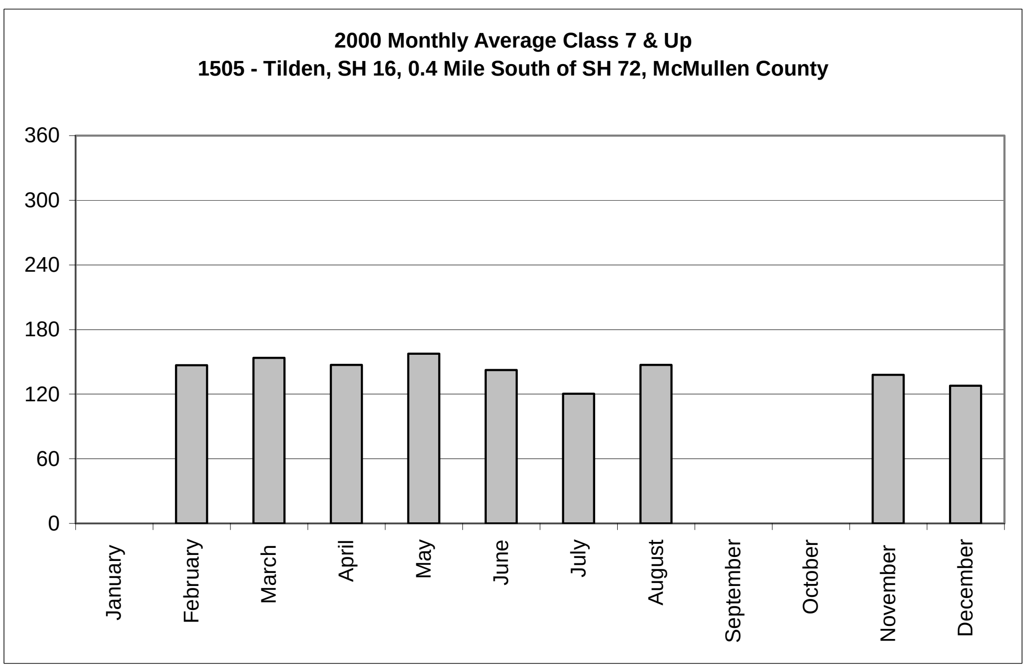


Figure 58. 2000 Monthly Average Count for Class 7 and Up at Station 1505.

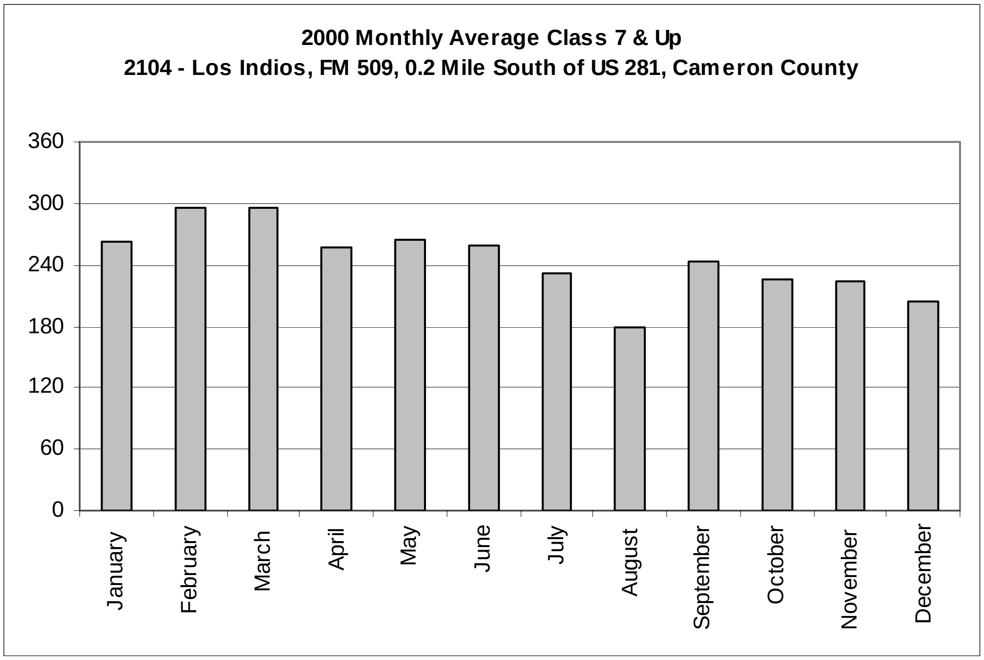


Figure 59. 2000 Monthly Average Count for Class 7 and Up at Station 2104.

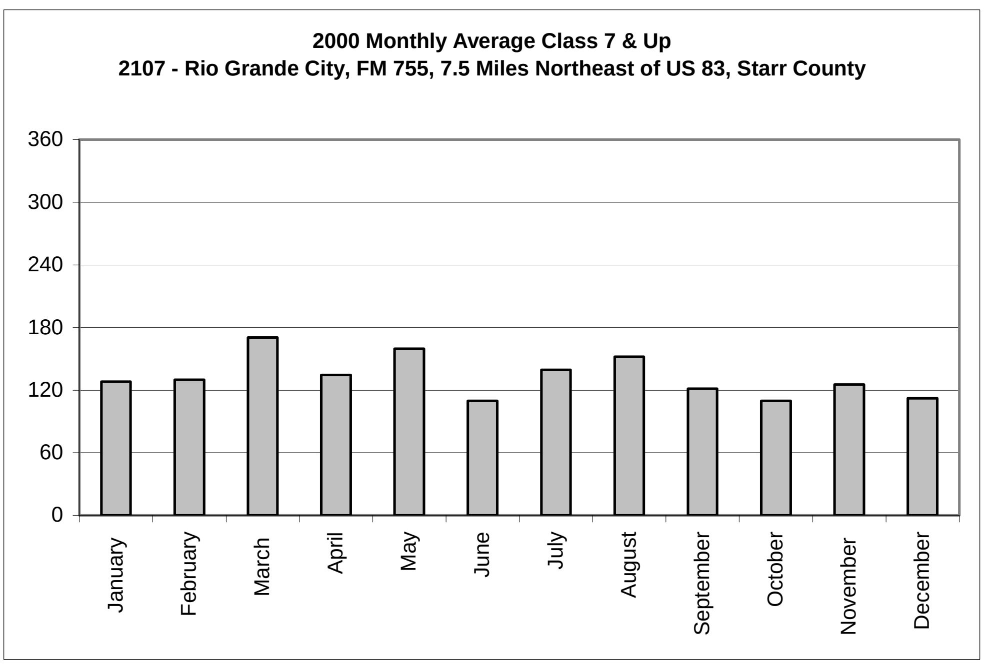


Figure 60. 2000 Monthly Average Count for Class 7 and Up at Station 2107.

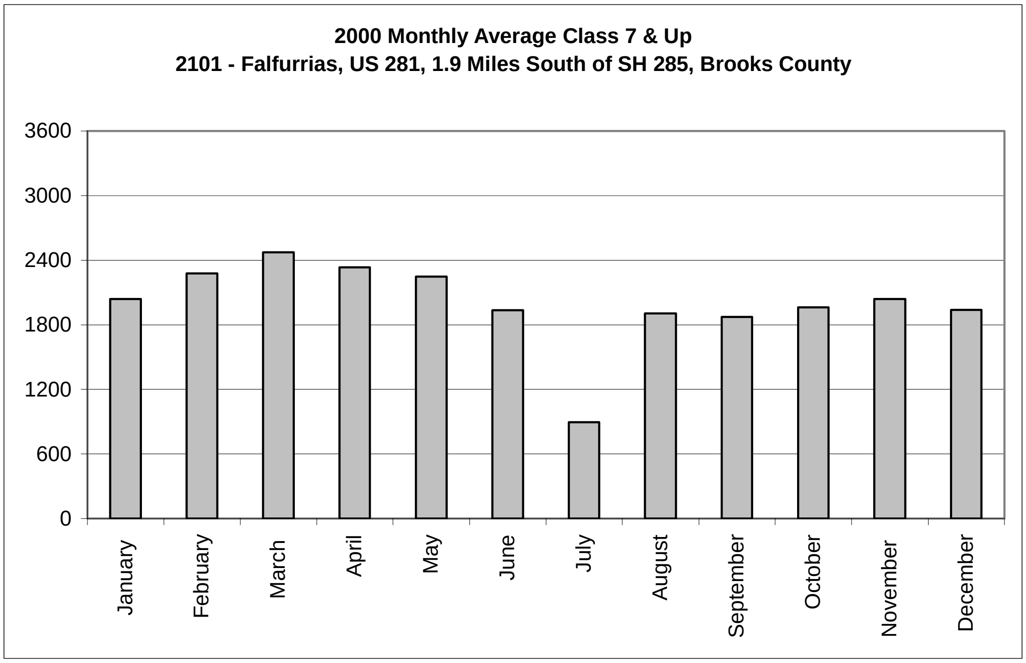


Figure 61. 2000 Monthly Average Count for Class 7 and Up at Station 2101.

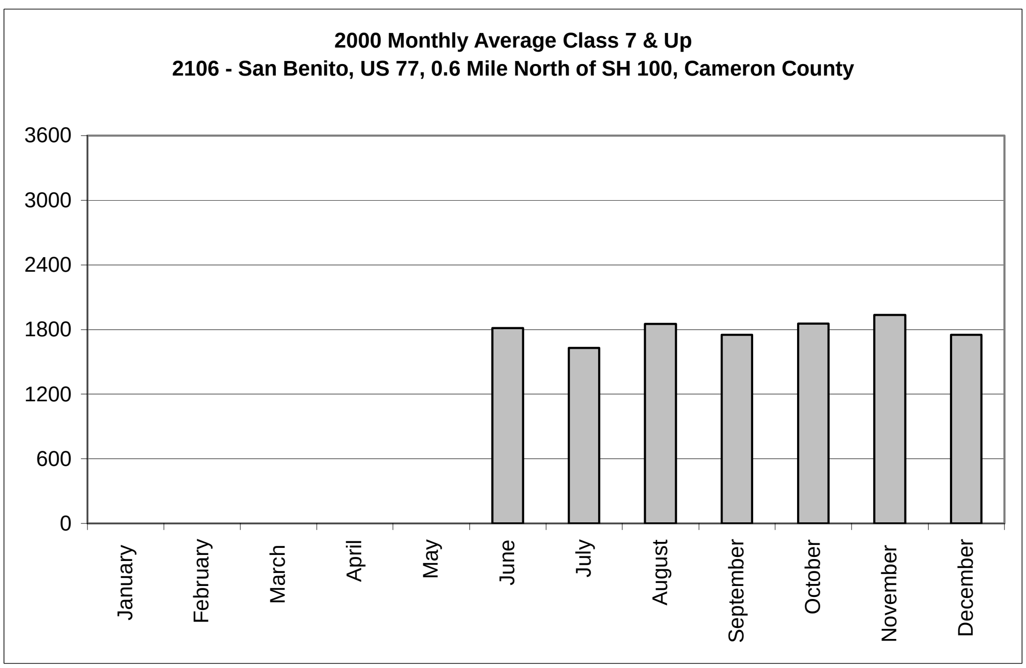


Figure 62. 2000 Monthly Average Count for Class 7 and Up at Station 2106.

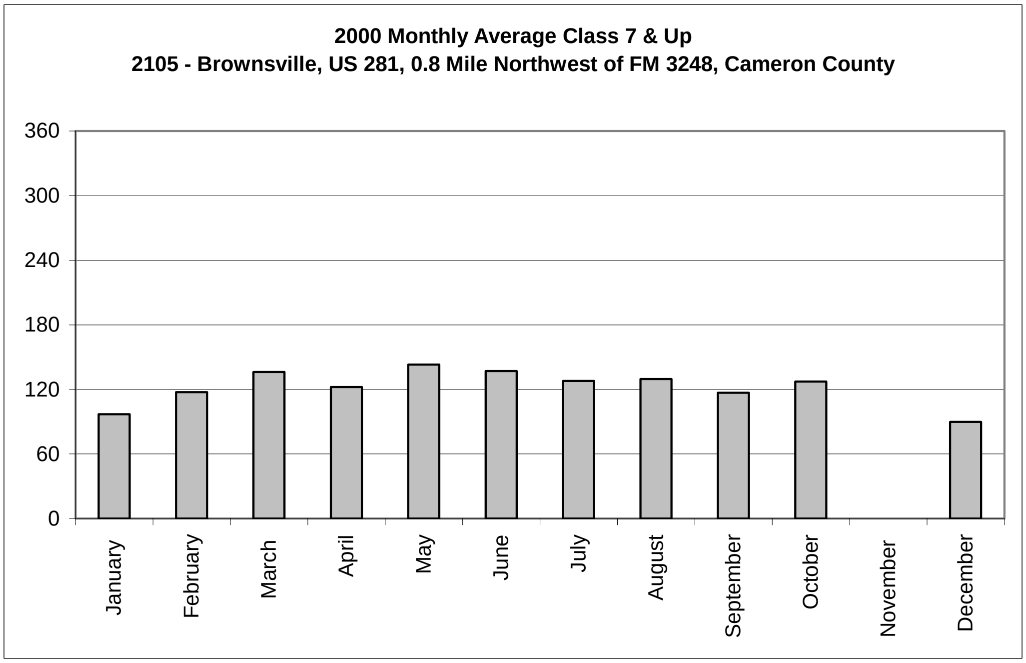


Figure 63. 2000 Monthly Average Count for Class 7 and Up at Station 2105.

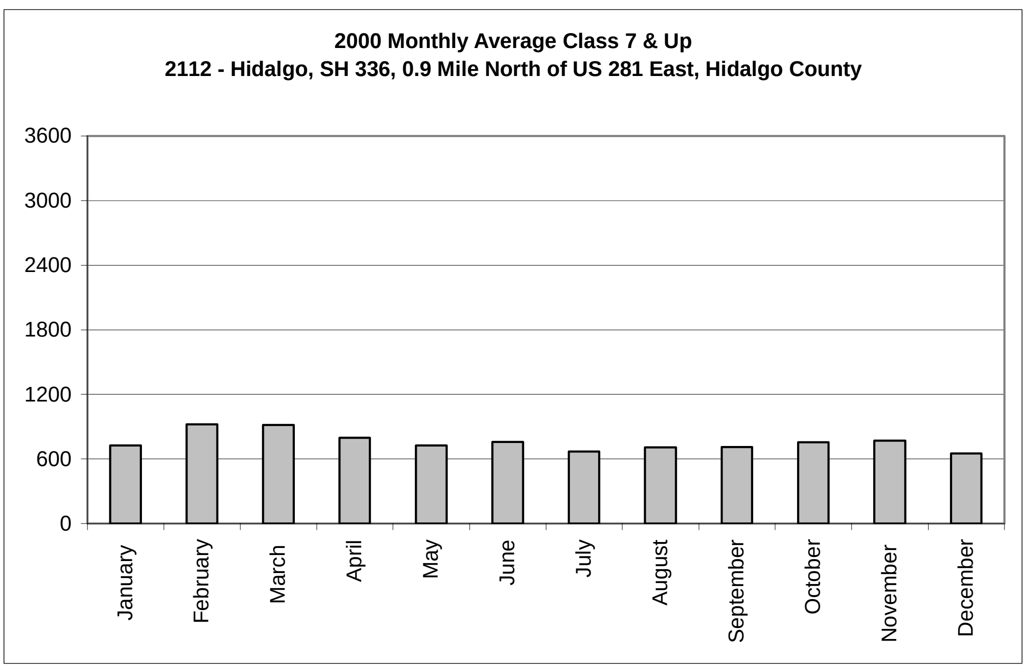


Figure 64. 2000 Monthly Average Count for Class 7 and Up at Station 2112.

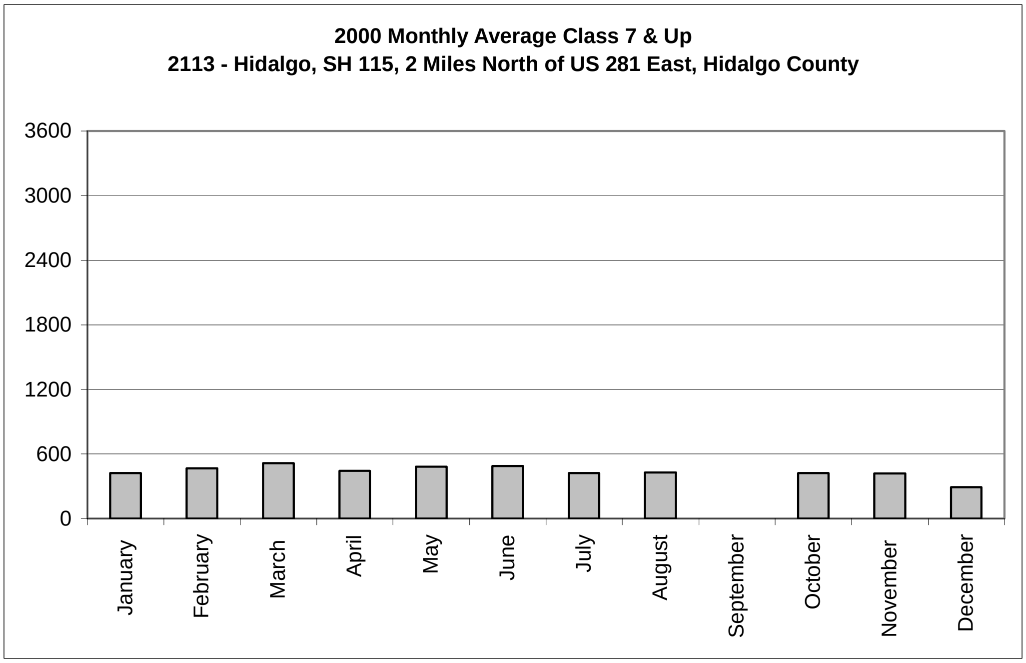


Figure 65. 2000 Monthly Average Count for Class 7 and Up at Station 2113.

