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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 that may be appropriate for those corridors to address issues caused by truck traffic. 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 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 *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 barrier, passive signs, and acceleration lanes.

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TRUCK ACCOMMODATION DESIGN GUIDANCE: DESIGNER WORKSHOP

by

Dan Middleton, P.E.
Program Manager
Texas Transportation Institute

Report 4364-2
Project Number 0-4364
Research Project Title: Truck Accommodation Design Guidance

Sponsored by the
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CHAPTER 1. BACKGROUND

1.1 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 (NAFTA). 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 that may be appropriate for those corridors to address issues caused by truck traffic.

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 the second and third scenarios, there need to be special design considerations given to accommodate trucks and make the roadway as safe as feasible. More information on the topics covered in this workshop document is available in Report 4364-1 *(1)*.

Large trucks operating together on the same lanes and separated from cars operating on their own lanes form 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.

1.2 ORGANIZATION OF THIS DOCUMENT

This document is intended to be used along with a PowerPoint slide session for mid-level designers. Each of the two slide sets and workbooks emphasizes areas pertinent to each of these groups. The document is organized along the following key topic areas:

- introduction,
- stakeholder input,
- Texas truck corridors,
- truck accommodation strategies, and
- design guidelines and Intelligent Transportation System (ITS) applications.

1.3 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.

CHAPTER 2. STAKEHOLDER INPUT

2.1 INTRODUCTION

Stakeholders in the considerations of truck design accommodation include the Texas Department of Transportation (TxDOT), the motor carrier industry, the various enforcement agencies, and particularly the Texas Department of Public Safety (DPS). Researchers contacted the various stakeholders to solicit input, and then summarized findings.

2.2 TXDOT DISTRICTS AND DIVISIONS

This section summarizes two surveys and results of office visits to TxDOT districts and division personnel. Texas Transportation Institute (TTI) researchers conducted one survey and the Research and Technology Implementation (RTI) office conducted the other one.

2.2.1 Project 4364 Survey

Table 1 summarizes district responses to a survey 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.

There was valuable input from several division personnel, but only the following input from the Maintenance Division is included in this document. 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.

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.

2.2.2 TxDOT RTI Survey

The Research and Technology Implementation survey report *(2)* 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

Table 1. Summary of TxDOT 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	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

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.

2.2.2.1 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:

- implementing 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:

- reducing 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;
- adopting the Texas Super 2 guidelines as the standard for primary two-lane roads with high truck traffic volumes; and
- considering 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 (ROW), are unpopular in many areas, and take a long time to develop and construct.

2.2.2.2 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.

2.2.2.3 Pavements

Eleven of twenty-four districts report 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.

2.3 DPS SURVEY

Table 2 indicates the results of the 84 survey forms returned for evaluation. There were four general questions and four specific questions about geometric design problems, followed by questions about vehicle trends. 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 2. DPS Survey Result 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 Semi Trailers	7
Trend in Different Vehicle Types	4

2.4 MOTOR CARRIER INPUT

The following input came from Texas Motor Transport Association (TMTA) personnel or from other representatives of motor carriers. Some TMTA members 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 might 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.

The TMTA spokesman said that 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.

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 ITS 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.

One of the factors related to truck size that affects geometric design is trailer length. There seems to be some movement toward longer trailers, and in Texas, they can be as long as 59 ft. If there is a trend toward longer semitrailers, it will be because shippers demand it. Motor carriers and TMTA recently spoke out against size/weight increases such as expanded use of Longer Combination Vehicles (LCVs) because carriers do not get paid any 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, so why should carriers want it? Motor carriers contend that many problems happen as a result of shippers dictating what is done.

Truckers 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 a tight turning radius.

Another 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. He also mentioned very short weaving distances as 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.

Another motor carrier 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.

A truck driver in El Paso stated that many entrance ramps merge with the main lanes at an undesirable angle, creating a blind spot for many truck drivers. 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.

When project personnel talked to truck drivers on the New Jersey Turnpike, they found out that these drivers strongly oppose having cars on the outer lanes where trucks and buses are required to drive. Truck drivers cited lack of understanding on the part of the car drivers pertaining to performance characteristics of large trucks.

Finally, in a survey by TTI in another TxDOT research project, truck drivers cited the following deficiencies related to geometric design:

- short entrance and exit ramps,
- one-way versus two-way frontage roads,
- differential speed limits (day versus night),
- lack of center median barrier,
- insufficient number of rest areas, and
- failure of traffic on frontage roads to yield to exiting traffic.

CHAPTER 3. TEXAS TRUCK CORRIDORS

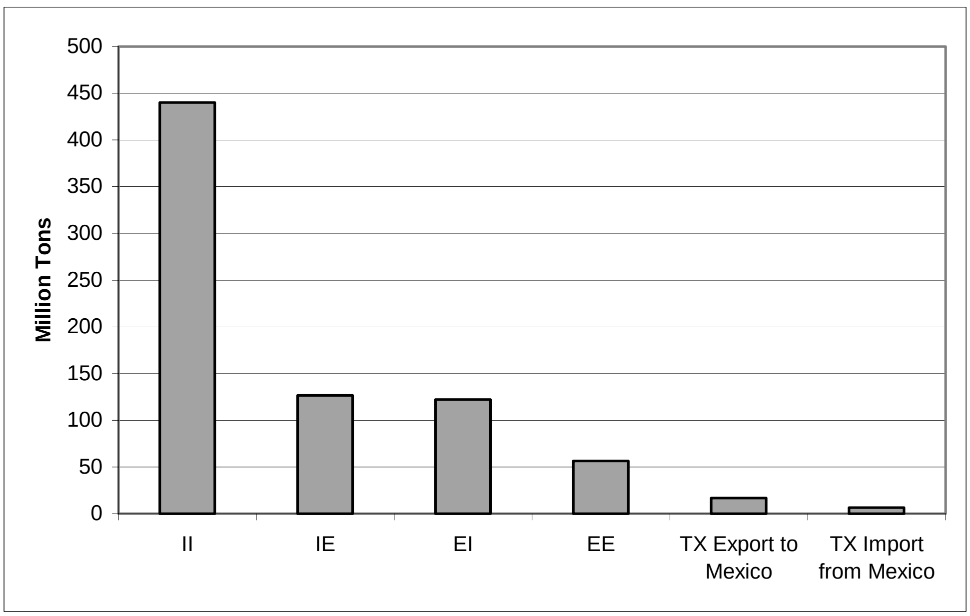
3.1 INTRODUCTION

For purposes of analysis of the Texas road network, 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 (NHS) network in Texas, but the selected network is actually more than that network. Road classes retained are Interstate (IH), U.S. highways, and a subset of State (ST) highways.

3.2 COMMODITY FLOWS

The analysis in this study of truck-transported commodity movements relied upon the freight movement database, TRANSEARCH, provided by Reebie Associates through the state of Texas for 1998 *(3)*. The complete database contains freight movement of all transportation modes, but this analysis only considers the truck transport data. In 1998, trucks moved a total of 769 million tons of commodities on Texas highways. This includes 23.3 million tons of commodities moved between Texas and Mexico. Figure 1 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 *(3)*, Reebie TRANSEARCH database

Figure 1. 1998 Texas-Related Commodity Movements by Movement Type.

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. The research project developed 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 2 shows origin-destination patterns of these intrastate truck movements for Houston-Galveston-Brazoria (BEA 131) for those components that average more than 480 two-way truck trips per day. Report 4364-1 *(1)* provides similar graphics for the entire state.

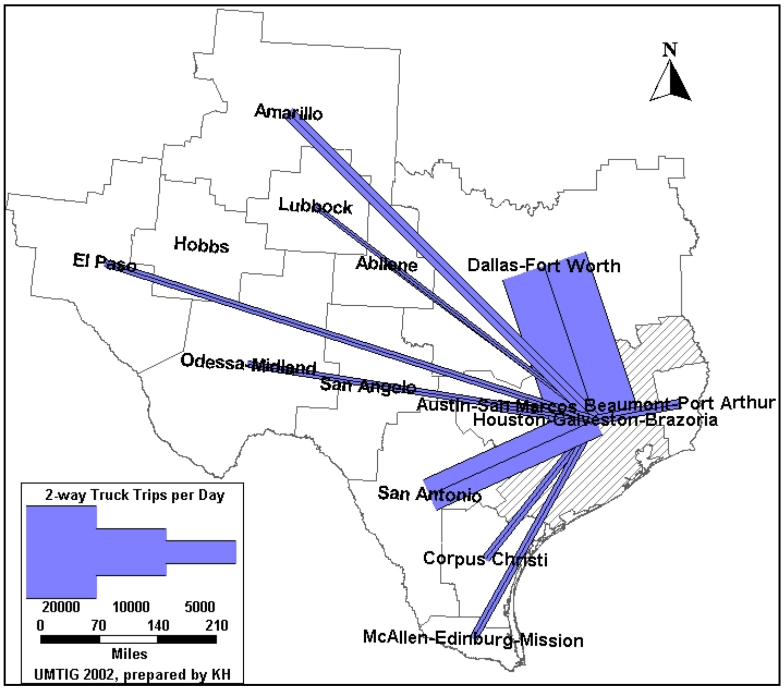


Figure 2. Texas Intrastate Truck Movement between BEA 131 and Other BEAs.
(Reebie estimated two-way total truck trips per day)

3.3 VEHICULAR TRAFFIC

This section covers truck flows, beginning with statewide truck counts on the major truck corridors. It also includes information pertaining to trucks crossing the U.S./Mexico border.

3.3.1 Basic Truck Flows

Table 3 shows the average annual daily truck traffic (AADTT) categories developed for the purposes of 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; and that all trucks travel at 60 mph (88 ft/sec) and at constant time and spacing headways, varying only by AADTT level.

Table 3. AADTT Categories.

CATEGORY NAME	AADTT RANGE
Very Low	0-480
Low	480-960
Medium	960-2880
Medium High	2880-5760
High	5760-11,520
Very High	11,520 plus

Table 4 is a summary of route-miles and truck-miles traveled (TMT) for all State, Interstate, and U.S. routes in Texas. From it come the following findings:

- 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 plus) 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.

Figure 3 graphically depicts the truck-miles traveled by these same AADTT categories. Figure 4 shows sections of Texas Interstates experiencing AADTT levels in each of the respective categories.

Table 4. Route-Miles and Truck-Miles Traveled.

AADTT	Route Miles			Ann. Truck-Miles Traveled (Millions)		
Category	IH	US	State	IH	US	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
5760-11520	1560.8	295.1	101.8	4602.5	780.0	284.3
11520-23040	558.8	40.1	0.0	2940.0	220.1	0.0
23040-46060	12.8	0.0	0.0	115.0	0.0	0.0
Total	3234.1	12160.7	15237.5	9031.4	5840.0	3641.0

Source: University of Manitoba, Based on TxDOT input

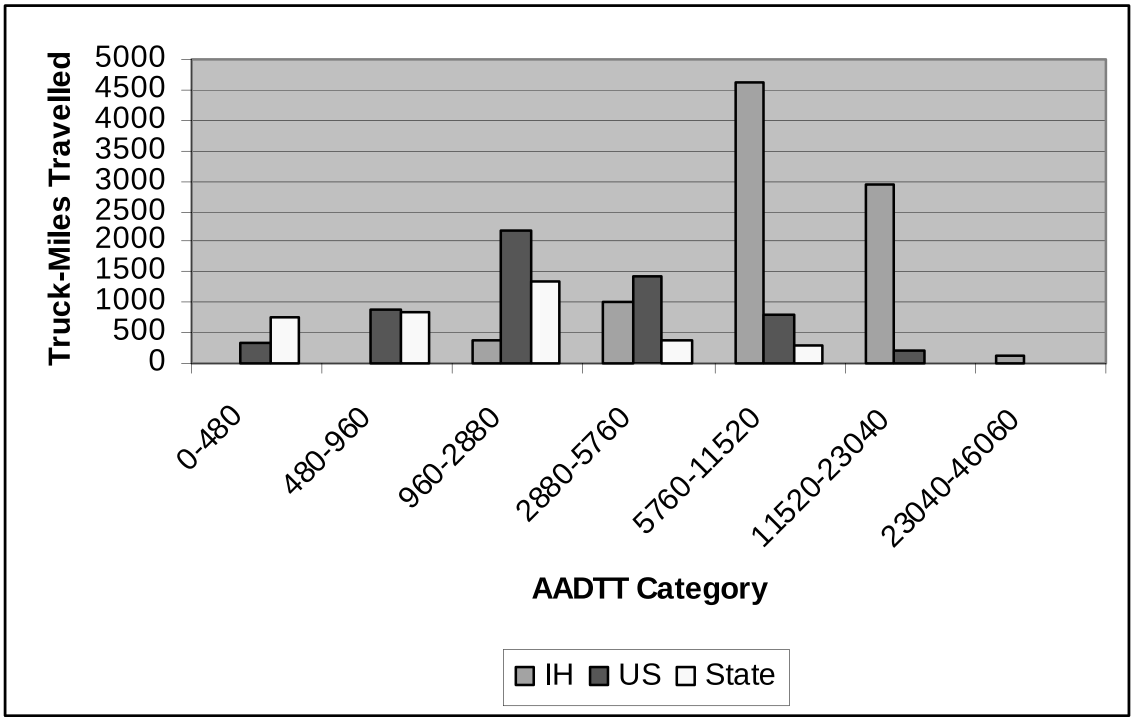
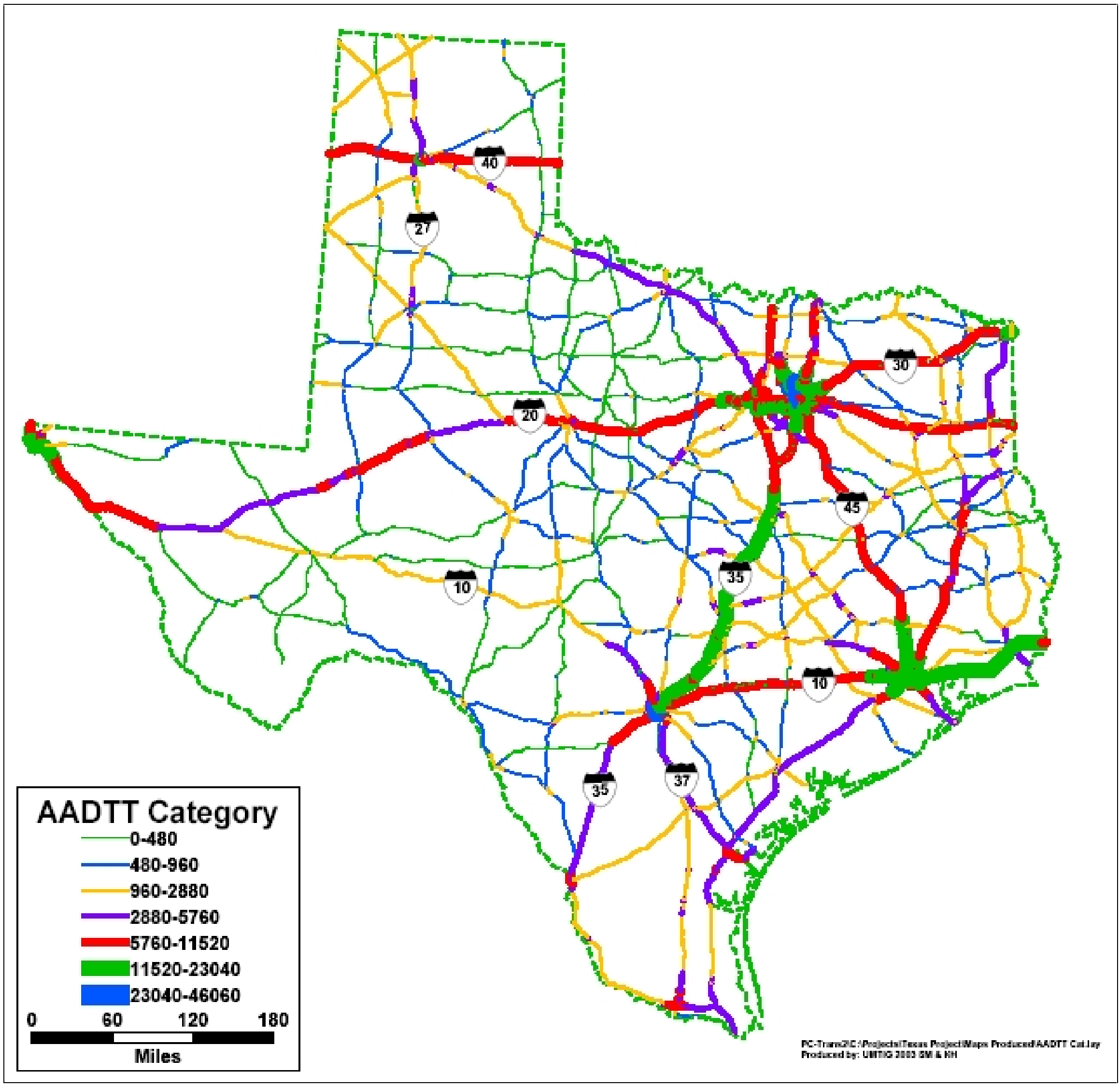


Figure 3. Truck-Miles Traveled by AADTT Category.

3.3.2 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.

Figure 5 and Table 5 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 for 8 percent, and New Mexico for less than 1 percent. The 2001 movement was 5 percent less than that experienced in 2000 *(4)*.