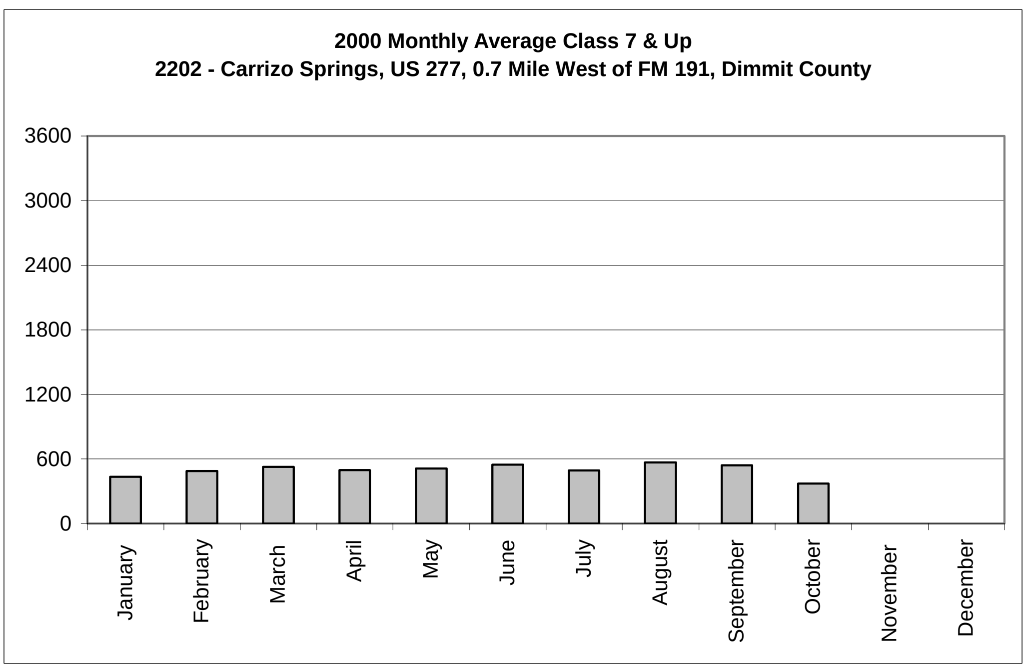


Figure 66. 2000 Monthly Average Count for Class 7 and Up at Station 2202.

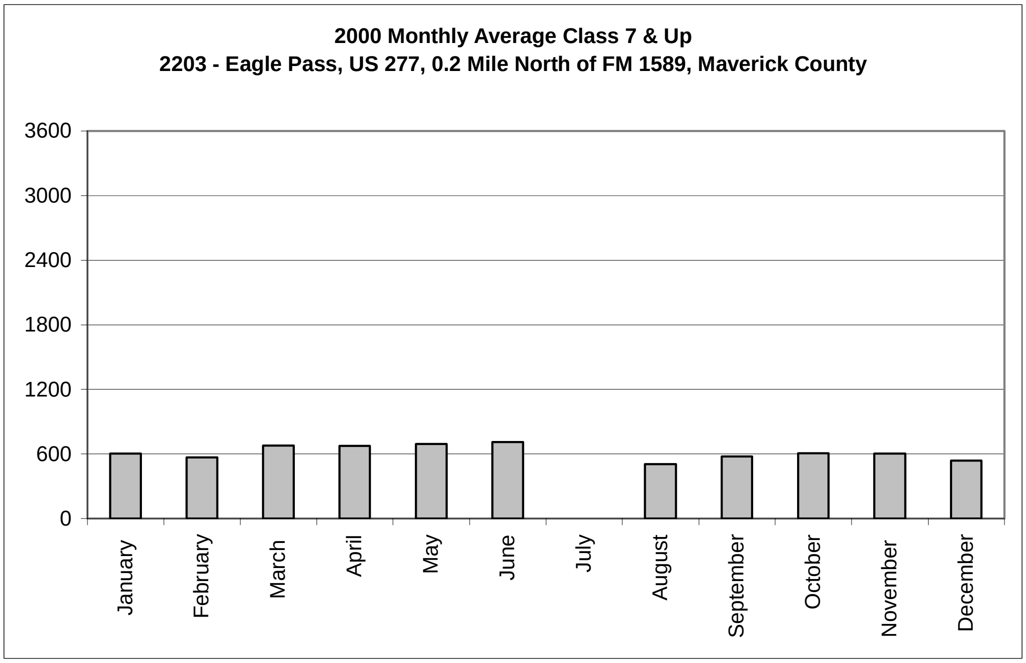


Figure 67. 2000 Monthly Average Count for Class 7 and Up at Station 2203.

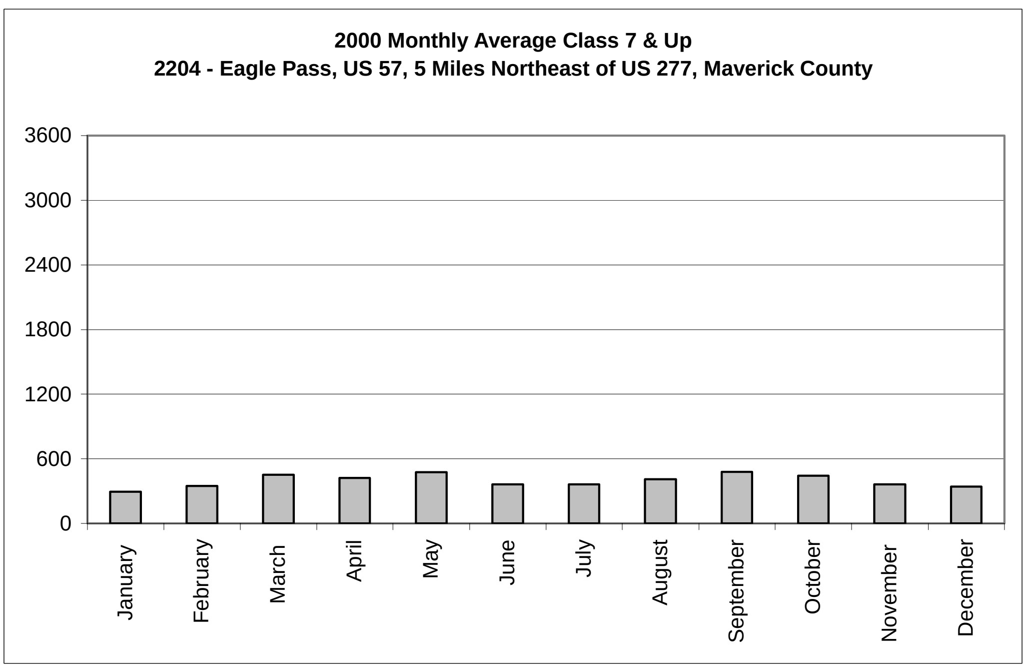


Figure 68. 2000 Monthly Average Count for Class 7 and Up at Station 2204.

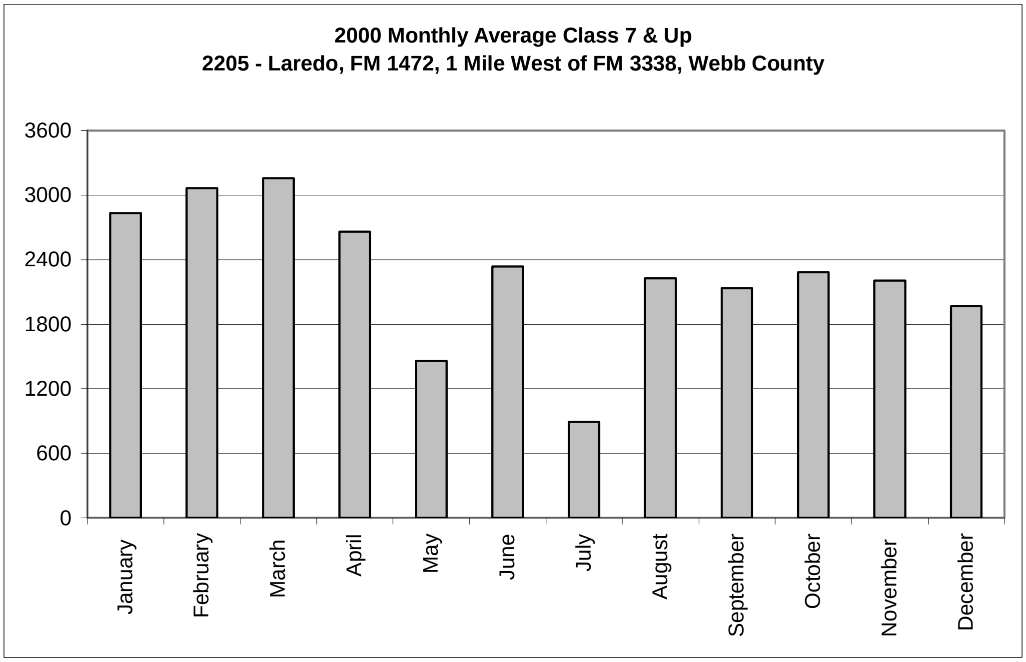


Figure 69. 2000 Monthly Average Count for Class 7 and Up at Station 2205.

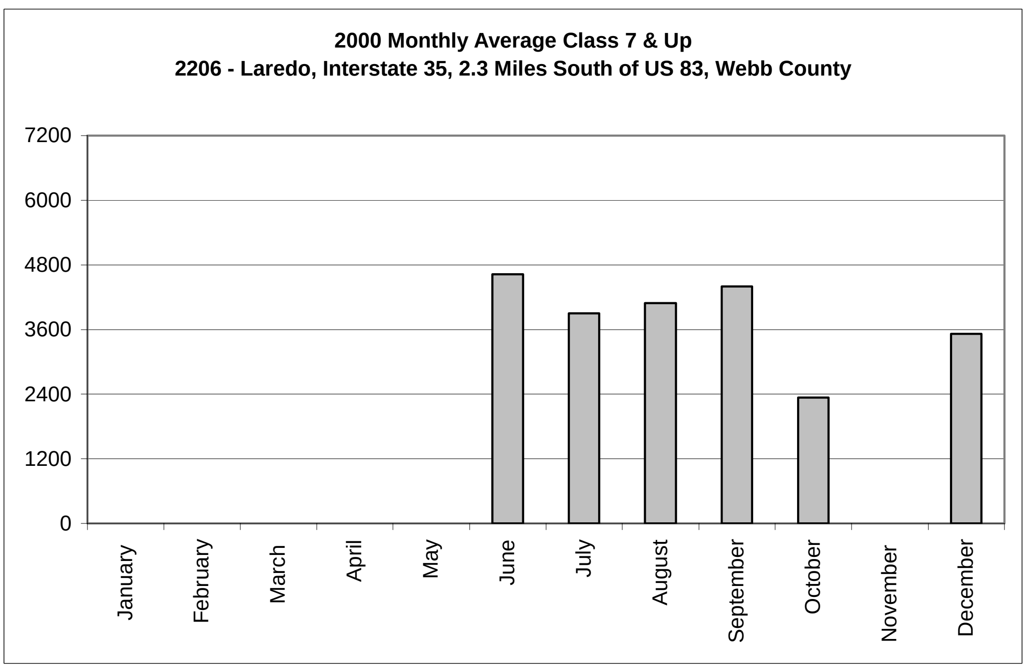


Figure 70. 2000 Monthly Average Count for Class 7 and Up at Station 2206.

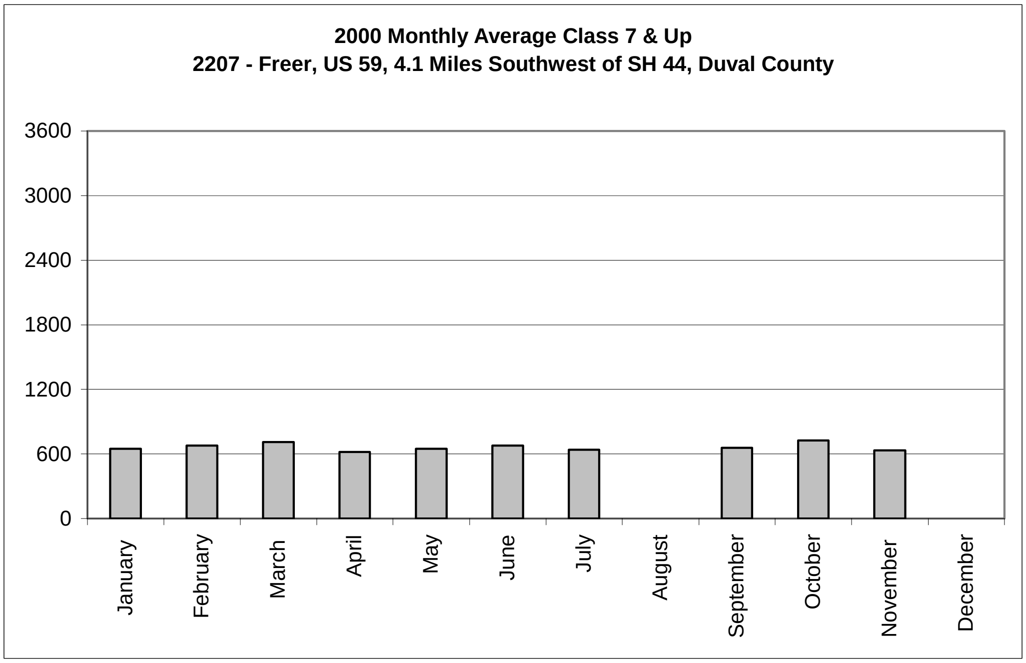


Figure 71. 2000 Monthly Average Count for Class 7 and Up at Station 2207.

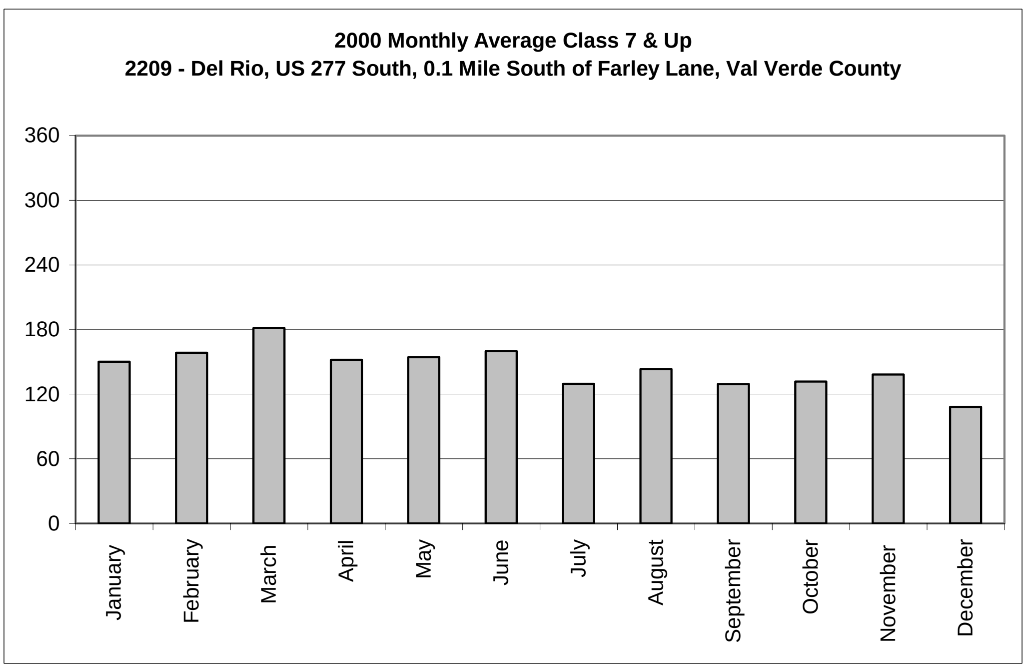


Figure 72. 2000 Monthly Average Count for Class 7 and Up at Station 2209.

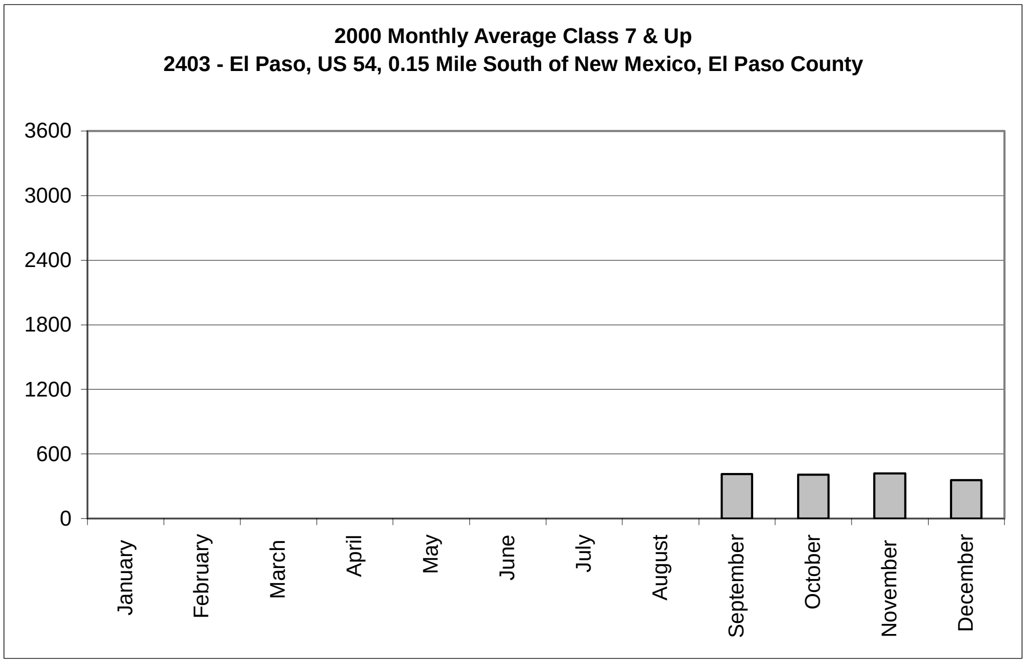


Figure 73. 2000 Monthly Average Count for Class 7 and Up at Station 2403.