Source: University of Manitoba

Figure 4. Texas Highway AADTT Categories.

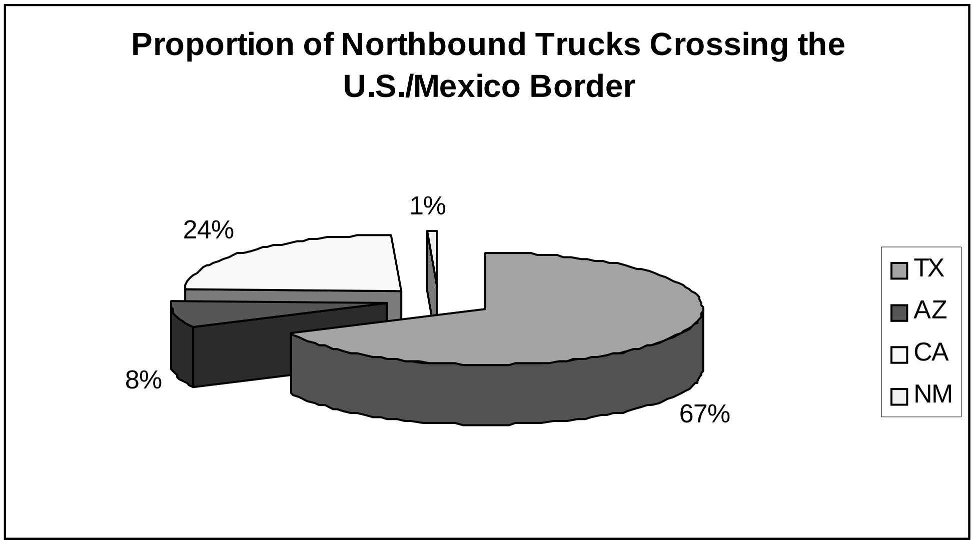


Figure 5. Northbound Truck Proportions by State.

Table 5. 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
Progresso	40	8	16,649	18
Roma	40	8	12,141	19
Naco	40	8	9,976	20
Presidio	45	9	7,562	21
Lukeville	48	8	4,271	22
Columbus	44	8	4,239	23
Sasabe	54	9	2,215	24
Andrade	45	9	1,727	25

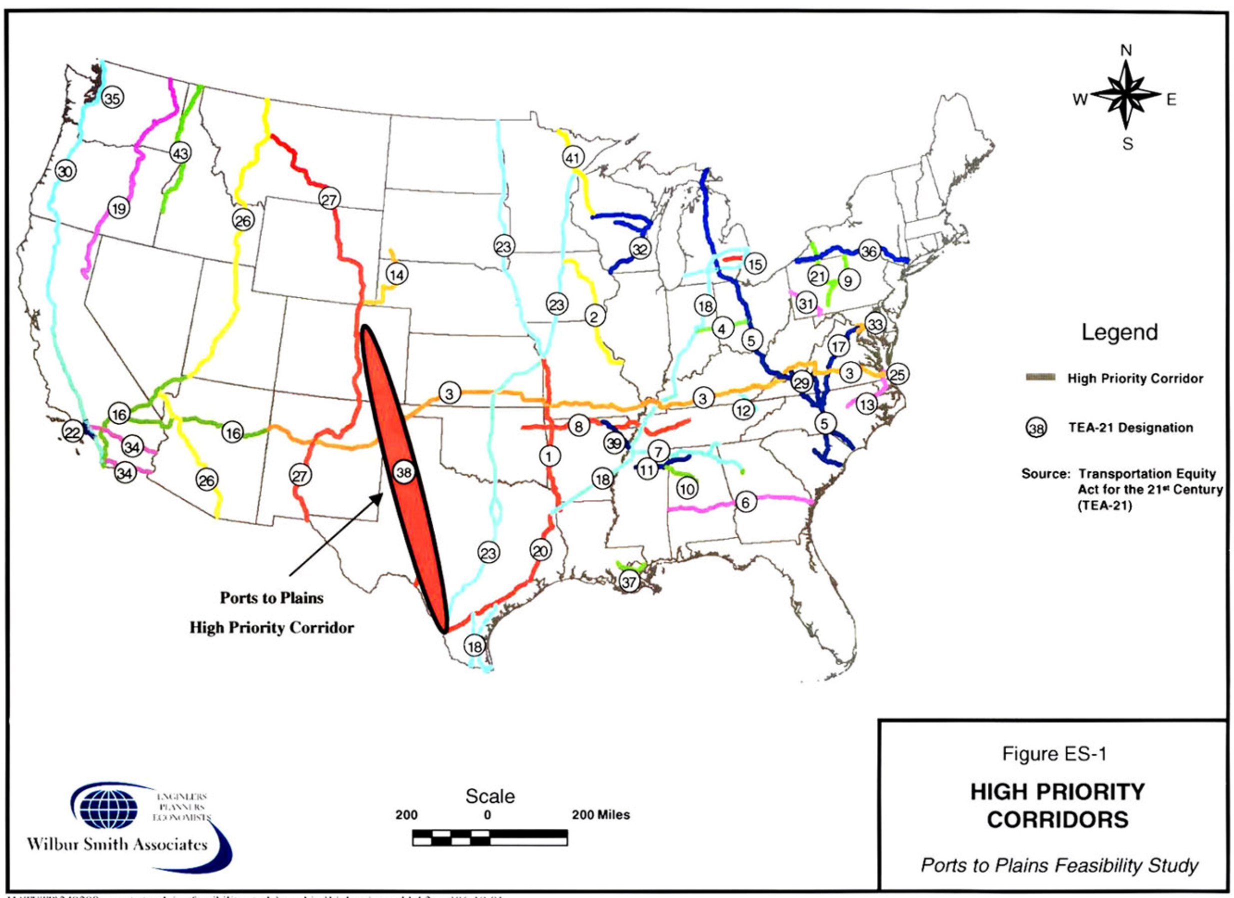
Source: Reference *(4)*

3.3.3 Truck Forecasts for Specific Corridors

There are six high-priority corridors designated in Transportation Equity Act for the 21st Century (TEA-21) passing though 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 6 illustrates these high-priority corridors *(5)*. This section summarizes truck forecast information presented in readily available studies for three of these proposed projects—the I-69, I-35, and Ports-to-Plains corridors (corridors 18/20, 23, and 38).



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Source: Ports to Plains Study

Figure 6. High-Priority Corridors.

As an example of information being disseminated from recent corridor studies, this discussion includes a brief synopsis of recommendations coming from the I-35 study. 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." A recommended investment strategy for the corridor is outlined, the purpose of which is to guide future, potential improvements *(6)*. 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 *(6)*. 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 various consultants working on these corridor plans had to address the growth in truck traffic for the next 20 or so years. The TTI team summarized these growth rates to be able to predict needs for truck accommodation. For example, the I-35 corridor growth rate, based on Transportation Planning and Programming (TPP) estimates, was around 3 percent per year (compounded annually). However, the Waco District predicted a higher value at around 5.0 percent per year based on historical information for the corridor. The Ports-to-Plains study *(5)* estimated a lower value for the corridor that would connect Denver, Colorado, with the Mexican border at Del Rio/Eagle Pass/Laredo. Their estimates for various segments of the corridor were predominantly in the 1.5 to 2.0 percent range, with the exception of near the border where it was nearer 4.0 percent per year. In summary, future growth in truck traffic will probably be in the range of 3.0 to 5.0 percent per year.

CHAPTER 4. TRUCK ACCOMMODATION STRATEGIES

4.1 INTRODUCTION

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 *(7, 8)*. 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 *(7)*. This chapter investigates some of the ways to accommodate trucks, including some real world examples. The major initiatives covered in this chapter include the New Jersey Turnpike, the proposed Trans Texas Corridor, and some truck accommodation projects in California.

4.2 EVALUATION OF STRATEGIES

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 because 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 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.

4.2.1 Lane Restrictions for Trucks

Lane designations or 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 effects, have implemented truck lane restrictions or have designated exclusive truck lane facilities.

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 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 to which municipalities request truck lane restrictions *(9)*.

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 *(10)*. Increased enforcement during the period of the lane restriction should not be ignored as part of the reason for the reduction in crashes.

Some of the specific findings or observations coming from past studies of truck lane designations include the following:

- A 1989 study by Garber and Joshua *(11)* that examined large truck crashes on Interstate highways in Virginia for the period from 1983 to 1985 concluded that safety could be enhanced by reducing interaction between large trucks and smaller vehicles.
- A 1990 study by Zavoina, Urbanik and Hinshaw *(12)* that examined the effects of truck restrictions on rural Interstates in Texas on six-lane, rural Interstate highway sections concluded that even though truck lane restrictions should theoretically improve capacity and safety, the research evidence did not support this assumption.
- Mannering, Koehne, and Araucto *(13)* conducted a study in the Puget Sound region that considered lane restrictions and 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 authors recommended that truck lane restrictions not be implemented in the Puget Sound area.