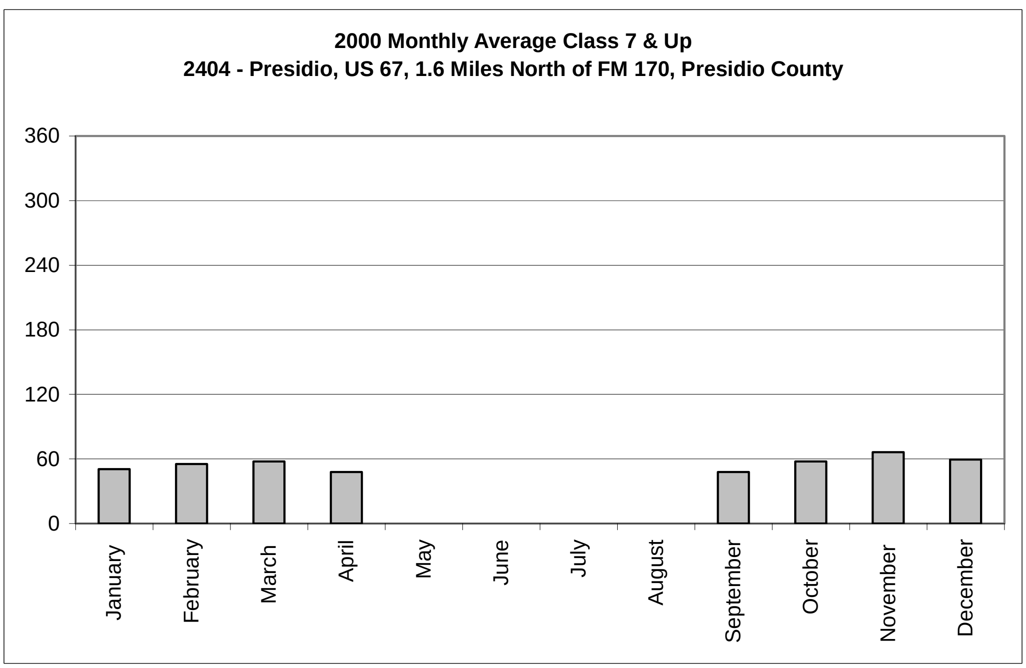


Figure 74. 2000 Monthly Average Count for Class 7 and Up at Station 2404.

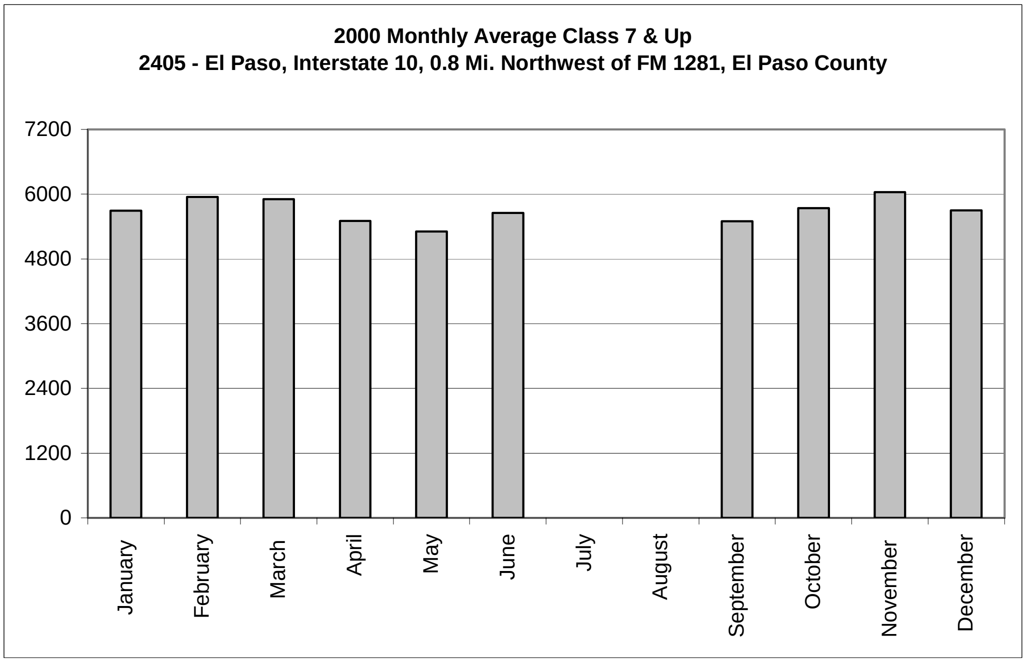


Figure 75. 2000 Monthly Average Count for Class 7 and Up at Station 2405.

APPENDIX D

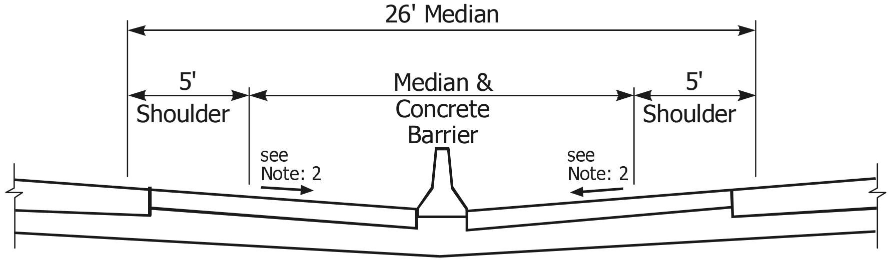
NEW JERSEY TURNPIKE TRAFFIC VOLUME BY VEHICLE CLASS AND SEGMENT

Table 54. New Jersey Turnpike Traffic Volumes in 2001.

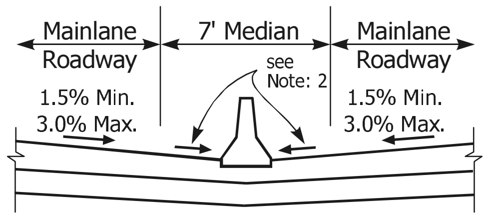
Intchgs	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class B2	Class B3
1 - 2	16,221,541	416,349	393,326	289,127	2,047,599	29,957	13,696	131,302
2 - 3	16,908,061	454,757	412,993	308,476	2,173,525	31,129	14,254	132,468
3 - 4	19,145,582	561,639	438,764	347,943	2,343,603	34,407	16,401	132,017
4 - 5	23,765,080	743,417	480,075	424,119	2,664,285	37,583	29,134	183,973
5 - JCT	25,580,209	801,854	495,143	454,311	2,806,369	39,976	30,718	197,586
JCT - 6	10,549,754	401,443	114,608	188,937	1,029,624	21,933	10,768	28,434
Bridge	11,453,454	455,316	145,264	220,350	1,228,607	25,116	11,208	28,863
JCT - 7	33,867,111	1,133,581	588,301	610,650	3,640,357	59,023	40,318	222,584
7 - 7A	36,828,739	1,249,049	645,630	674,223	4,562,387	67,680	45,629	230,789
7A - 8	39,881,067	1,393,947	707,108	762,603	5,308,454	76,193	53,476	249,435
8 - 8A	41,651,012	1,416,072	718,235	768,984	5,346,343	78,018	54,452	257,811
8A - 9	48,429,052	1,567,511	779,112	871,771	5,723,435	82,164	58,941	282,319
9 - 10	61,858,627	1,893,962	877,767	920,071	6,118,075	83,483	80,764	373,616
10 - 11	58,360,605	1,980,810	898,203	916,101	5,582,344	69,689	81,717	365,966
11 - 12	68,728,132	2,530,457	1,045,721	1,016,469	6,033,961	83,630	115,116	764,910
12 - 13	71,808,854	2,727,808	1,159,297	1,088,735	6,394,485	84,237	116,498	781,112
13 - 13A	75,636,510	2,881,748	1,311,743	1,134,210	6,685,561	88,866	125,905	859,698
13A - 14	68,004,724	2,803,844	1,176,836	1,139,143	6,153,075	78,460	92,909	836,070
14 - 14A	25,548,414	737,841	370,084	169,069	1,071,056	18,439	35,251	91,301
14A - 14B	19,959,714	564,283	222,493	91,013	322,172	10,069	61,067	94,802
14B - 14C	18,655,897	576,572	184,633	66,812	220,106	8542	71,436	88,847
14 - W	70,415,075	2,924,581	1,153,176	1,143,344	6,078,631	86,206	136,575	966,058
W - 15E	33,471,237	1,207,907	557,822	566,723	2,729,028	34,084	94,395	880,846
15E - JE	32,811,781	1,188,324	551,684	549,252	2,595,315	31,753	108,542	896,012
JE - 16E	38,133,219	1,334,102	604,959	596,686	2,699,581	32,676	136,862	955,412
16E - 17	13,428,733	525,518	217,558	274,381	1,755,953	21,788	21,922	104,086
17 - 18E	23,700,536	858,424	380,946	419,909	2,132,458	24,722	69,585	612,098
N - JW	36,943,838	1,716,674	595,354	576,621	3,349,603	52,122	42,180	85,212
JW - 15W	40,052,220	1,949,618	757,690	658,873	3,868,458	56,283	45,784	88,320
15W - 16W	37,169,471	1,701,806	571,694	557,193	3,453,620	48,519	44,197	84,398
16W - 18W	26,037,397	1,091,572	353,340	380,831	2,644,869	32,070	31,864	67,179
15W - JE	5,321,438	145,778	53,275	47,434	104,266	923	28,320	59,400
15E - JW	3,108,382	232,944	162,336	82,252	518,855	4161	3604	3108

APPENDIX E

NEW JERSEY TURNPIKE SELECTED SPECIFICATIONS



Standard



Minimum

CENTER MEDIAN

Notes:

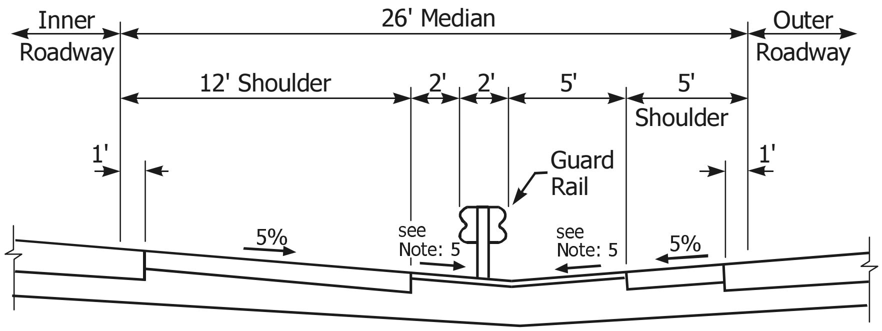
1. Medians other than Standard require Authority approval.

2. Slope varies from 5% minimum to 4% maximum. The 4% maximum slope is to provide for future surfacing.

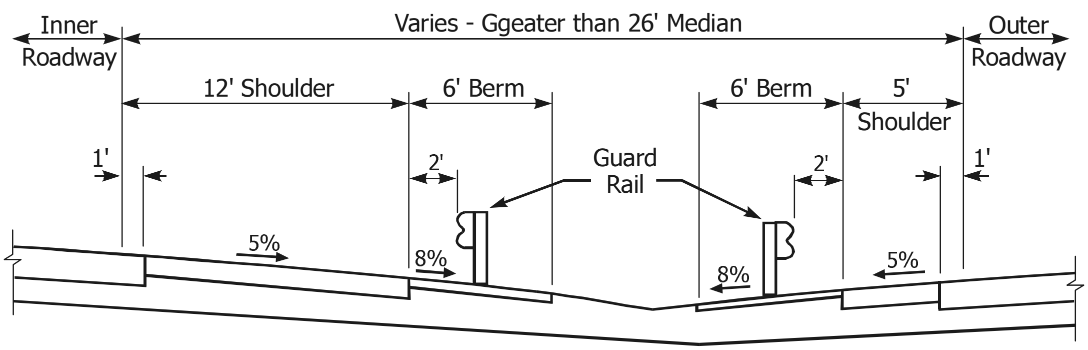
3. Double Beam Guard Rail shall be set at an appropriate height to provide effectiveness of beam from both roadways.

4. For Superelevation requirement, see Manual page HD-3.

5. For Underdrain Details, see Std. Dwg. DR-9.



Standard

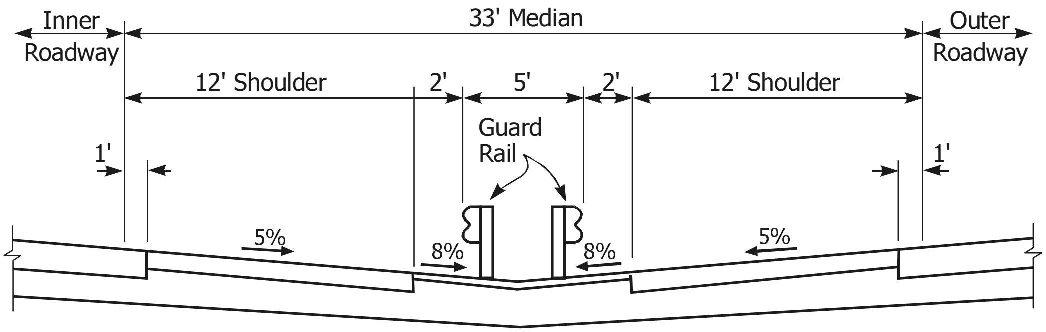


Wide Median

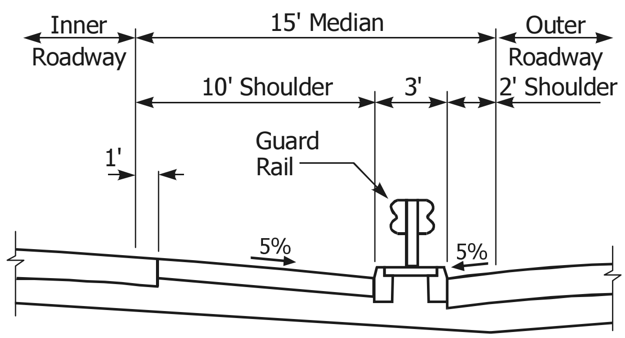
INNER-OUTER MEDIAN - 10-12 LANES

Notes:

1. Medians other than Standard require Authority approval.
2. Double Beam Guard Rail shall be set at an appropriate height to provide effectiveness of beam from both roadways.
3. For Superelevation requirement, see Manual page HD-3.
4. For Underdrain Details, see Std. Dwg. DR-9.
5. Maximum Cross Slope of 10%. Where profile and median width require using steeper slopes, the double face median guardrail shall be split to two single face guardrail units located 2' behind the edge of shoulders.



Standard

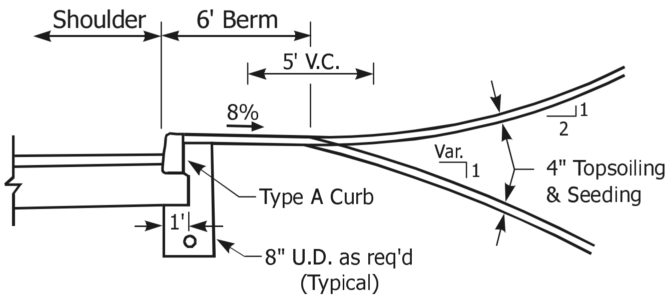


Minimum

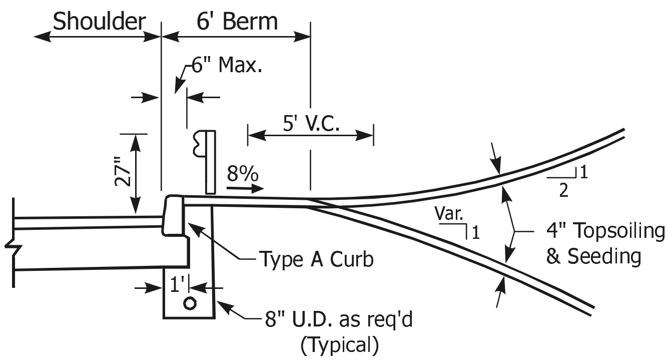
INNER-OUTER MEDIAN - 14 LANES

Notes:

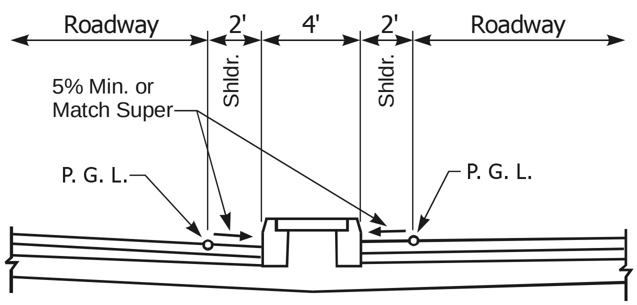
1. Medians other than Standard require Authority approval.
2. Slope varies from 5% minimum to 4% maximum. The 4% maximum slope is to provide for future surfacing.
3. Double Beam Guard Rail shall be set at an appropriate height to provide effectiveness of beam from both roadways.
4. For Superelevation requirement, see Manual page HD-3.
5. For Underdrain Details, see Std. Dwg. DR-9.