- 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 (tph). Densities lower than this range would result in inefficient lane usage, whereas higher truck traffic densities would result in bottlenecks *(14)*.

- 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 *(15, 16)*.

- Trowbridge et al. *(17)* discovered considerable resistance by the general public to any strategy that was perceived as a special benefit to truck traffic. However, the general public favored truck lane restrictions. Both the Organisation for Economic Co-operation and Development (OECD) study *(14)* and public input on the Capital Beltway truck lane restrictions supported the notion of lane restrictions. Public opinion on the beltway study was so favorable that lane restrictions were maintained even though there was no indication of improved traffic operations or a reduction of crashes *(18, 19)*.

General findings from the literature pertaining to lane restrictions include *(20)*:

- 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.

4.2.2 Truck Roadways and Truck Bypasses

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 a physically separated inner and outer roadway in each direction.

Some specific findings from the literature pertaining to truck roadways are as follows:

- A Samuel study for the Reason Public Policy Institute proposed self-financing toll truckways consisting of one or two lanes in each direction built in the existing right-of-way. 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 *(21)*. 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.

- The S.R. 60 Truck Facility Project in California would have raised $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 *(22)*.

- Trowbridge et al. investigated the benefits and costs of using reserved capacity lanes as exclusive truck lanes in the Seattle area. 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, responses from the general public indicated considerable resistance to any strategy that was perceived as a special benefit to truck traffic *(17)*.

- Hoel and Vidunas *(23)* examined the economics of exclusive vehicle facilities defined by the 1990 Exclusive Vehicle Facilities (EVFS) model developed by Janson and Rathi *(24)*. Although no single factor is dominant; the ones that contribute to the feasibility of exclusive lanes include: traffic volume, vehicle mix percentage, crash rate, and maintenance and construction costs.

- The OECD report on truck roads verified that exclusive truck facilities would be unpopular with the general public. Also, this same study noted that 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 *(14)*.

- A special conference on the environment in 1989 called by the European Conference of Ministers of Transport found that 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 *(25)*.

The best example in the U.S. of a truck freeway alongside a car freeway 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 separated facilities, which are also referred to as dual-dual segments, were implemented to relieve congestion. The turnpike has a 32-mi segment that consists of interior (passenger car) lanes and exterior (truck/bus/car) lanes within the same right-of-way *(26)*.

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 *(15, 16)*.

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 mi bypass of I-5 in the vicinity of S.R.14 and I-210 (known locally as I-5S). This latter bypass facility might also be considered as a short truck roadway due to its longer length compared to other bypasses. Figures 7 and 8 show this truck bypass. 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 to avoid the weaving sections *(26)*.

4.2.3 New Jersey Turnpike

The New Jersey Turnpike, the first controlled-access toll road to span the entire state, was opened in stages as sections were completed (see Figure 9). The first section from Interchange 1 (Deepwater) to Interchange 7 (Bordentown) opened on November 15, 1951. The turnpike has been lengthened and widened over the years since its construction; five major improvement projects have both improved safety and increased capacity. Today, the dual-dual roadway extends from Interchange 8A to Interchange 14, a distance of 32 mi *(27)*. 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 10 shows the general layout of the inner and outer roadways, although some sections have more separation between the inner and outer "barrels." As Figure 11 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.

Figure 7. I-5 Traffic Lanes and Parallel Truck Facility.

Report 4364-1 contains detailed information about the traffic volume, and specifically the truck volume operating on the New Jersey Turnpike. Table 6 shows the traffic volume associated with vehicle classification groups on the section of the turnpike from Interchange 8A to Interchange 14. For trucks, these numbers represent AADTT, and the total commercial motor vehicle (CMV) values include two- and three-axle buses. Class 1 and 2 vehicles are passenger vehicles and two-axle trucks, while Class 3 vehicles are heavier three-axle trucks.

Figure 12 shows total crash rates on the turnpike for 1999, 2000, and 2001. On a comparative basis, one might expect 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 is true in some years but not all. 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. Obviously, the crash rates are not the only variable of interest. Car crashes with other cars are usually less severe than truck crashes with cars. Also, separating trucks from other traffic on the dual-dual sections of the turnpike is not the only factor that might contribute to crash rates. Other factors include construction or design standards, lane restrictions for commercial vehicles, enforcement level, incident response, use of ITS, and strategic locations of service plazas.

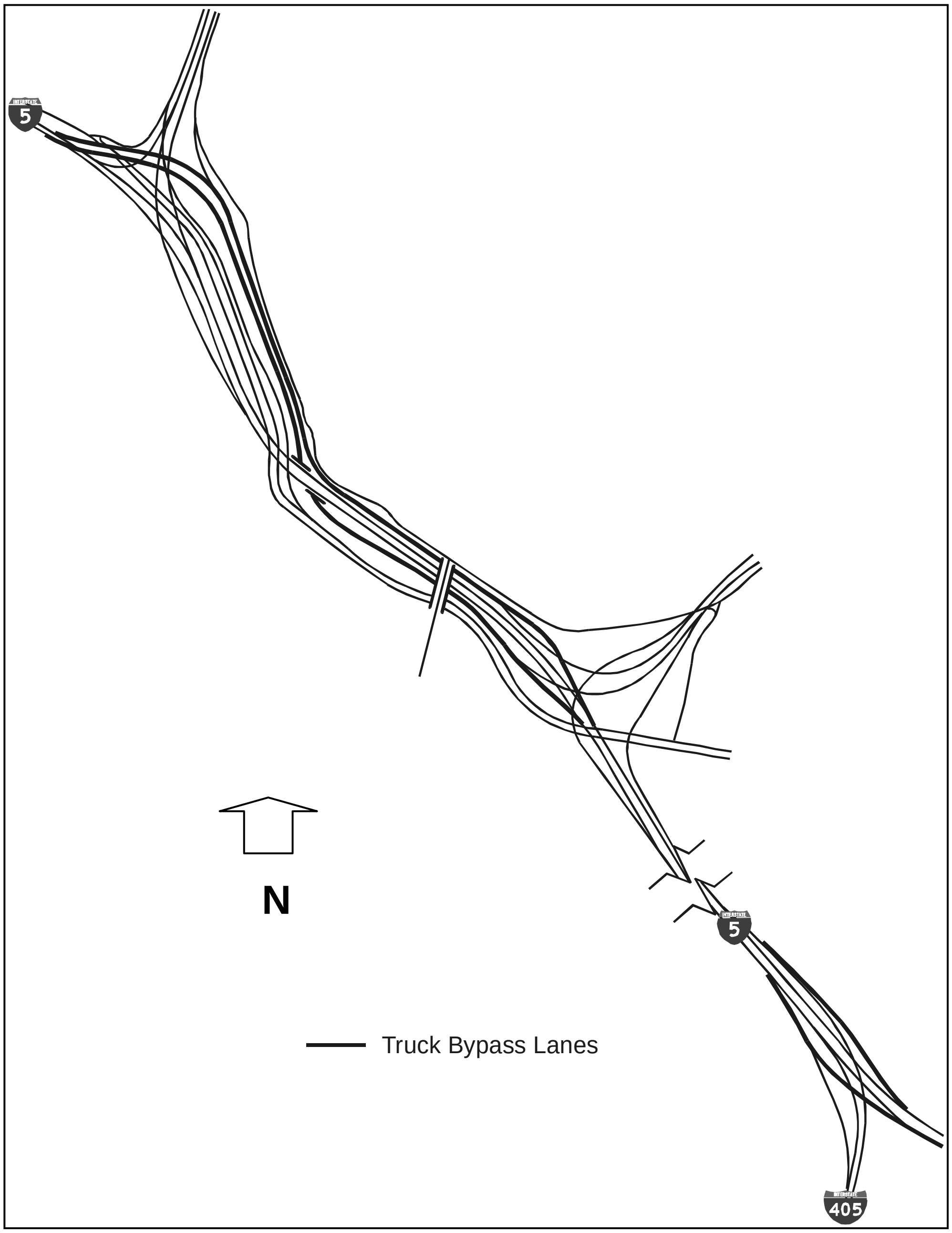


Figure 8. Schematic of I-5 Truck Bypass.