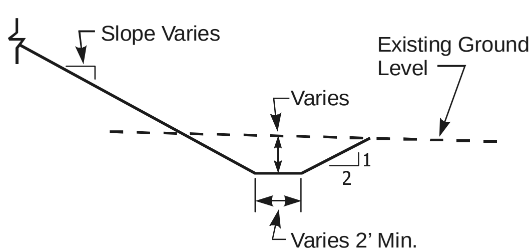
TYPICAL CURB SECTION



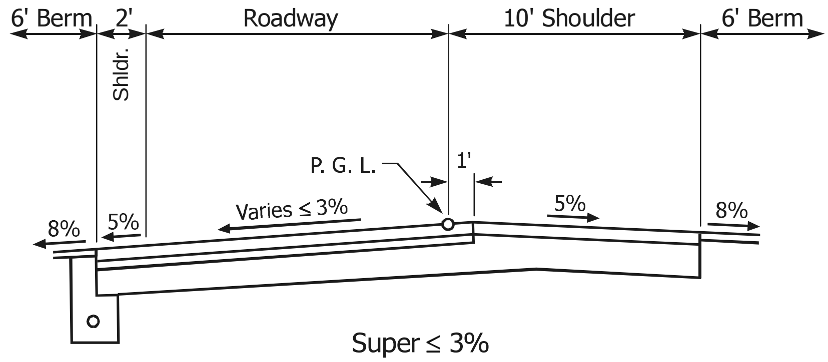
TYPICAL CURB SECTION WITH GUARDRAIL



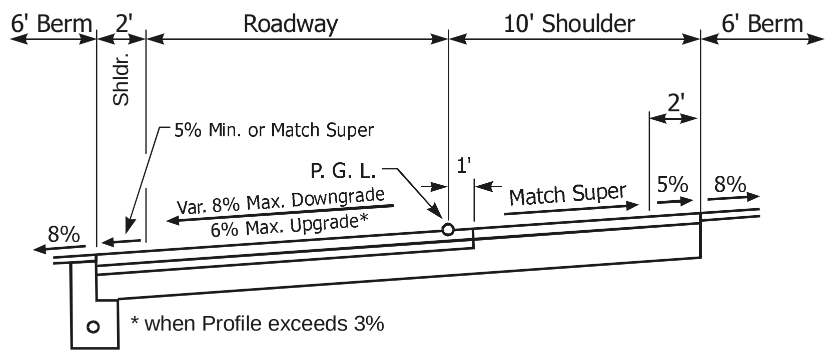
TWO-WAY RAMP DIVIDER



TOE OF SLOPE DITCH

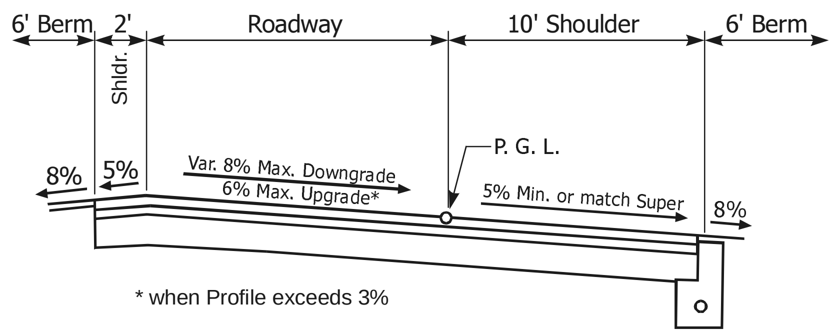


Super ≤ 3%

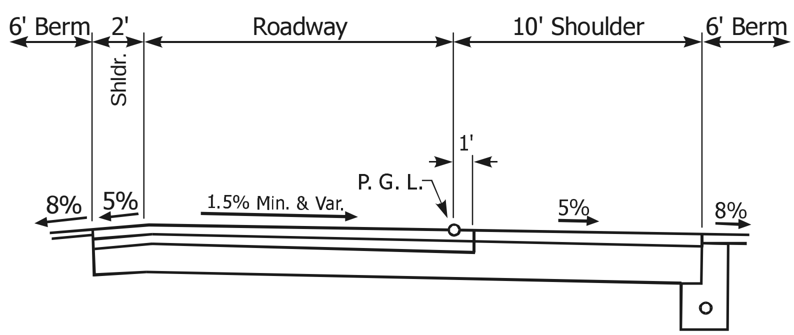


Super > 3%

ONE-WAY RAMP - CURVE LEFT



ONE-WAY RAMP - CURVE RIGHT



ONE-WAY RAMP - NORMAL SECTION

APPENDIX F

CALTRANS TRAFFIC VOLUME AND CRASH DATA FOR THE I-5 TRUCK ROADWAY

1997 CRASHES ON I-5 AND I-5S												
										Rate (MVM)		
Route	Segment	Crash	Fatal	Injury	AADT	From	To	Length	MVM/year	Crash	Fatal	Injury
5	1	41	1	22	264000	36.36	37.41	1.05	101.18	0.4052	0.0099	0.2174
5	2	23	0	15	266000	37.41	37.96	0.55	53.40	0.4307	0.0000	0.2809
5	3	34	0	17	257000	37.96	38.5	0.54	50.65	0.6712	0.0000	0.3356
5	4	51	0	23	245000	38.5	39.36	0.86	76.91	0.6632	0.0000	0.2991
5	5	19	0	14	126000	39.36	39.98	0.62	28.51	0.6663	0.0000	0.4910
5	6	5	0	1	120000	39.98	40.24	0.26	11.39	0.4391	0.0000	0.0878
5	7	36	0	18	111000	40.24	41.6	1.36	55.10	0.6534	0.0000	0.3267
5	10	79	2	57	208000	44.01	45.58	1.57	119.19	0.6628	0.0168	0.4782
5	11	19	0	9	165000	45.58	46.35	0.77	46.37	0.4097	0.0000	0.1941
5S	1	2	0	1	26000	43.93	44.18	0.25	2.37	0.8430	0.0000	0.4215
5S	2	27	1	9	41500	44.18	45.73	1.55	23.48	1.1500	0.0426	0.3833
5S	3	2	0	2	17000	45.73	46.35	0.62	3.85	0.5199	0.0000	0.5199
SUM:												
5	**1-7**	**209**	**1**	**110**		**36.36**	**41.26**	**4.9**	**377.14**	**0.5542**	**0.0027**	**0.2917**
5	**10-11**	**98**	**2**	**66**		**44.01**	**46.35**	**2.34**	**165.57**	**0.5919**	**0.0121**	**0.3986**
5S	**1-3**	**31**	**1**	**12**		**43.93**	**46.35**	**2.42**	**29.70**	**1.0438**	**0.0337**	**0.4041**

1998 CRASHES ON I-5 AND I-5S												
										Rate (MVM)		
Route	Segment	Crash	Fatal	Injury	AADT	From	To	Length	MVM/year	Crash	Fatal	Injury
5	1	56	1	29	260000	36.36	37.41	1.05	99.64	0.5620	0.0100	0.2910
5	2	34	0	19	262000	37.41	37.96	0.55	52.60	0.6464	0.0000	0.3612
5	3	21	1	8	253000	37.96	38.5	0.54	49.87	0.4211	0.0201	0.1604
5	4	66	0	29	242000	38.5	39.36	0.86	75.96	0.8688	0.0000	0.3818
5	5	15	0	2	127000	39.36	39.98	0.62	28.74	0.5219	0.0000	0.0696
5	6	8	0	0	121000	39.98	40.24	0.26	11.48	0.6967	0.0000	0.0000
5	7	45	0	17	112000	40.24	41.6	1.36	55.60	0.8094	0.0000	0.3058
5	10	84	0	36	220000	44.01	45.58	1.57	126.07	0.6663	0.0000	0.2856
5	11	14	0	10	165000	45.58	46.35	0.77	46.37	0.3019	0.0000	0.2156
5S	1	1	0	0	26500	43.93	44.18	0.25	2.42	0.4135	0.0000	0.0000
5S	2	26	0	12	42000	44.18	45.73	1.55	23.76	1.0942	0.0000	0.5050
5S	3	3	0	0	17500	45.73	46.35	0.62	3.96	0.7575	0.0000	0.0000
SUM:												
5	**1-7**	**245**	**2**	**104**		**36.36**	**41.26**	**4.9**	**373.89**	**0.6553**	**0.0053**	**0.2782**
5	**10-11**	**98**	**0**	**46**		**44.01**	**46.35**	**2.34**	**172.44**	**0.5683**	**0.0000**	**0.2668**
5S	**1-3**	**30**	**0**	**12**		**43.93**	**46.35**	**2.42**	**30.14**	**0.9954**	**0.0000**	**0.3981**

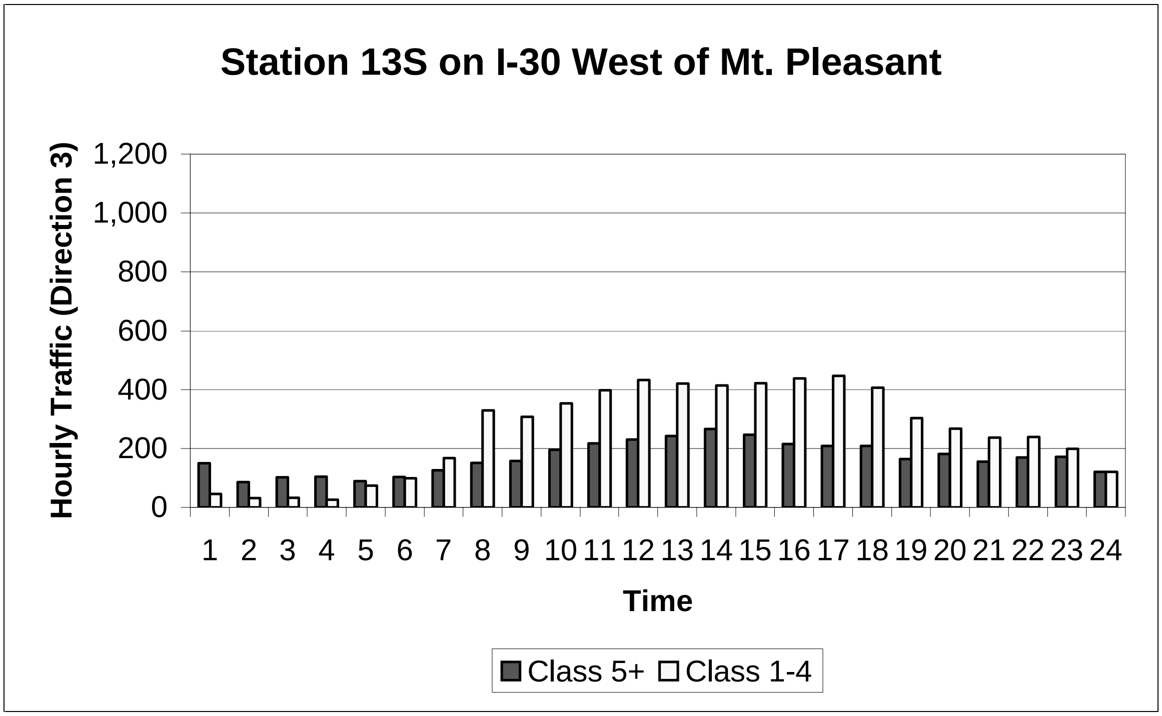
1999 CRASHES ON I-5 AND I-5S												
										Rate (MVM)		
Route	Segment	Crash	Fatal	Injury	AADT	From	To	Length	MVM/year	Crash	Fatal	Injury
5	1	80	2	37	270000	36.36	37.41	1.05	103.48	0.7731	0.0193	0.3576
5	2	47	0	24	259000	37.41	37.96	0.55	51.99	0.9039	0.0000	0.4616
5	3	13	0	6	250000	37.96	38.5	0.54	49.27	0.2638	0.0000	0.1218
5	4	54	1	32	240000	38.5	39.36	0.86	75.34	0.7168	0.0133	0.4248
5	5	14	0	2	126000	39.36	39.98	0.62	28.51	0.4910	0.0000	0.0701
5	6	5	0	7	120000	39.98	40.24	0.26	11.39	0.4391	0.0000	0.6147
5	7	32	0	10	114000	40.24	41.6	1.36	56.59	0.5655	0.0000	0.1767
5	10	101	2	55	229000	44.01	45.58	1.57	131.23	0.7697	0.0152	0.4191
5	11	13	0	6	165000	45.58	46.35	0.77	46.37	0.2803	0.0000	0.1294
5S	1	0	0	0	28000	43.93	44.18	0.25	2.56	0.0000	0.0000	0.0000
5S	2	16	0	3	44000	44.18	45.73	1.55	24.89	0.6428	0.0000	0.1205
5S	3	6	0	0	18200	45.73	46.35	0.62	4.12	1.4568	0.0000	0.0000
SUM:												
5	**1-7**	**245**	**3**	**118**		**36.36**	**41.26**	**4.9**	**376.57**	**0.6506**	**0.0080**	**0.3134**
5	**10-11**	**114**	**2**	**61**		**44.01**	**46.35**	**2.34**	**177.60**	**0.6419**	**0.0113**	**0.3435**
5S	**1-3**	**22**	**0**	**3**		**43.93**	**46.35**	**2.42**	**31.57**	**0.6969**	**0.0000**	**0.0950**

2000 CRASHES ON I-5 AND I-5S												
										Rate (MVM)		
Route	Segment	Crash	Fatal	Injury	AADT	From	To	Length	MVM/year	Crash	Fatal	Injury
5	1	74	1	30	283000	36.36	37.41	1.05	108.46	0.6823	0.0092	0.2766
5	2	47	0	33	286000	37.41	37.96	0.55	57.41	0.8186	0.0000	0.5748
5	3	31	0	19	275000	37.96	38.5	0.54	54.20	0.5719	0.0000	0.3505
5	4	56	1	22	262000	38.5	39.36	0.86	82.24	0.6809	0.0122	0.2675
5	5	16	0	8	125000	39.36	39.98	0.62	28.29	0.5656	0.0000	0.2828
5	6	7	0	5	118000	39.98	40.24	0.26	11.20	0.6251	0.0000	0.4465
5	7	29	0	13	108000	40.24	41.6	1.36	53.61	0.5409	0.0000	0.2425
5	10	86	1	32	230000	44.01	45.58	1.57	131.80	0.6525	0.0076	0.2428
5	11	25	1	9	175000	45.58	46.35	0.77	49.18	0.5083	0.0203	0.1830
5S	1	1	0	0	28000	43.93	44.18	0.25	2.56	0.3914	0.0000	0.0000
5S	2	8	0	3	44000	44.18	45.73	1.55	24.89	0.3214	0.0000	0.1205
5S	3	5	0	3	18200	45.73	46.35	0.62	4.12	1.2140	0.0000	0.7284
SUM:												
5	**1-7**	**260**	**2**	**130**		**36.36**	**41.26**	**4.9**	**395.42**	**0.6575**	**0.0051**	**0.3288**
5	**10-11**	**111**	**2**	**41**		**44.01**	**46.35**	**2.34**	**180.99**	**0.6133**	**0.0111**	**0.2265**
5S	**1-3**	**14**	**0**	**6**		**43.93**	**46.35**	**2.42**	**31.57**	**0.4435**	**0.0000**	**0.1901**

2001 CRASHES ON I-5 AND I-5S												
										Rate (MVM)		
Route	Segment	Crash	Fatal	Injury	AADT	From	To	Length	MVM/year	Crash	Fatal	Injury
5	1	74	0	54	280000	36.36	37.41	1.05	107.31	0.6896	0.0000	0.5032
5	2	38	0	13	281000	37.41	37.96	0.55	56.41	0.6736	0.0000	0.2305
5	3	18	0	5	272000	37.96	38.5	0.54	53.61	0.3358	0.0000	0.0933
5	4	46	0	29	260000	38.5	39.36	0.86	81.61	0.5636	0.0000	0.3553
5	5	19	0	14	139000	39.36	39.98	0.62	31.46	0.6040	0.0000	0.4451
5	6	6	0	2	133000	39.98	40.24	0.26	12.62	0.4754	0.0000	0.1585
5	7	43	0	18	124000	40.24	41.6	1.36	61.55	0.6986	0.0000	0.2924
5	10	126	0	60	230000	44.01	45.58	1.57	131.80	0.9560	0.0000	0.4552
5	11	24	0	3	184000	45.58	46.35	0.77	51.71	0.4641	0.0000	0.0580
5S	1	0	0	0	28000	43.93	44.18	0.25	2.56	0.0000	0.0000	0.0000
5S	2	11	0	2	44000	44.18	45.73	1.55	24.89	0.4419	0.0000	0.0803
5S	3	4	0	6	18200	45.73	46.35	0.62	4.12	0.9712	0.0000	1.4568
SUM:												
5	**1-7**	**244**	**0**	**135**		**36.36**	**41.26**	**4.9**	**404.58**	**0.6031**	**0.0000**	**0.3337**
5	**10-11**	**150**	**0**	**63**		**44.01**	**46.35**	**2.34**	**183.51**	**0.8174**	**0.0000**	**0.3433**
5S	**1-3**	**15**	**0**	**8**		**43.93**	**46.35**	**2.42**	**31.57**	**0.4752**	**0.0000**	**0.2534**

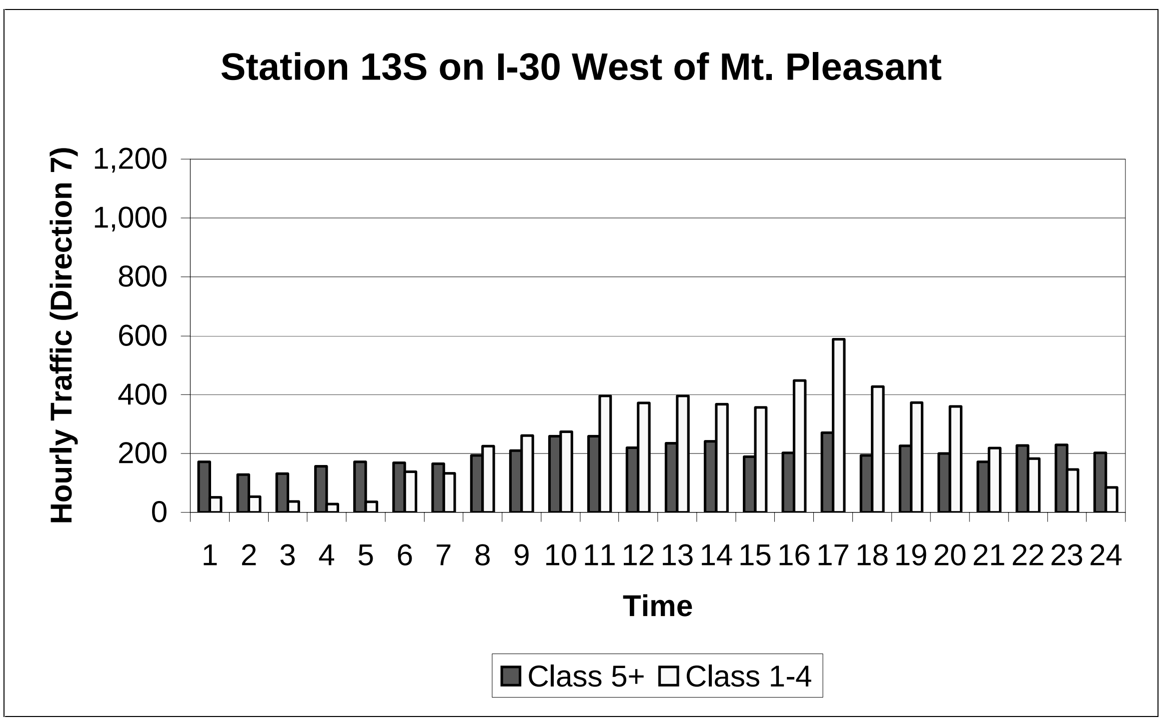
APPENDIX G

HOURLY VEHICLE CLASSIFICATION COUNTS FROM SEVEN TXDOT SITES



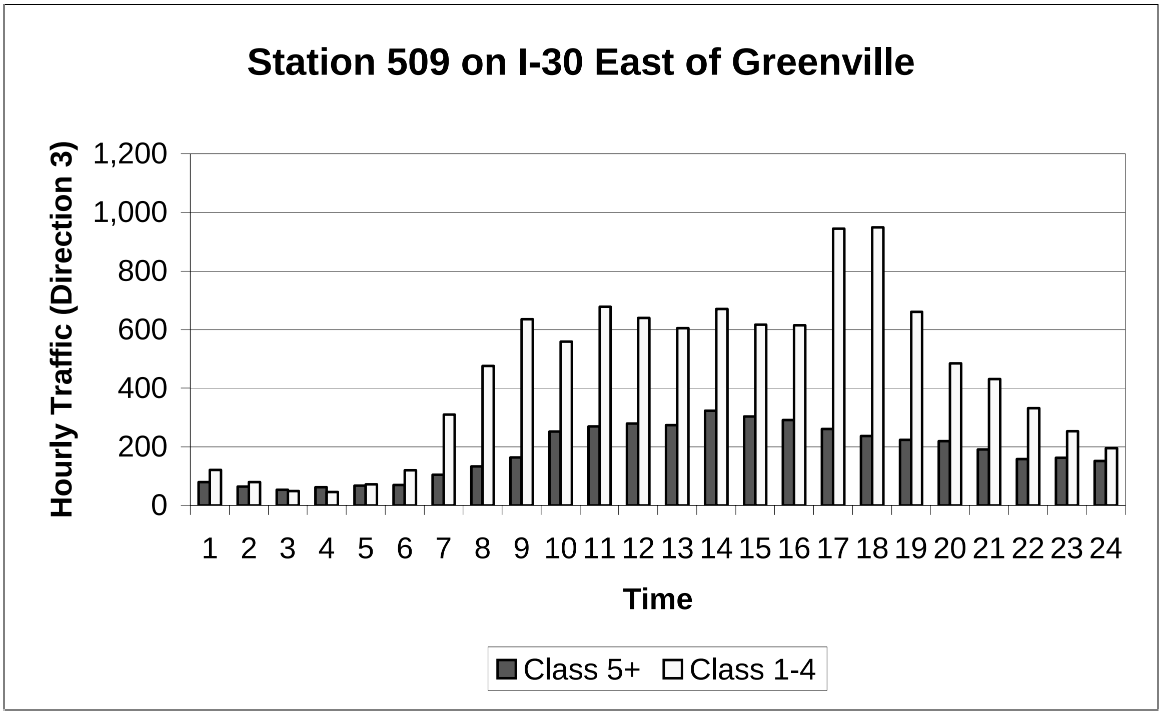
Source: TxDOT

Figure 76. Hourly Traffic Volume at Station 13S (Direction 3).



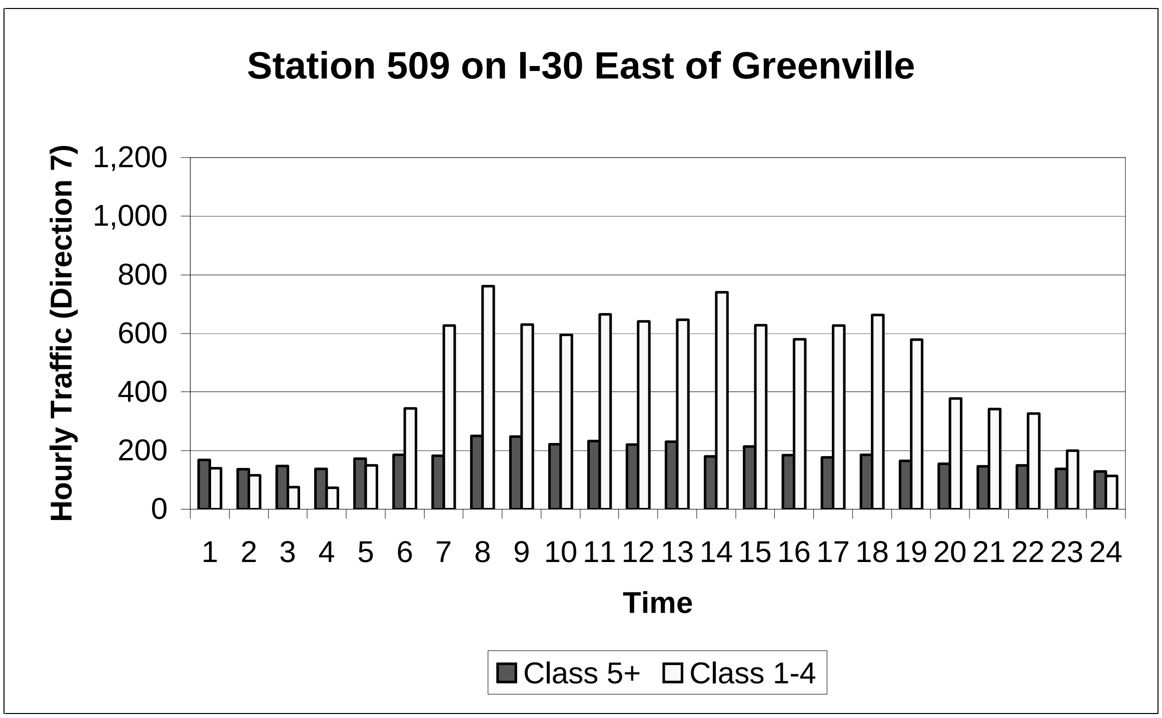
Source: TxDOT

Figure 77. Hourly Traffic Volume at Station 13S (Direction 7).



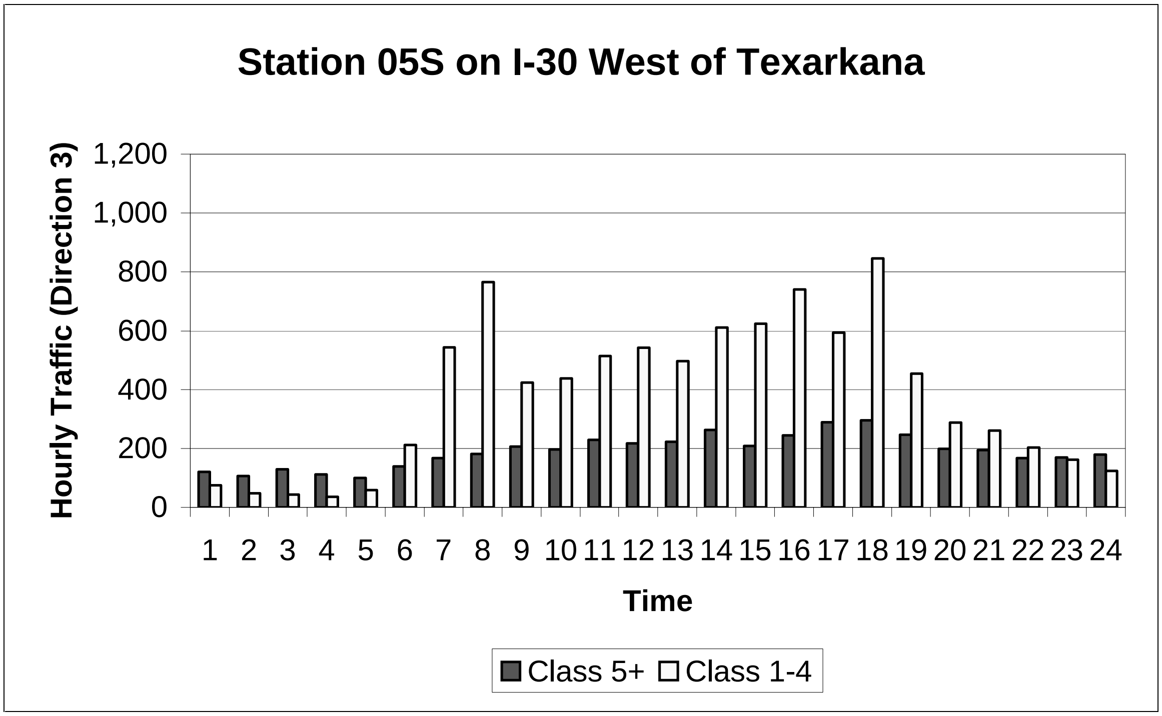
Source: TxDOT

Figure 78. Hourly Traffic Volume at Station 509 (Direction 3).



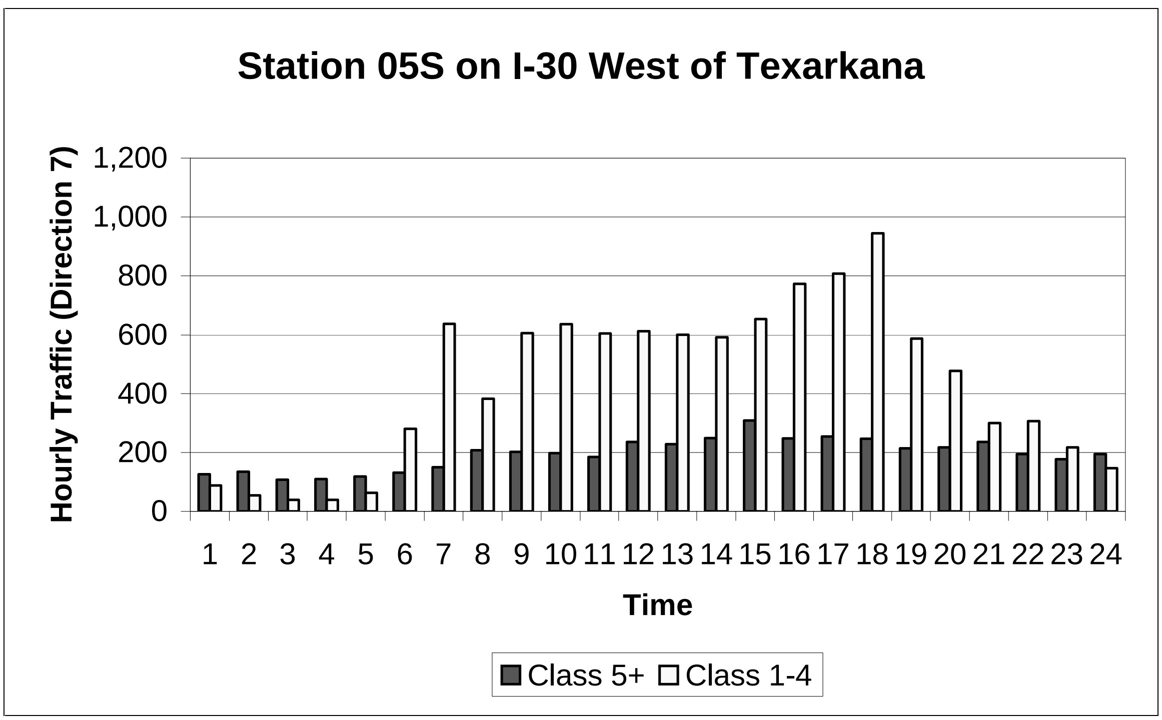
Source: TxDOT

Figure 79. Hourly Traffic Volume at Station 509 (Direction 7).



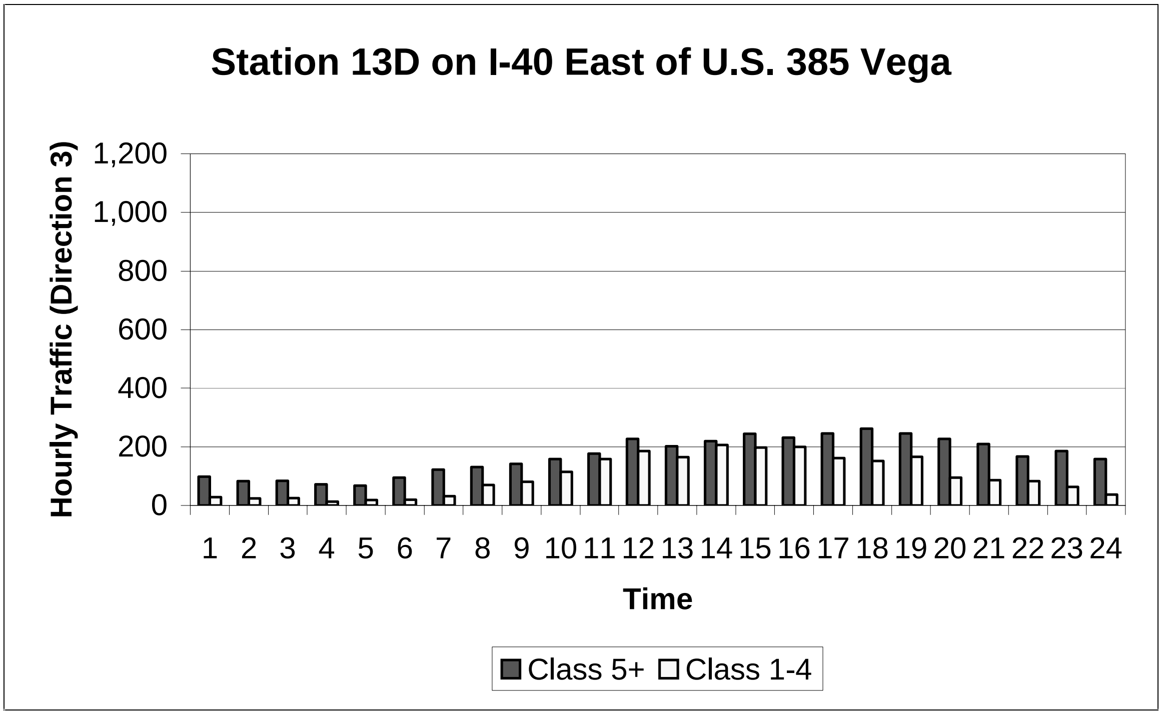
Source: TxDOT

Figure 80. Hourly Traffic Volume at Station 05S (Direction 3).



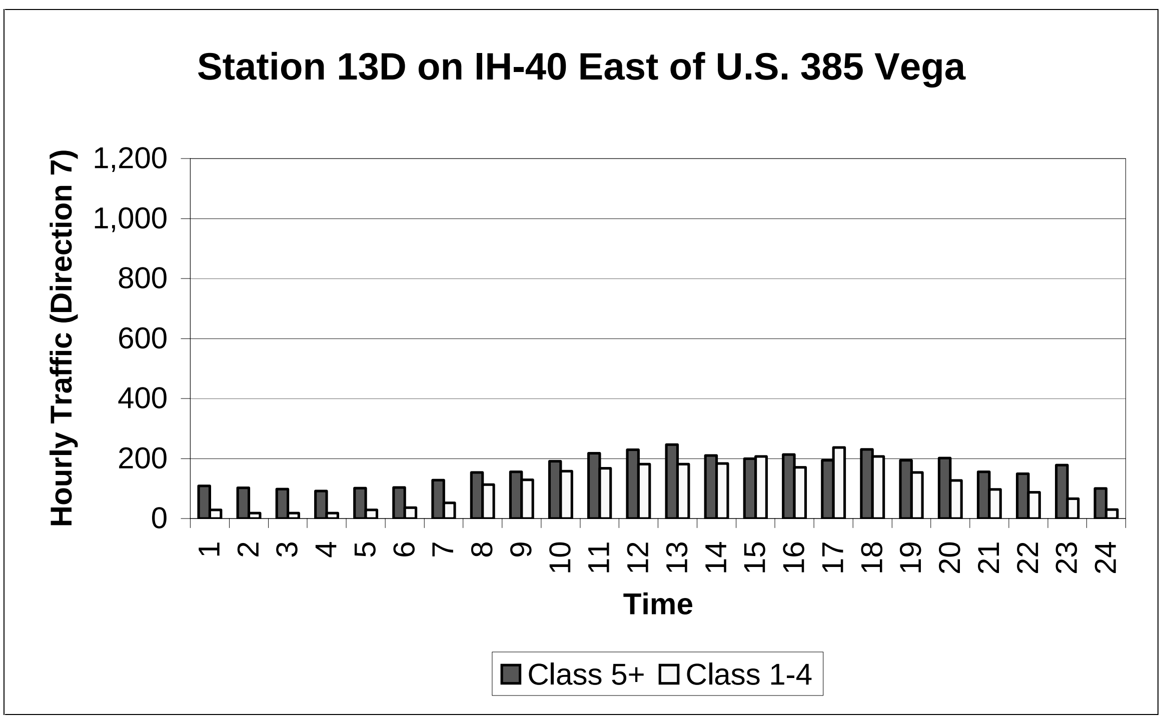
Source: TxDOT

Figure 81. Hourly Traffic Volume at Station 05S (Direction 7).



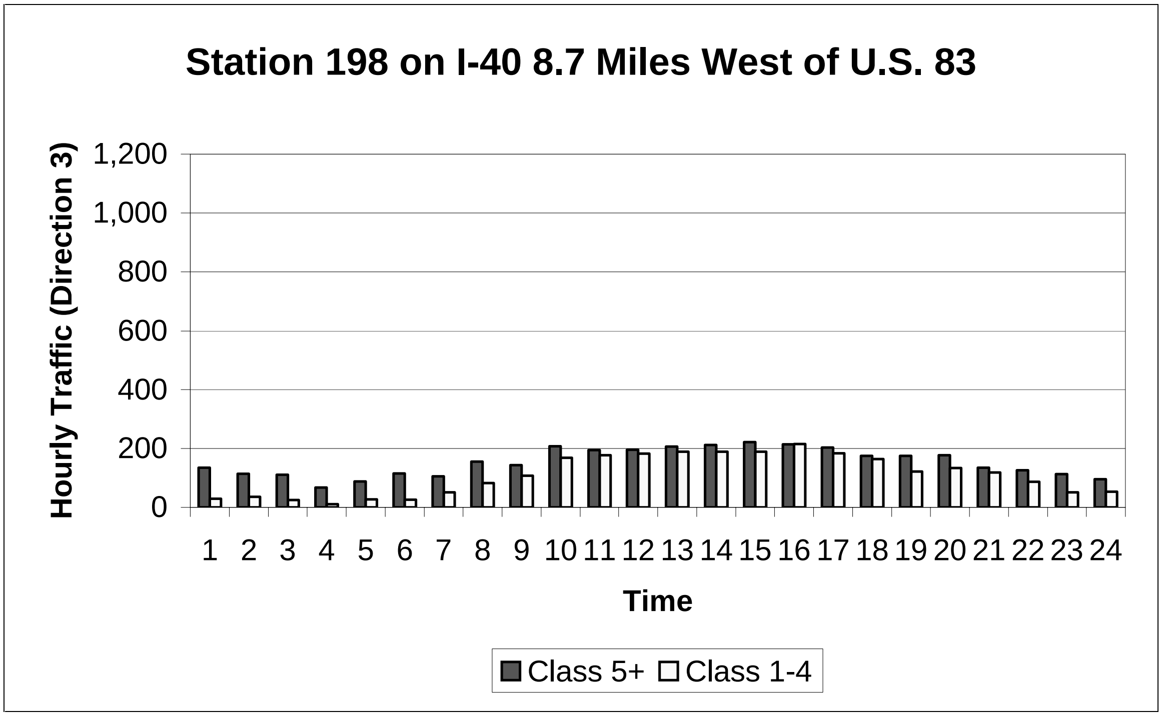
Source: TxDOT

Figure 82. Hourly Traffic Volume at Station 13D (Direction 3).