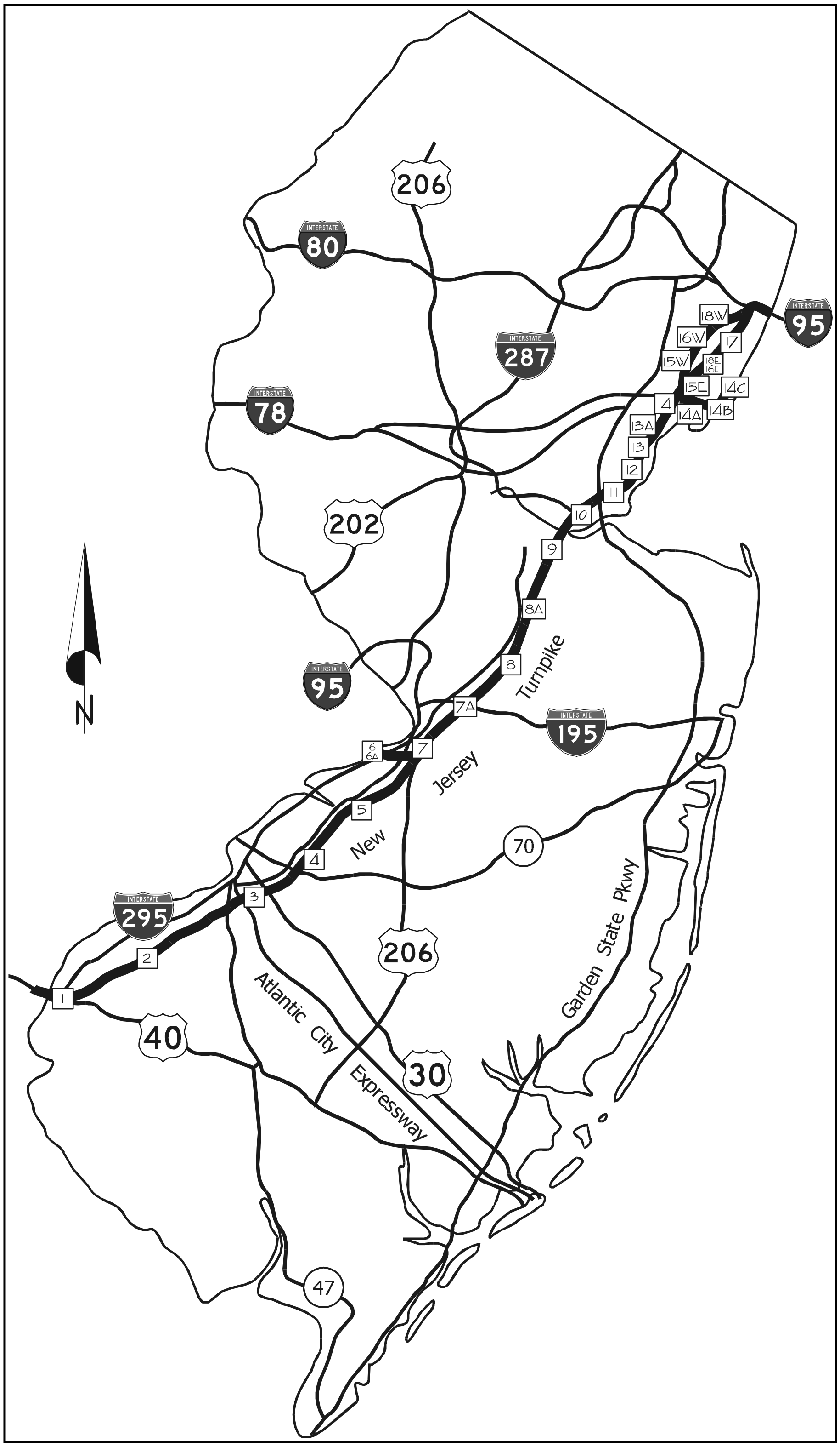


Figure 9. New Jersey Turnpike.

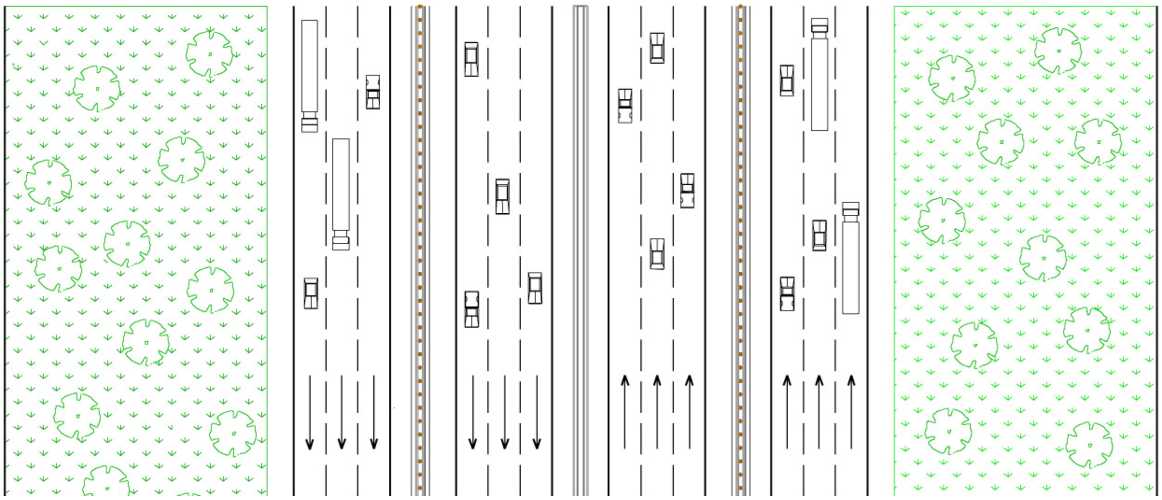


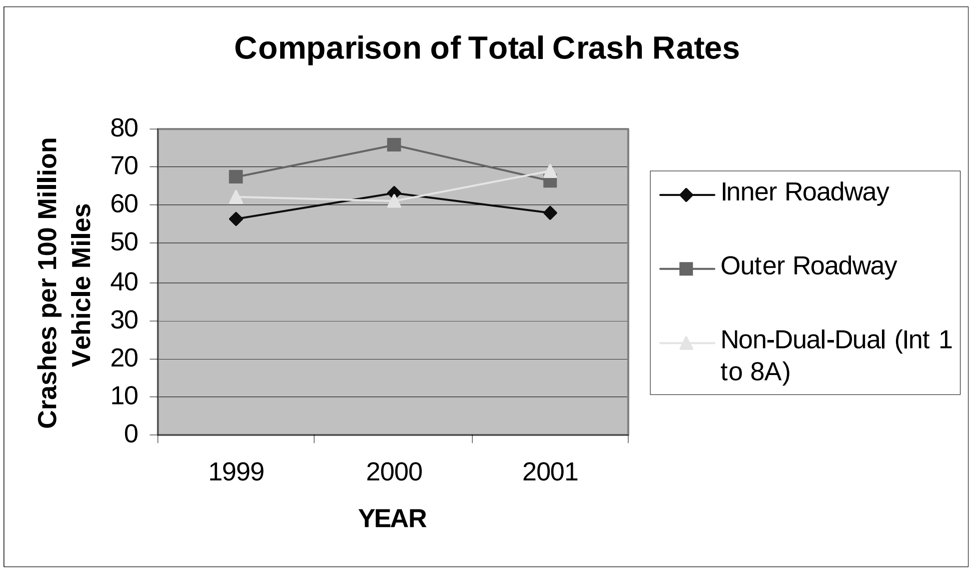
Figure 10. Typical Cross-Section of Dual-Dual Roadway.

Figure 11. Individual Ramp Access for the Inner and Outer Roadways.

Table 6. New Jersey Turnpike AADTT Link Volumes by Vehicle Classification.

Link	Class 1,2	Class 3+	Buses	Total CMV	% CMV
8A - 9	136977	20429	935	21364	14.9%
9-10	174665	21916	1245	23161	12.5%
10-11	165319	20456	1227	21682	12.4%
11-12	195229	22410	2411	24821	11.5%
12-13	204210	23909	2459	26368	11.7%
13 - 13A	215119	25261	2700	27962	11.7%
13A - 14	193996	23418	2545	25963	12.1%

Source: New Jersey Turnpike Authority



Source: New Jersey Turnpike Authority

Figure 12. Turnpike Total Crash Rates for 1999, 2000, and 2001.

Examples of design standards used by the New Jersey Turnpike Authority (NJTA) are 12-ft travel lanes throughout on both the inner and outer roadways (allowing exceptions in construction areas) and 12-ft paved shoulders on the right side of the travel way on newer sections of the turnpike. The turnpike's 42-inch high concrete barrier provides a more positive barrier than shorter cross-sections to contain commercial vehicles while not increasing the risk for passenger vehicles impacting the barrier. 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 lead to its acceptance for use by the turnpike authority *(28)*. 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.

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.

The enforcement unit of the New Jersey Police serving the New Jersey Turnpike is known as Troop D. The New Jersey Turnpike employs more state police per lane-mile than other jurisdictions in the New Jersey Troop. According to NJTA personnel, these troopers also 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.

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.

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.

The NJTA has variable message signs, drum signs, neon signs, and highway advisory radio (HAR) in addition to fixed signs. 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 11.

The turnpike’s 12 service plazas offer locations that are strategically placed to provide motorists with convenient places to eat, refuel and other vehicle services, and relax. Closely related is the need for truck parking to provide adequate rest and minimize fatigue as well as meet hours-of-service requirements.

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 mile 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 (using existing outside ramps) cost $45 million. An improvement project completed in the early 1990s, which widened a 6-mi 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.

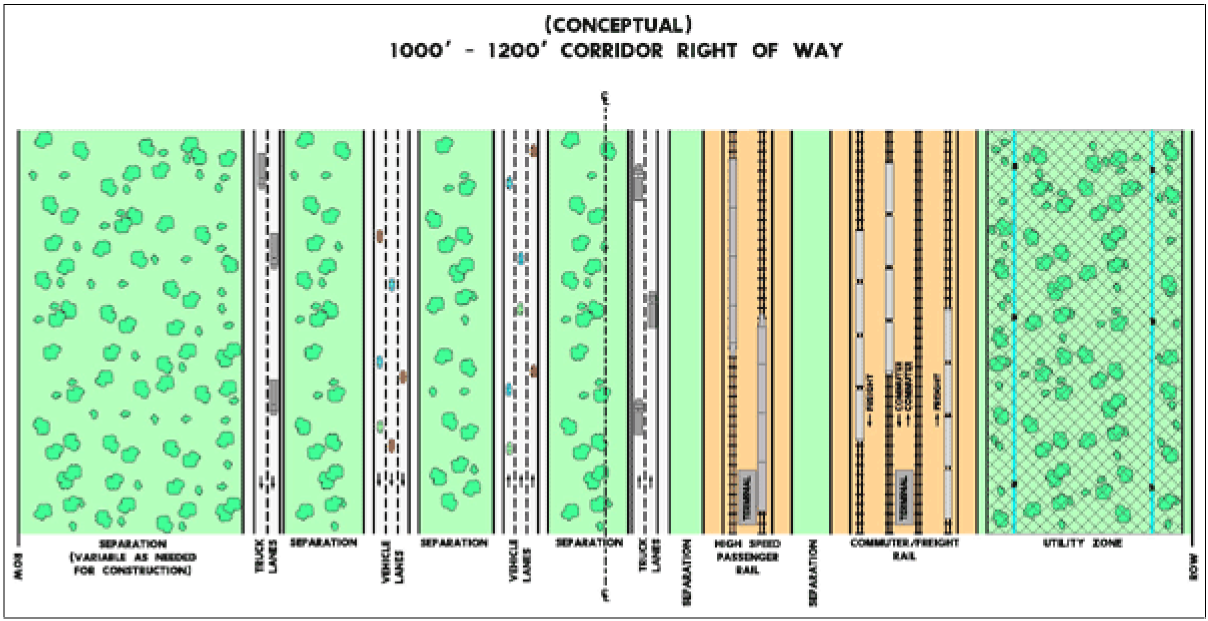
Rough estimates of non-dualized freeway indicate a cost of approximately $10 million per mile, excluding environmental challenges, which must be addressed. For example, noise barrier is required now, whereas it was not required as much in recent years. In one example, the cost of noise barrier construction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

4.2.4 Proposed 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-mi 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 *(29)*. Figure 13 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.



Source: Reference *(2).*

Figure 13. Concept Plan View of the Proposed Trans Texas Corridor.

Four corridors have been identified 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 corridor will connect to major cities while not sending traffic directly through them, and it will be designed to take advantage of ITS. It will be developed in phases through several scenarios. For example, the truck lanes (two in each direction) might be built first and 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 *(29)*.

4.3 THRESHOLDS FOR TRUCK ACCOMMODATION

To determine the need for specific truck treatments, designers rely upon recently developed computer models, experience from other states, and engineering judgement. This discussion is not intended as an endorsement of any of these treatments or evaluation methods; they are simply presented as a point of beginning to determine possible application in Texas. One of the latest computer models is an update by Battelle *(31)* of the 1990 Exclusive Vehicle Facilities model developed by Janson and Rathi *(24)* that examined the feasibility of designating exclusive lanes for vehicles by type. This Janson and Rathi model evaluated exclusive lane use feasibility by utilizing a benefit/cost analysis. State experience came from California and New Jersey.

One evaluation of the EVFS program by Wishart and Hoel *(30)* examined problems with mixed vehicle traffic and the four truck traffic strategies described in the original 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.

The Battelle effort 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 *(31)*. Designers can use the program to evaluate the economic feasibility of exclusive lanes for specific sites on high-volume, limited access highways in both urban and rural areas. In order for a highway to be considered, three or more lanes in one direction must be available. The program allows the user to input site-specific information for 57 variables grouped into three categories: a) traffic characteristics; b) cost of construction, maintenance, and right-of-way; and c) 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 calculates 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 number 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 (no mixed lanes).

The Battelle work resulted in some criteria for providing truck facilities based on annual average daily traffic (AADT), annual average daily truck traffic, level of service (LOS), truck-involved crash rates, daily traffic delays, and proximity to freight origin-destination points. Table 7 summarizes the proposed thresholds.

Truck treatments in California (I-5S north of Los Angeles, and S.R. 60 near Los Angeles) and on the New Jersey Turnpike can also be helpful from the standpoint of demand (truck volume) and crash rates. The general useful information gleaned from truck treatments on these facilities, based on information from Douglas *(20)*, pertains primarily to vehicular volumes.

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 Douglas criterion for traffic volume is an AADT of at least 120,000 vehicles per day (vpd) and 20,000 (large) trucks per day (tpd) where there are at least four lanes in each direction and the traffic demand occurs over at least a 10-mi length or has a large truck traffic generator at one terminus.

- 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.

Table 7. Suggested Evaluation Criteria.

Measure	Suggested Threshold	Remarks
AADT	≥ 100,000 vpd	Use in combination with AADTT percent
AADTT	≥ 25 %	Use in combination with AADT
Level of Service	E or lower – urban hwys F or lower – rural hwys (v/c ratio ≥ 1)	To rank potential locations that satisfy traffic criteria
Truck-involved fatal crash rate	≥ national average (2.3 per 100 million VMT, 1999)	To rank potential locations that satisfy traffic criteria
Proximity to intermodal facilities/ processing centers	≤ 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

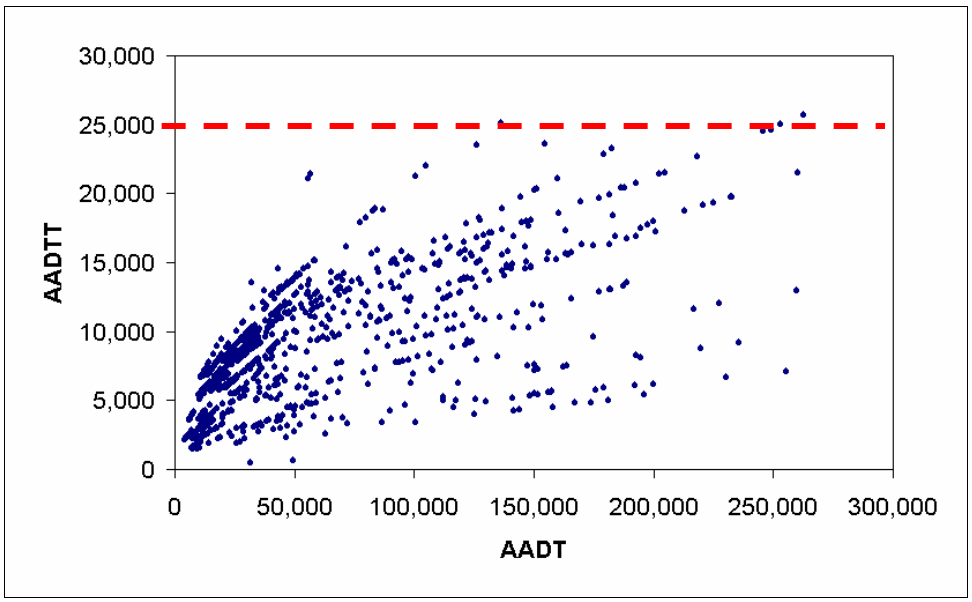
Source: Reference *(31)*

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 14 and 15 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 be most highly correlated with urban areas versus rural areas and time of day. There are more of these smaller trucks (and buses) in and near urban areas and during daylight hours.

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.