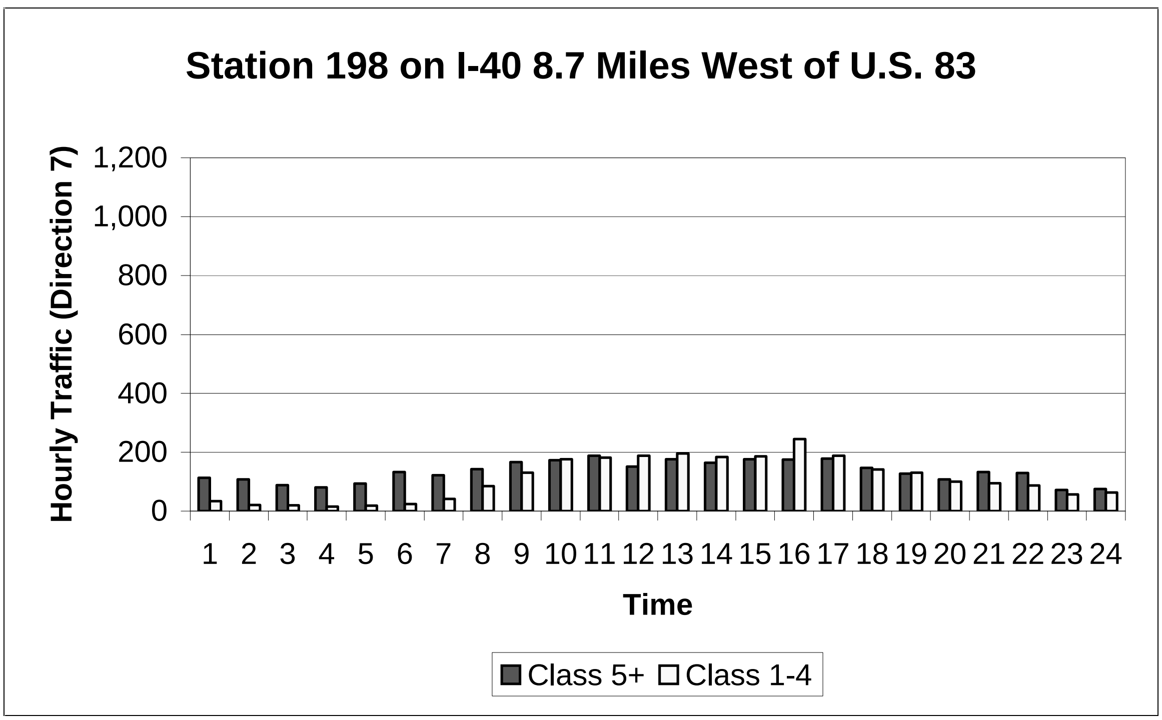
Source: TxDOT

Figure 83. Hourly Traffic Volume at Station 13D (Direction 7).



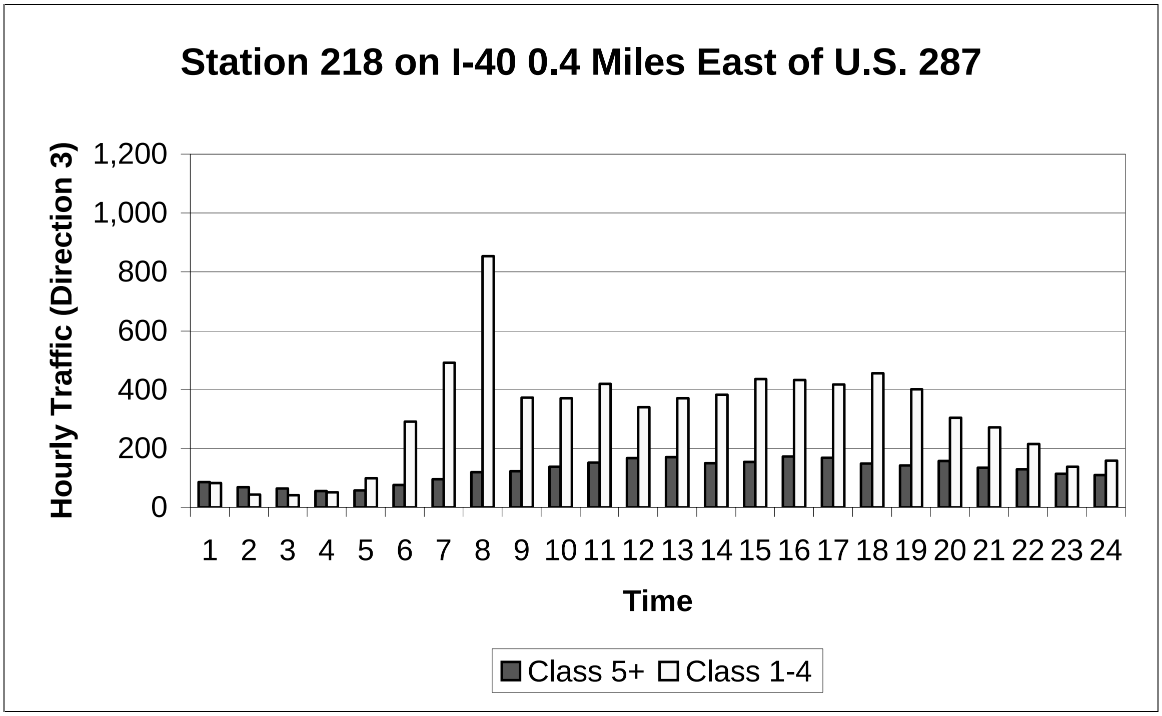
Source: TxDOT

Figure 84. Hourly Traffic Volume at Station 198 (Direction 3).



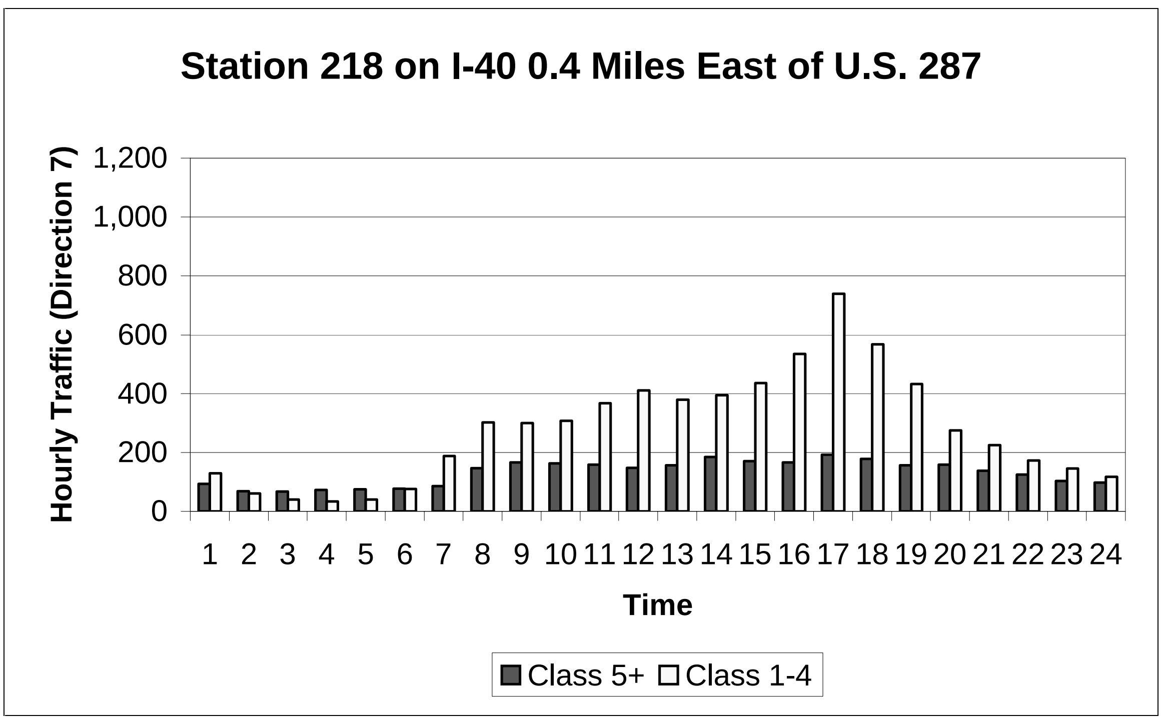
Source: TxDOT

Figure 85. Hourly Traffic Volume at Station 198 (Direction 7).



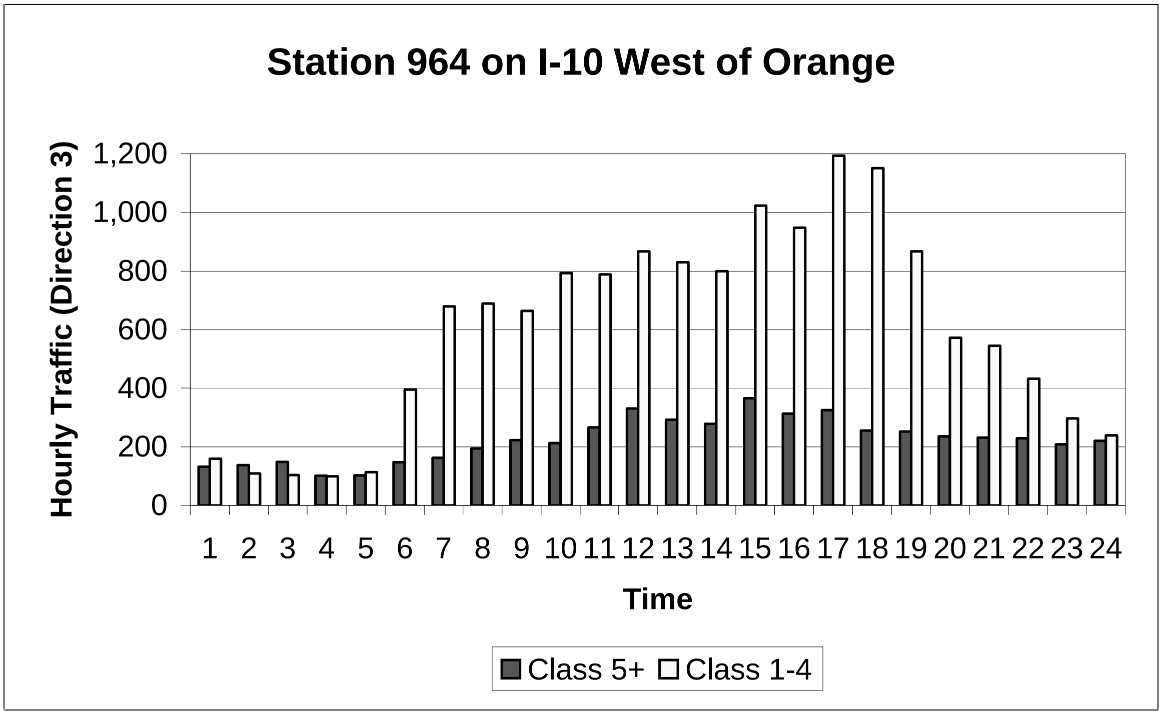
Source: TxDOT

Figure 86. Hourly Traffic Volume at Station 218 (Direction 3).



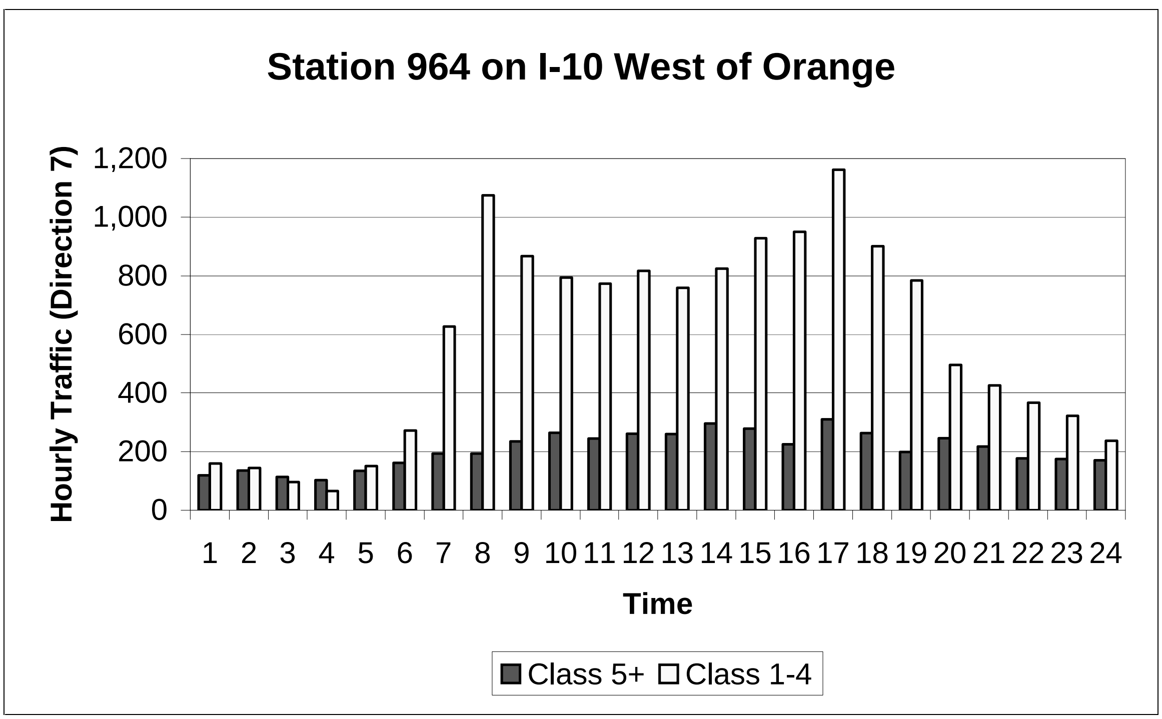
Source: TxDOT

Figure 87. Hourly Traffic Volume at Station 218 (Direction 7).



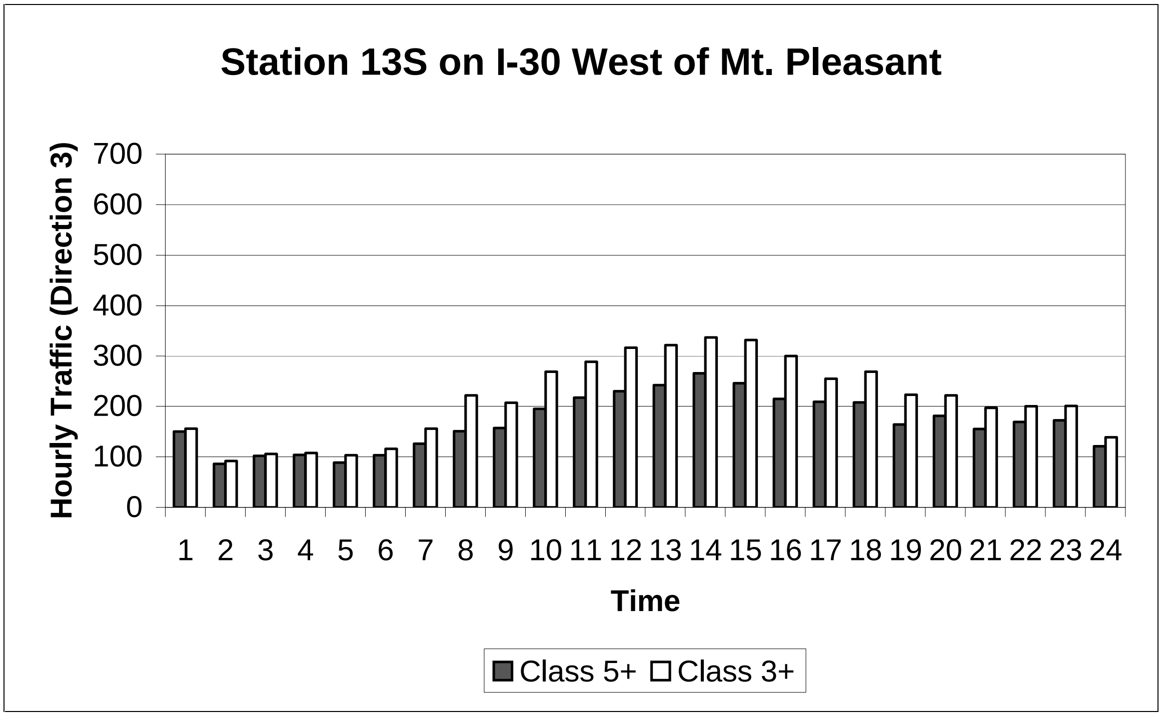
Source: TxDOT

Figure 88. Hourly Traffic Volume at Station 964 (Direction 3).