4.3.1 Texas Truck Volumes

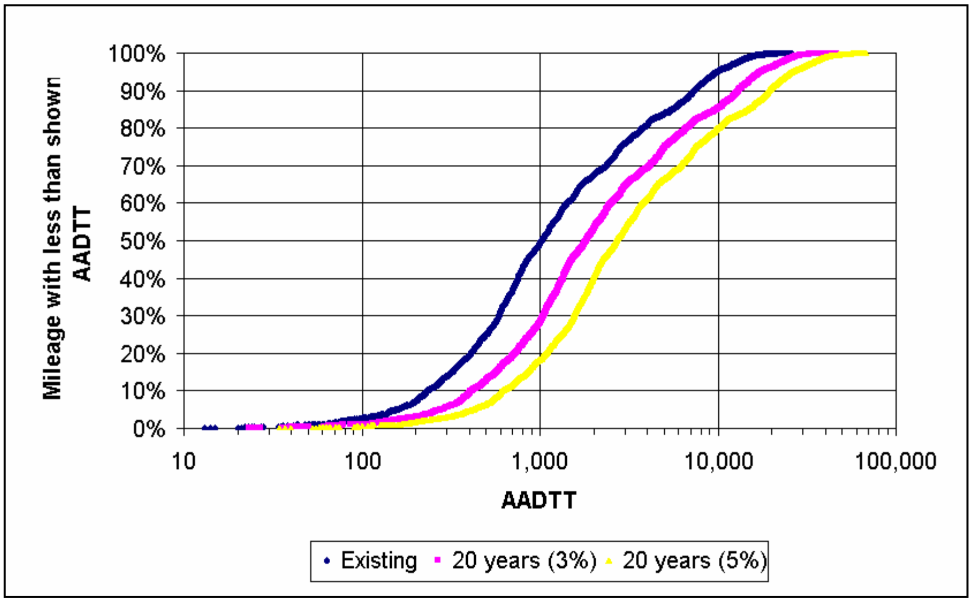
Figure 14 indicates the relationship between AADTT and AADT for Texas Interstate highways where most of the truck treatments will be warranted since Interstate class roadways serve the largest portion of the high truck demand, followed by U.S. highways. Comparing these volumes of trucks and other traffic with the Battelle and Douglas volumes, one can establish an approximate level of demand where truck treatments should be considered. Figure 15 represents a cumulative distribution of AADTT for 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.



Source: TxDOT

Figure 14. Correlation between AADT and AADTT (IH Road Class).

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 *(22).* 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 *(32).*



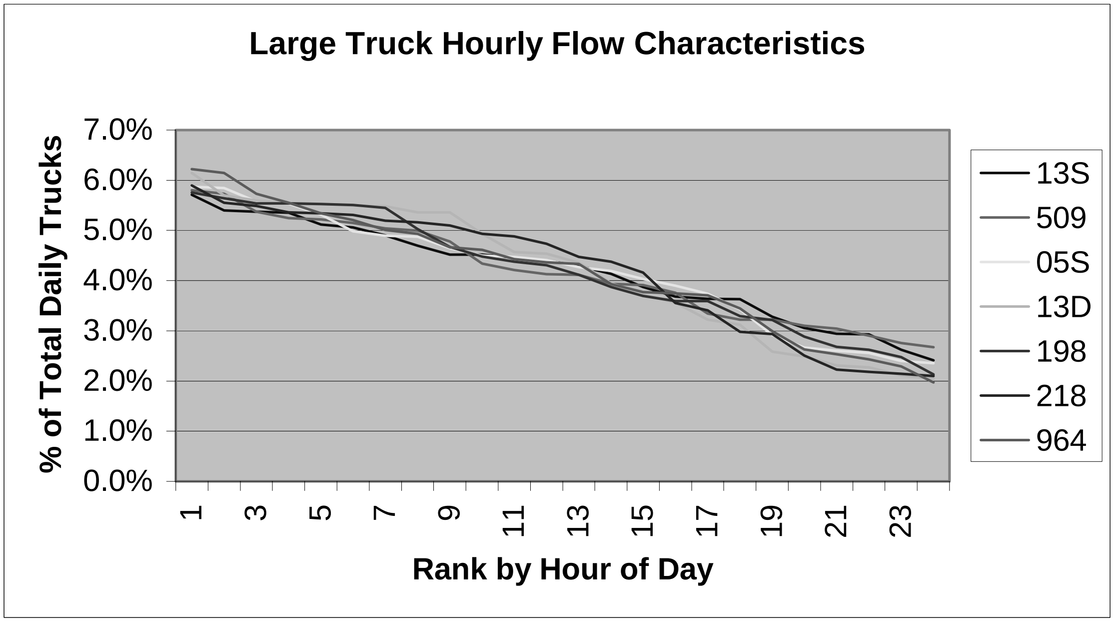
Source: Based on Data Provided by TxDOT

Figure 15. Cumulative Frequency Distribution for AADTT.

Translating from AADTT to hourly truck flows requires knowledge of large truck peaking characteristics. This analysis uses typical vehicle classification data from Texas sites to determine threshold information. Appendix G in Report 4364-1 *(1)* 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 16 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 (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 3). Figure 16 indicates a very consistent pattern for percentages by ranked hour of day for all sites represented. The consistency of these data suggests that these sites could be used 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. Report 4364-1 has a discussion of hourly directional splits as well 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 3, likely in the range of 3 to 5 percent growth per year.

Table 8 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.



Source: TxDOT

Figure 16. Bi-Directional Hourly Truck Percentages at Seven High-Volume Sites.

Table 8. 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

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 be considered 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 urban areas such as Houston, Dallas, Ft. Worth, El Paso, and portions of other urban areas.

The authors developed three plots of hourly volume from AADTT data by the following highway types: Interstate, U.S., and State. Again, the designer typically uses the 30^{th} 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 DDHV was as follows:

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

where:

- Truck DDHV = truck directional design hour volume (vehicles per hour);
- 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 Interstate road types. Figure 17 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 17 indicates a fairly constant slope from near zero to around the 95^{th} 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 the return for below 95 percent.

The 95^{th} percentile hourly design volume for a 20-year design on Interstate Highways would be between 1000 tph and 1700 tph. 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 95^{th} percentile truck volume would still require two lanes in rolling terrain and one lane in flat terrain (again strictly from a capacity standpoint).

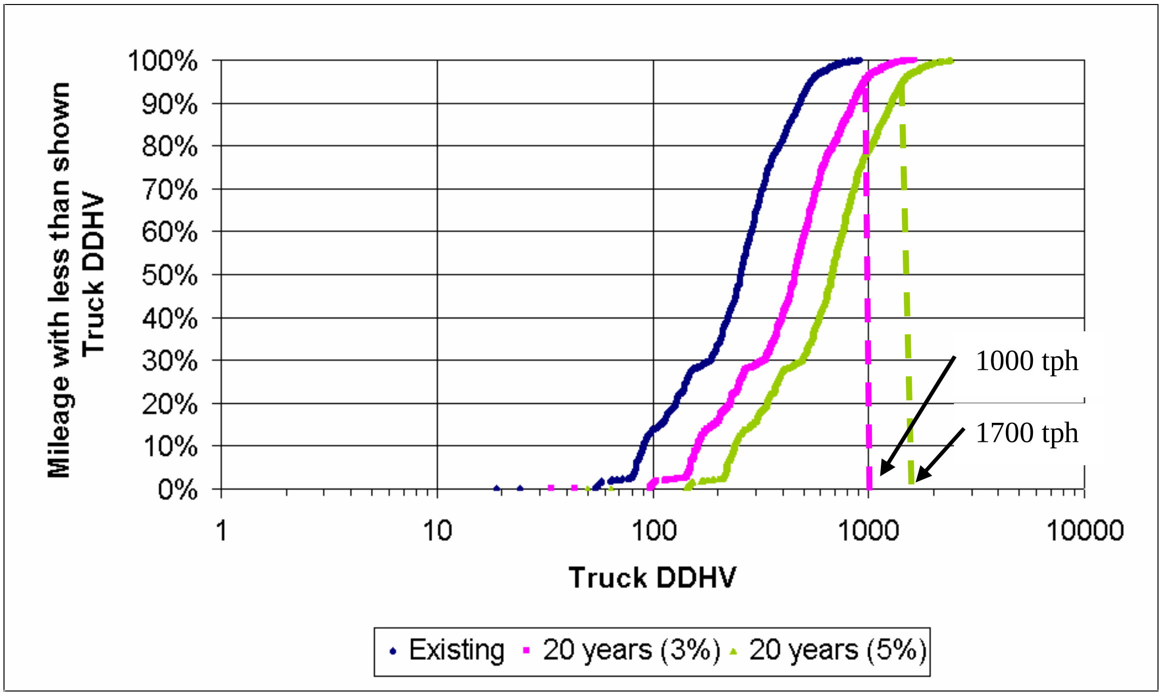


Figure 17. Cumulative Frequency Distribution for Peak-Hour Truck Traffic on Interstate Highways (3235 miles).