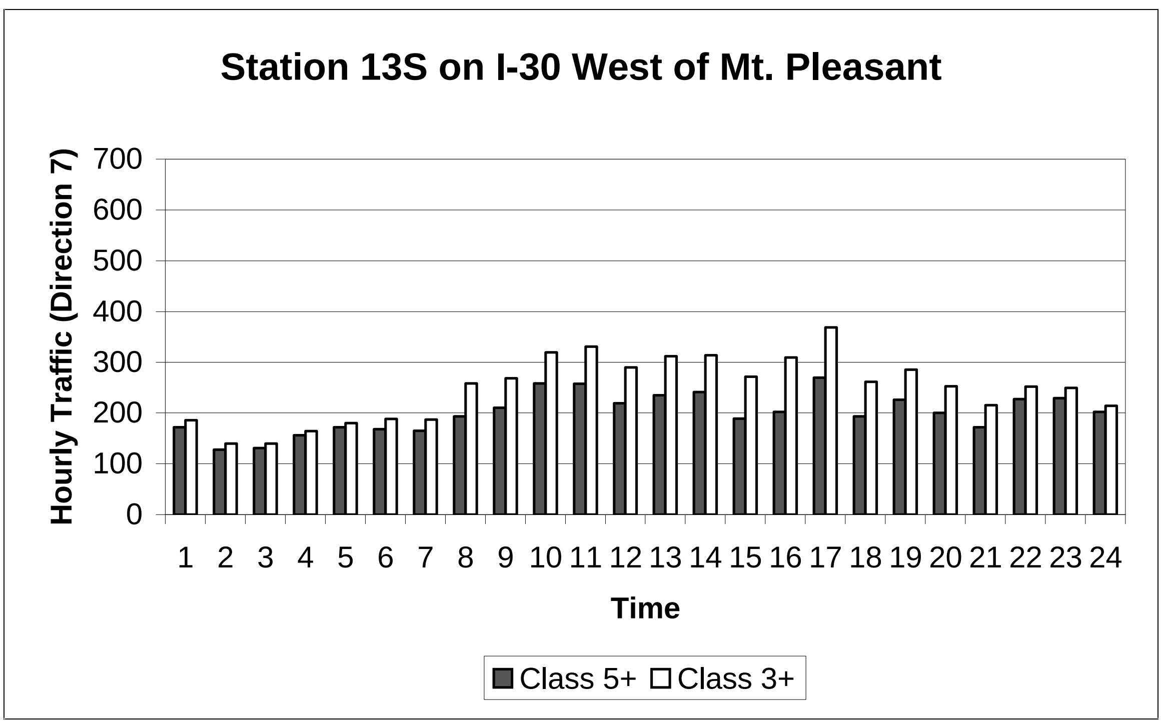
Source: TxDOT

Figure 89. Hourly Traffic Volume at Station 964 (Direction 7).



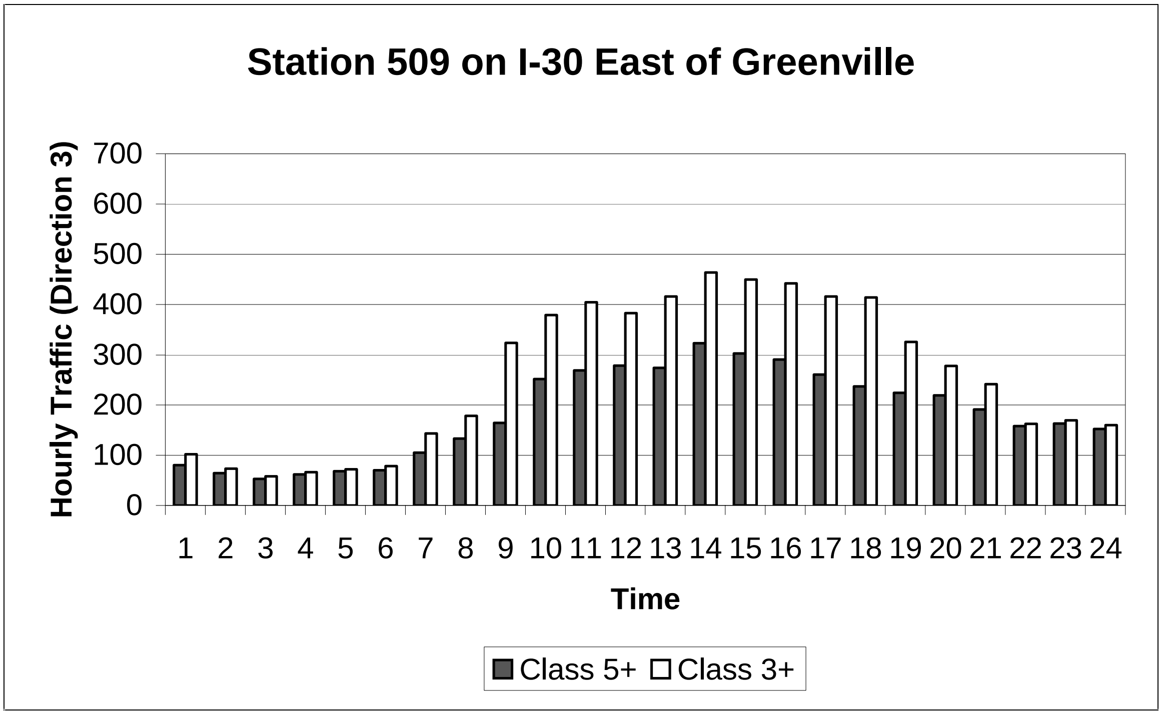
Source: TxDOT

Figure 90. Contribution of Classes 3 and 4 at Station 13S (Direction 3).



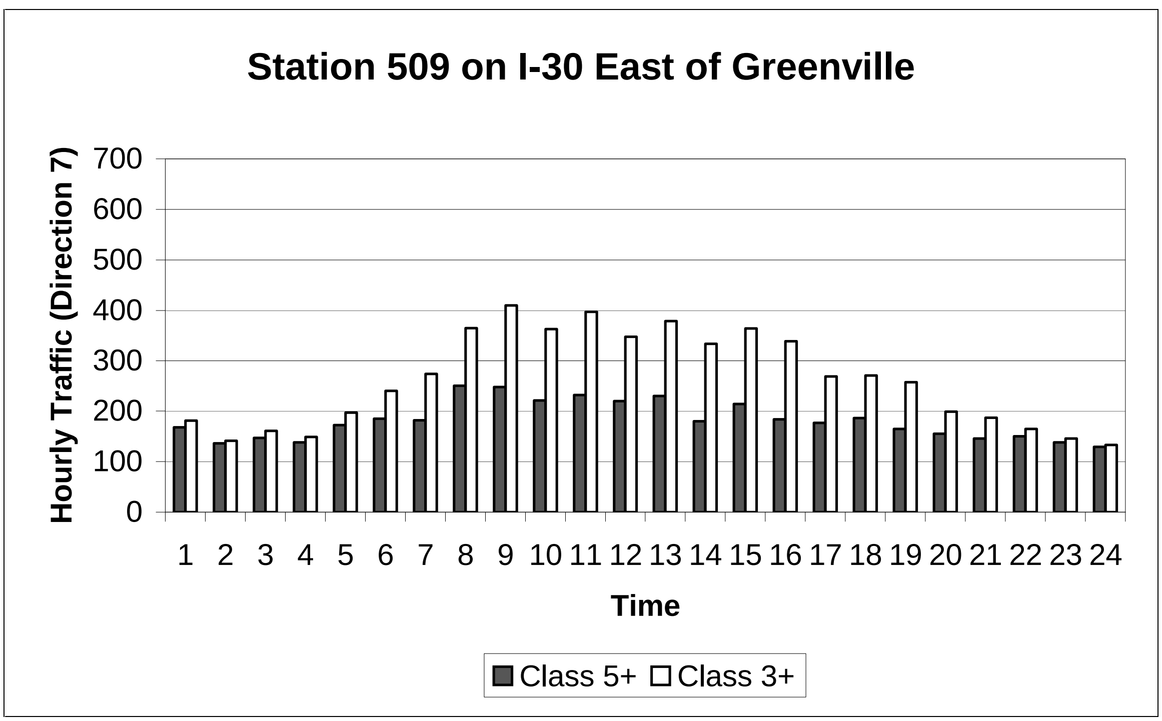
Source: TxDOT

Figure 91. Contribution of Classes 3 and 4 at Station 13S (Direction 7).



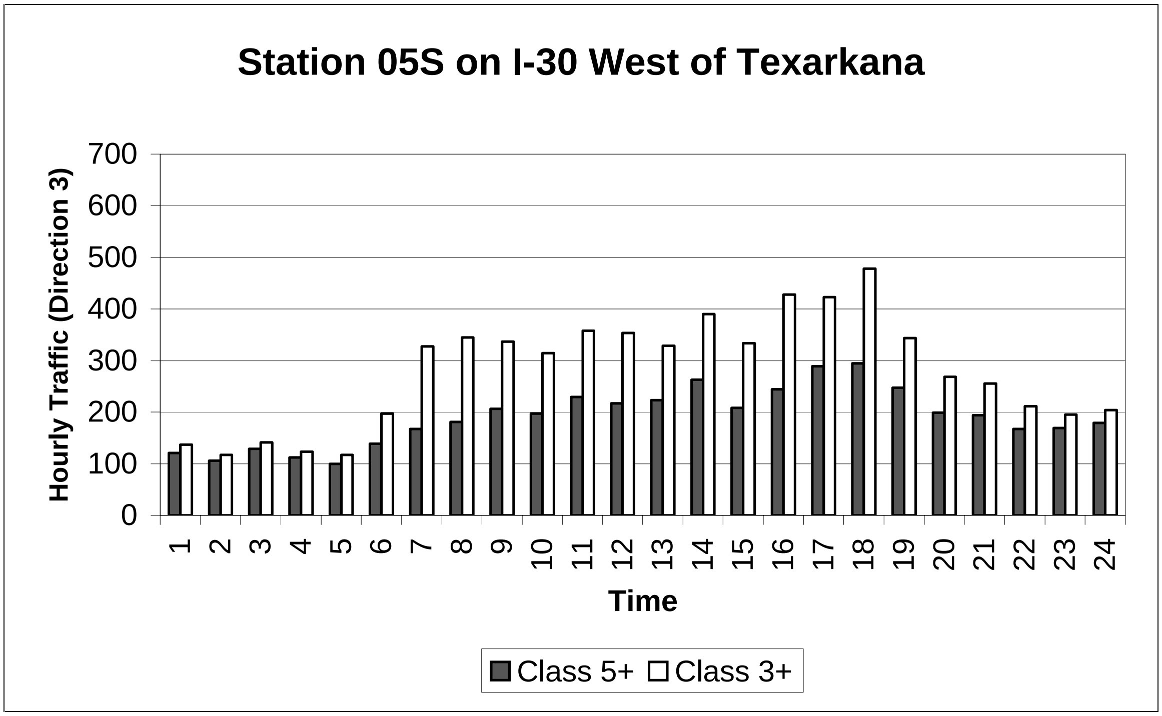
Source: TxDOT

Figure 92. Contribution of Classes 3 and 4 at Station 509 (Direction 3).



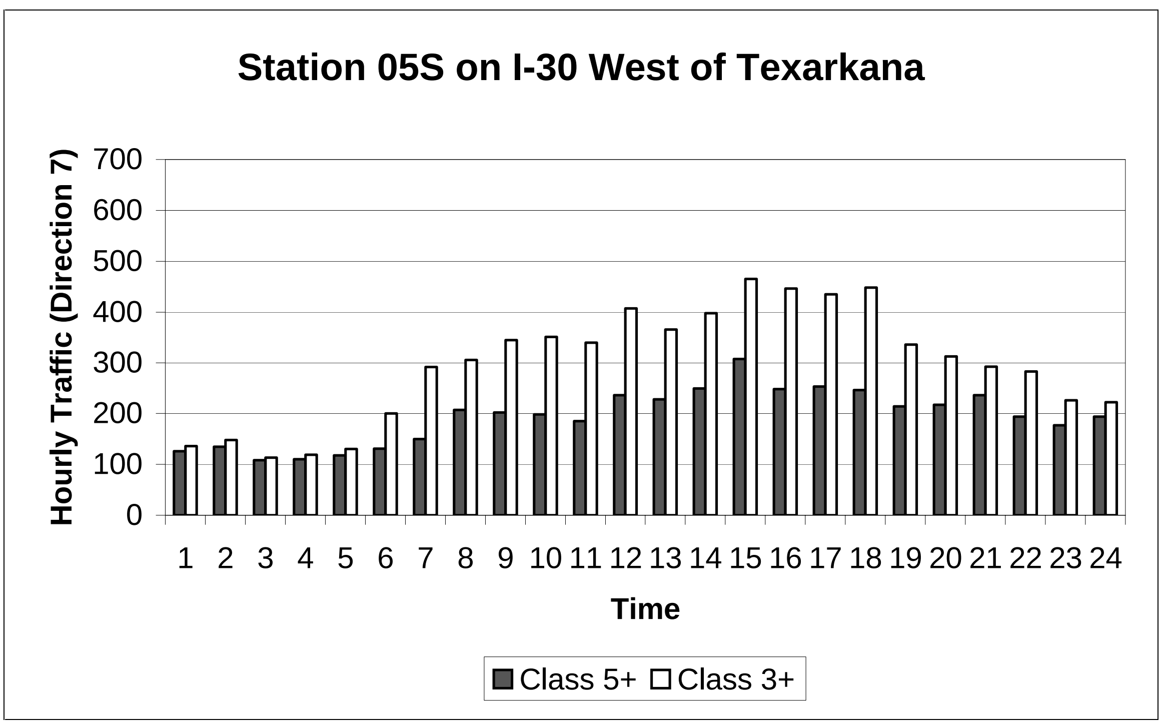
Source: TxDOT

Figure 93. Contribution of Classes 3 and 4 at Station 509 (Direction 7).



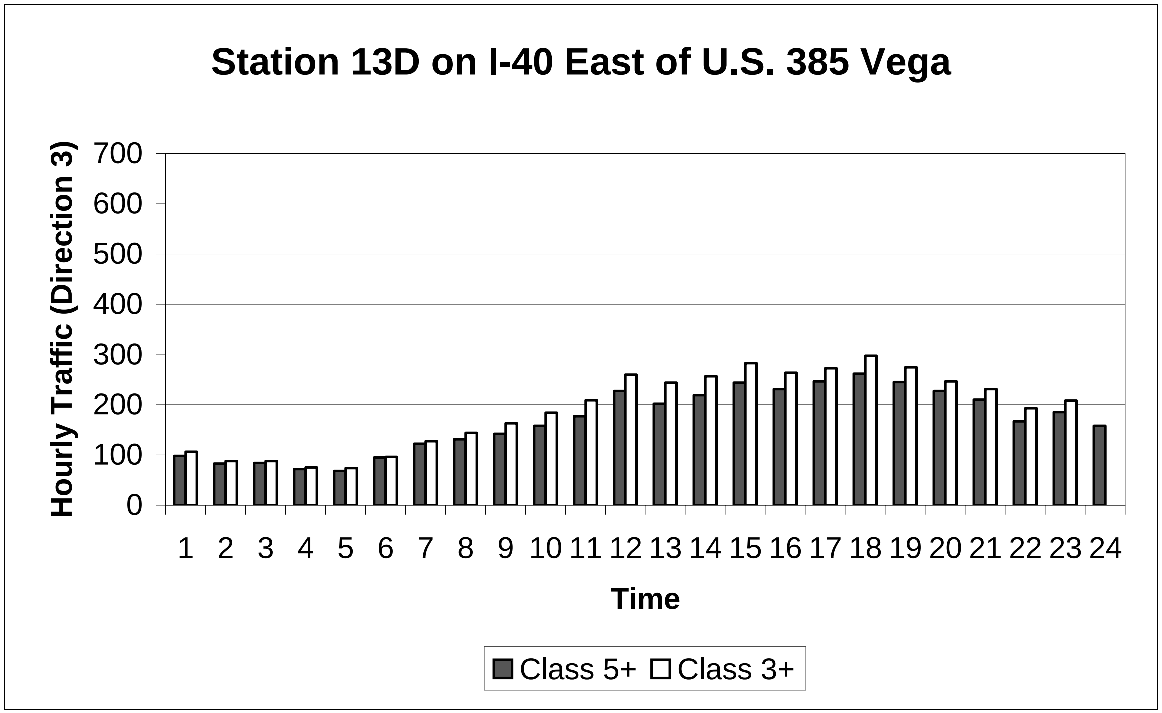
Source: TxDOT

Figure 94. Contribution of Classes 3 and 4 at Station 05S (Direction 3).



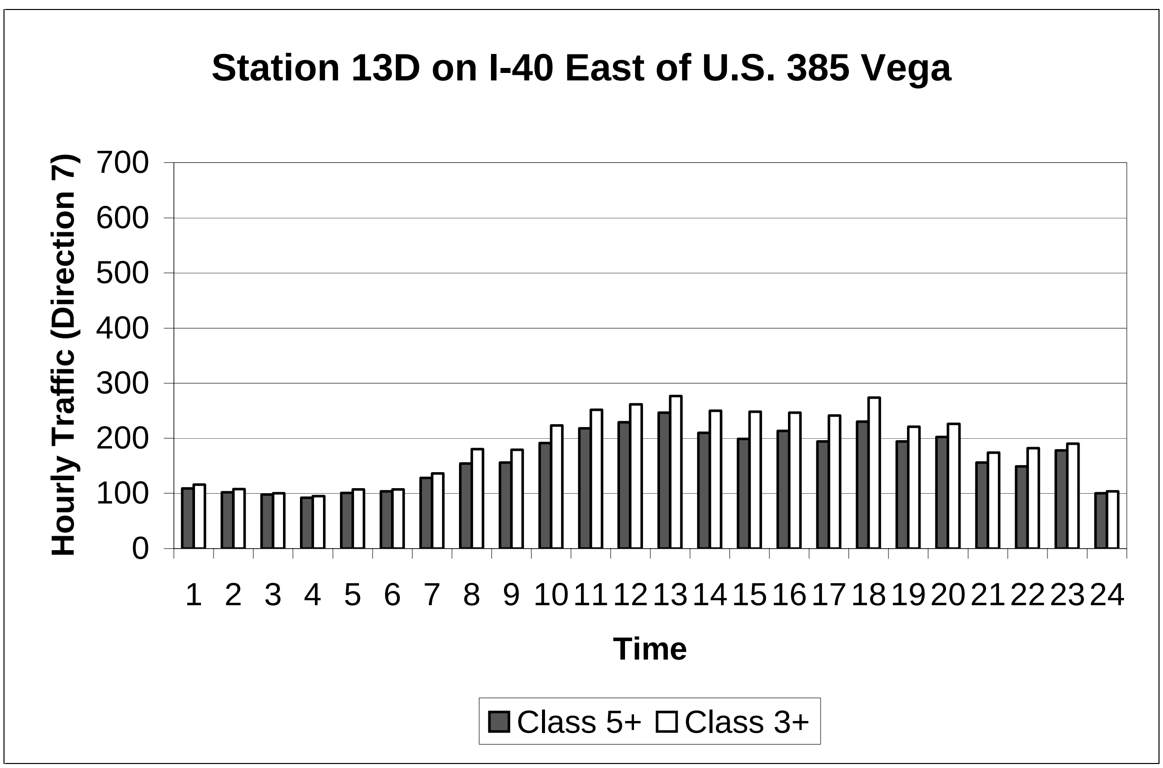
Source: TxDOT

Figure 95. Contribution of Classes 3 and 4 at Station 05S (Direction 7).



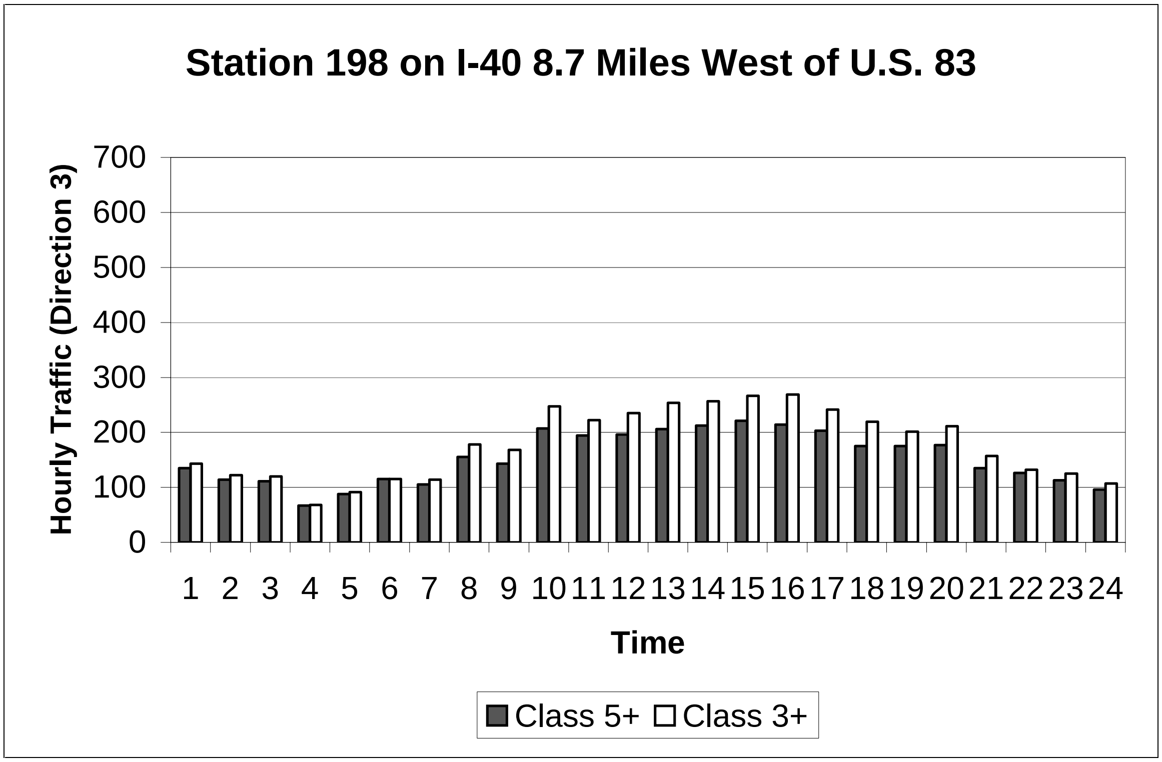
Source: TxDOT

Figure 96. Contribution of Classes 3 and 4 at Station 13D (Direction 3).



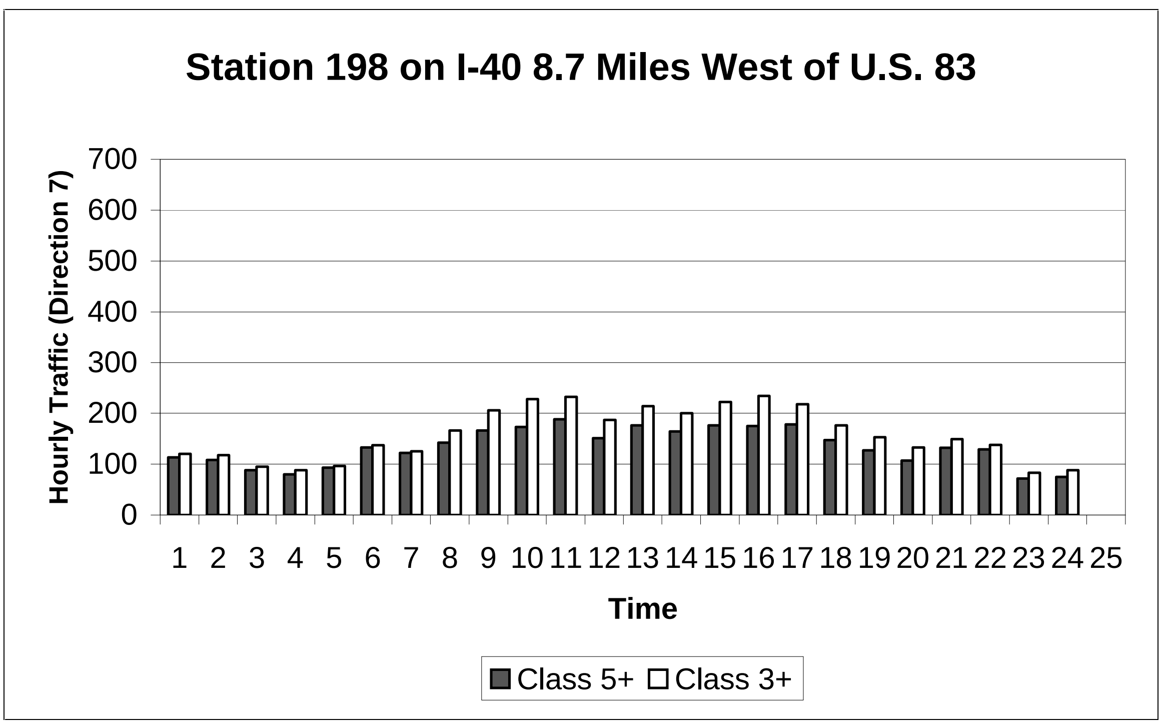
Source: TxDOT

Figure 97. Contribution of Classes 3 and 4 at Station 13D (Direction 7).



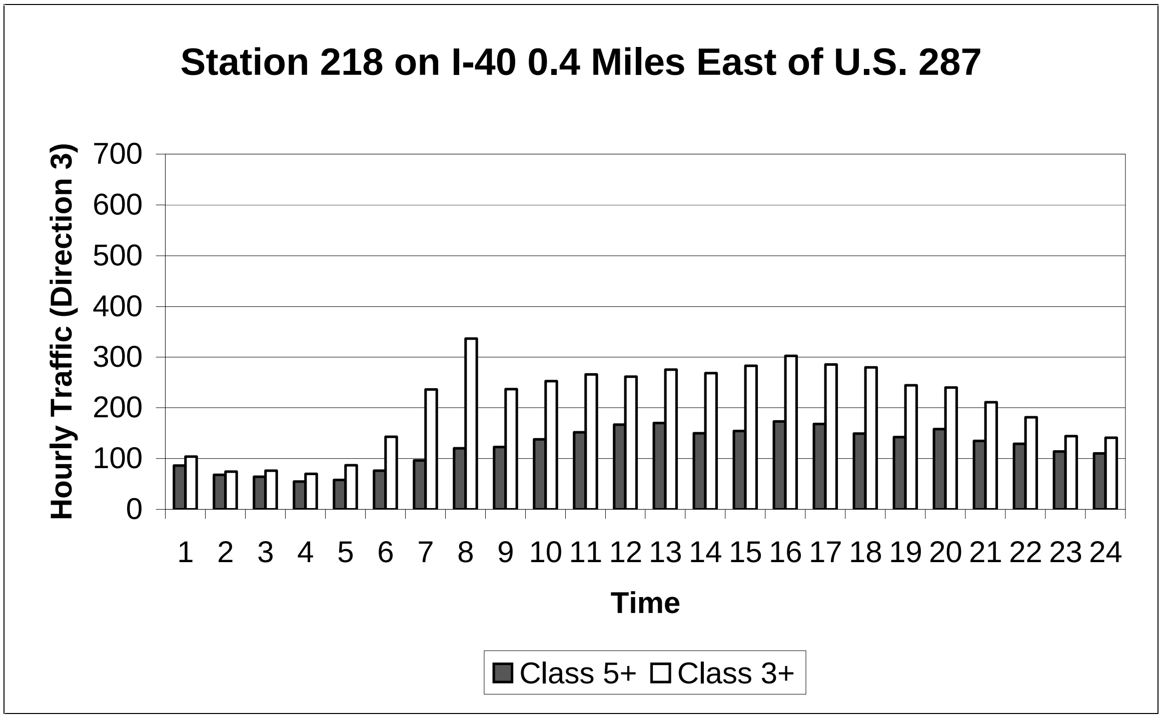
Source: TxDOT

Figure 98. Contribution of Classes 3 and 4 at Station 198 (Direction 3).



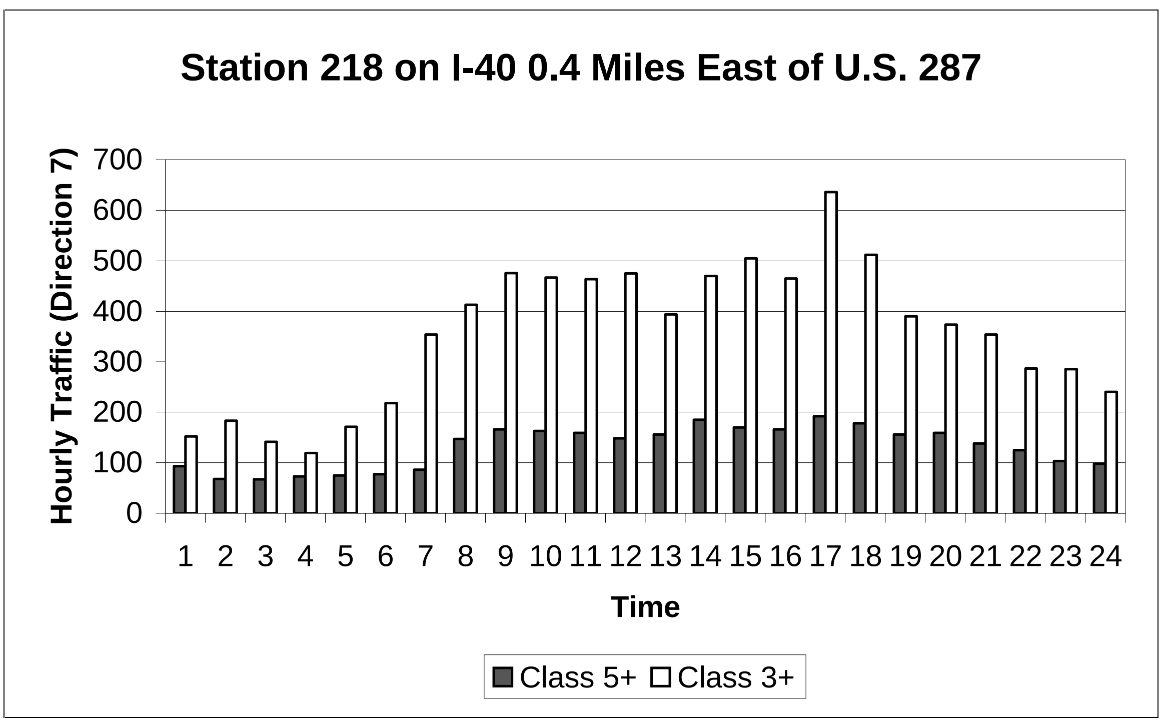
Source: TxDOT

Figure 99. Contribution of Classes 3 and 4 at Station 198 (Direction 7).



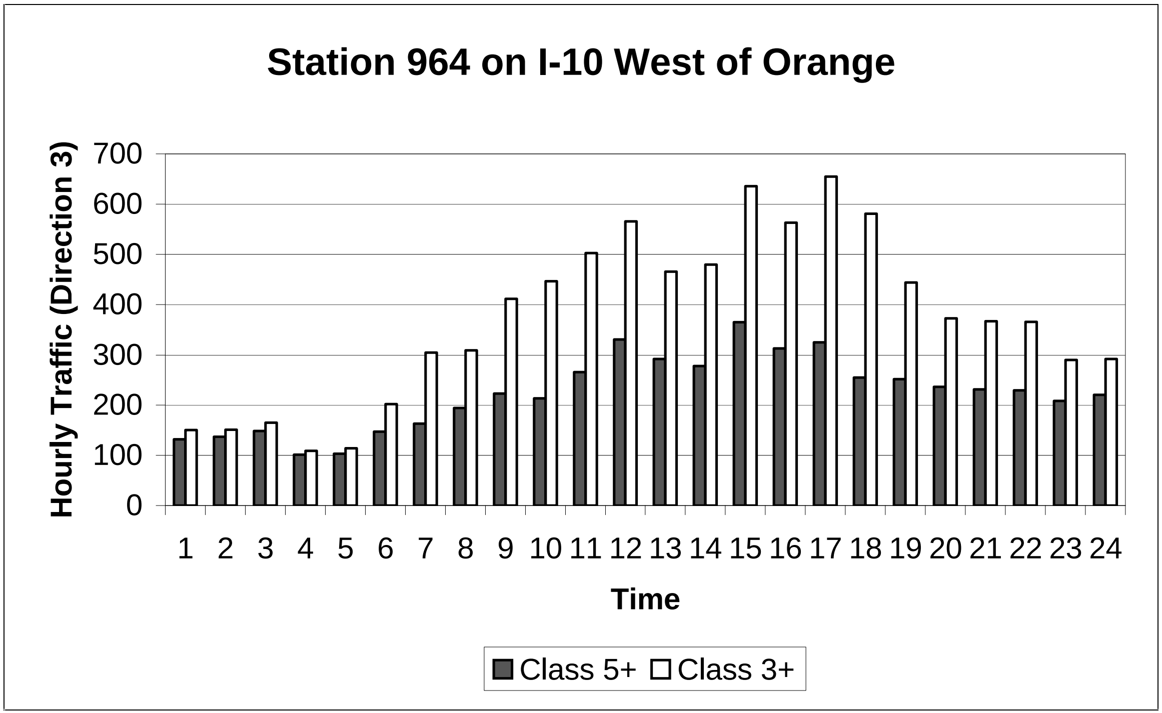
Source: TxDOT

Figure 100. Contribution of Classes 3 and 4 at Station 218 (Direction 3).



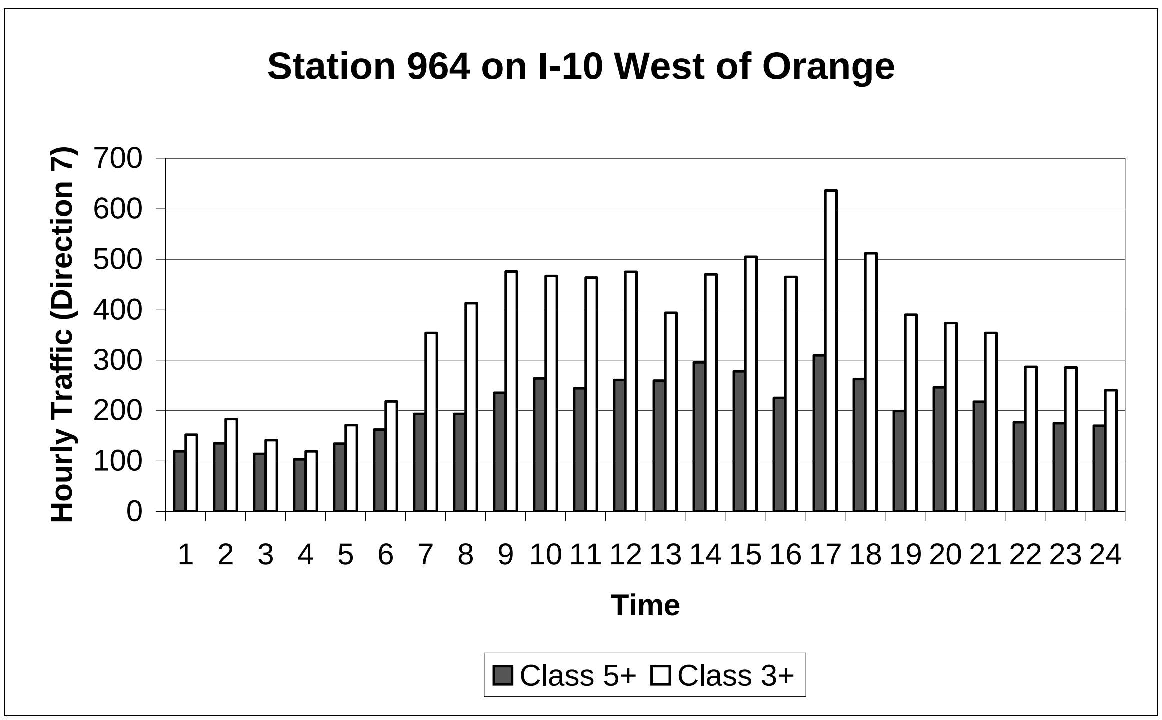
Source: TxDOT

Figure 101. Contribution of Classes 3 and 4 at Station 218 (Direction 7).



Source: TxDOT

Figure 102. Contribution of Classes 3 and 4 at Station 964 (Direction 3).



Source: TxDOT

Figure 103. Contribution of Classes 3 and 4 at Station 964 (Direction 7).