4.3.2 Truck Accommodation Threshold Summary

First, the authors encourage widespread practice of *truck-friendly design* at all levels of truck activity, especially if future truck growth rates are expected to be high. In general terms, this concept means designing a "forgiving environment." For example, intersection design for undeveloped areas in or near urban areas should ask the question, "What if a large truck stop is proposed nearby?" Based on data presented in Report 4364-1, 85 percent of the truck-miles of travel in Texas occurs on roadways where the AADTT is at least 1000 trucks per day. Table 9 helps visualize breakpoints in truck activity. Based upon this information, designers should give explicit consideration to trucks when the AADTT within the design period is expected to reach 1000 or more trucks (Class 3 and above) per day.

Table 9. 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%

Source: Based on TxDOT data

Moving beyond truck-friendly design, special treatments for trucks should be based upon measurable parameters. The one that is perhaps most often used is truck and/or total traffic volume. Implicit in this parameter is the quality of traffic flow or level of service. Based upon engineering judgment from the foregoing analysis, a reasonable criterion to begin considering special truck treatments is 5000 trucks per day (or 300 trucks per hour assuming the highest hour volume at 6 percent of daily volume). Truck roadways must only be considered when the volume of trucks reaches a threshold where there is reasonably full utilization. Based on the two literature sources cited in this chapter – Battelle *(31)* and Douglas *(20)* – and the current truck volumes being experienced in Texas compared to the California and New Jersey facilities, the truck volume that would justify building future separate truck roadways is 25,000 trucks per day (peak-hour volume of 1500 trucks per hour). Of course, the terrain factor and other localized factors still need to be applied. Table 10 summarizes the threshold values; the authors will consider them further for design issues in the next chapter.

Table 10. Threshold Summary.

AADTT	Design Hour Volume	Truck Treatment
0 – 1000	0 – 60	Truck-friendly design
1000 – 5000	60 – 300	Some design for trucks (see Chapter 5)
5000 – 25,000	300 – 1500	All design for trucks (see Chapter 5)
Over 25,000	Over 1500	Two-lane truck roadway

One of the questions 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), its corresponding AADTT value (two-way volume on a total of four lanes, dividing by 6 percent) would be over 106,000 trucks per day. According to Figure 15, 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 passenger vehicles are 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 15 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 preferred 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 truck roadways are really safer than maintaining mixed flows. 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 5. DESIGN GUIDELINES

5.1 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 American Association of State Highway and Transportation Officials (AASHTO) Green Book *(33)* and the TxDOT *Roadway Design Manual* (TRDM) *(34)*. 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.

TTI produced a preliminary list of design elements early in the project to use in developing guidelines; Table 11 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 ITS elements. To adequately design roadways for large trucks, one must first know the size and operational characteristics of the design vehicle population. Report 4364-1 provides information on these vehicle characteristics, and a parallel research project sponsored by the National Cooperative Highway Research Program (NCHRP) *(35)* 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.

5.2 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.

5.2.1 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* (SSD) 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 11. Design Factors Potentially Affected by Truck Characteristics.

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

5.2.1.1 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 *(36)* 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 those 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 SSD 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 author recommends 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.

5.2.1.2 Decision Sight Distance

The 1984 Green Book first introduced the concept of decision sight distance based on research by McGee et al *(37)*. 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
- 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 *(38, 39)* 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 author recommends no changes pertaining to decision sight distance.

5.2.1.3 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.

5.2.1.4 Railroad-Highway Grade Crossing Sight Distance

The criteria in the 2001 Green Book reflect the latest stopping sight distance criteria. Reference *(35)* 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 author recommends no change in railroad-highway grade crossing sight distance.

5.2.1.5 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.

Recommendation: The author recommends no change.

5.2.2 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.

5.2.2.1 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 National Highway Traffic Safety Administration (NHTSA) study *(40)* 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 to 0.35 g *(35)*. The report provides tabulated values of margins of safety for trucks (cars are different) against rollover and skidding. 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 author recommends no changes (other than a correction of the noted erratum).

5.2.2.2 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 *(35)*.

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.

<u>Recommendation</u>: The author recommends 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.

5.2.2.3 Pavement Widening

The authors do not anticipate 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.

<u>Recommendation</u>: The author does not recommend changes pertaining to pavement widening for design speeds of 60 mph or higher.

5.2.3 Vertical Alignment

5.2.3.1 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 85th 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.

<u>Recommendation</u>: 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 author recommends no changes to the TxDOT procedure.

5.2.3.2 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.

Recommendation: The author recommends no changes.

5.2.4 Cross-Section Elements

5.2.4.1 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 ft on freeways. Mason et al. *(41)* 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. It should be noted that 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 consideration should be given to 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 *(42, 43)*. 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 author 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.

5.2.4.2 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 main lanes.

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 author recommends 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.

5.2.4.3 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 author recommends no changes.

5.2.4.4 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 *(44)* 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 author recommends no changes.

5.2.4.5 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 author recommends no changes.

5.2.4.6 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 allow it to “slide” along the top of the barrier until it rights itself.

NCHRP 22-12 *(45)* 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 ¾-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 inches 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 built 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 *(46)*.

The Texas 42-inch barrier has a constant slope face, which makes an angle of 10.8 degrees with respect to vertical and was originally tested and developed for use as a temporary concrete barrier. However, it has since been widely used as a permanent concrete median barrier. This 42-inch single slope barrier has not been full-scale tested to TL-5 standards. A 32-inch version has been tested 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 *(46)*.

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 current barrier design is adequately reinforced to accommodate TL-5 impact loads. Other variables that would affect performance besides height and shape include the amount of reinforcing steel and barrier thickness. 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. 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, the reinforcement could be modified. If the strength can be demonstrated analytically, it is likely that the TxDOT 42-in 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 other types have been used 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 at 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 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. A third stage would be only for heavy trucks and would not be needed for an impact of smaller vehicles. Design only for trucks only could use a single stiffer unit.

<u>Recommendation</u>: The author recommends 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 where AADTT reaches 5000 trucks per day during the design

period should always be 42 inches in height and structurally sufficient for trucks, meeting the TL-5 barrier requirements.

5.2.4.7 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. Designers must give consideration 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 2-mile advance sign placed between the inner and outer roadways, followed by a 1-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) *(47)* 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 shown in the TMUTCD depend 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 ½ 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 mi and 2 mi in rural areas and at ½ mi and 1 mi 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 author also recommends the use of overhead signs for mixed flow roadways where the number of trucks predicted during the design period exceeds 5000 tpd.

5.2.4.8 Curbs

In past years, some freeway ramps have utilized 6-inch barrier curb for drainage purposes or simply for delineation. However, research by Ervin *(48)* 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 author recommends no changes.

5.2.4.9 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 85^{th} 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 *(35).* The report establishes the minimum acceleration lengths for a 180 lb/hp truck as shown in Table 12. These minimum acceleration lengths are, on average, about 1.8 times greater than the minimum acceleration lengths given in the Green Book.

Recommendation: The author recommends 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 12. Minimum Acceleration Lengths for a 180 lb/hp Truck.

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 *(35)*.

5.2.5 Design Element Thresholds

It is not only important to know what design elements are affected by truck characteristics; it is also important to know the appropriate conditions for application of each. This section draws upon the experience of others, the literature, and engineering judgment to establish thresholds for each of the design elements covered in this chapter. Table 13 is a summary of the design elements for assistance to designers to know the appropriate conditions for changing current design practice. The asterisk designates categories for special truck design.

5.3 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.

Table 13. Design Element Thresholds.

Design Element	Design Year AADTT (DHV)		
	1000 to 5000	5001 to 25,000	Over 25,000
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
Curve Radius and Superelev.	NC	NC	NC
Intersection & Channelization	NC	*	*
Pavement Widening	NC [b]	NC [b]	NC [b]
Critical Length of Grade	NC	NC	NC
Downgrades	NC	NC	NC
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	*	*

* Special design for trucks.
NA: Not applicable to high-volume, controlled-access roadways for trucks.
NC: No change from current design practice.
[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 ½ mi and 1 mi in urban areas and 1 mi and 2 mi in rural areas.

5.3.1 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.

5.3.1.1 Smart Signs

Variable message signs should be considered to control 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. The need for traffic monitoring systems needs to be assessed 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.

5.3.1.2 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 (UMTRI) *(49)* recently evaluated this system.

Most recently, Georgia Department of Transportation 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 I-20, I-75, and I-85 with I-285 surrounding the city of Atlanta *(50)*.

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 *(50)*.

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) *(50)*.

Relatively simple speed warning systems detect all vehicles over 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 *(50)*.

Middleton *(51)* 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 WIM 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. *(52)* 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-ft long at a height of 7 ft above the road surface and that were traveling at or above a speed of 56 mph 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 mph reduced their speed on average by 8 to 10 mph, while those in the lower speed range of 56 to 62 mph reduced their speed by 6 to 8 mph.

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

- 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 mph, 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 mph 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.

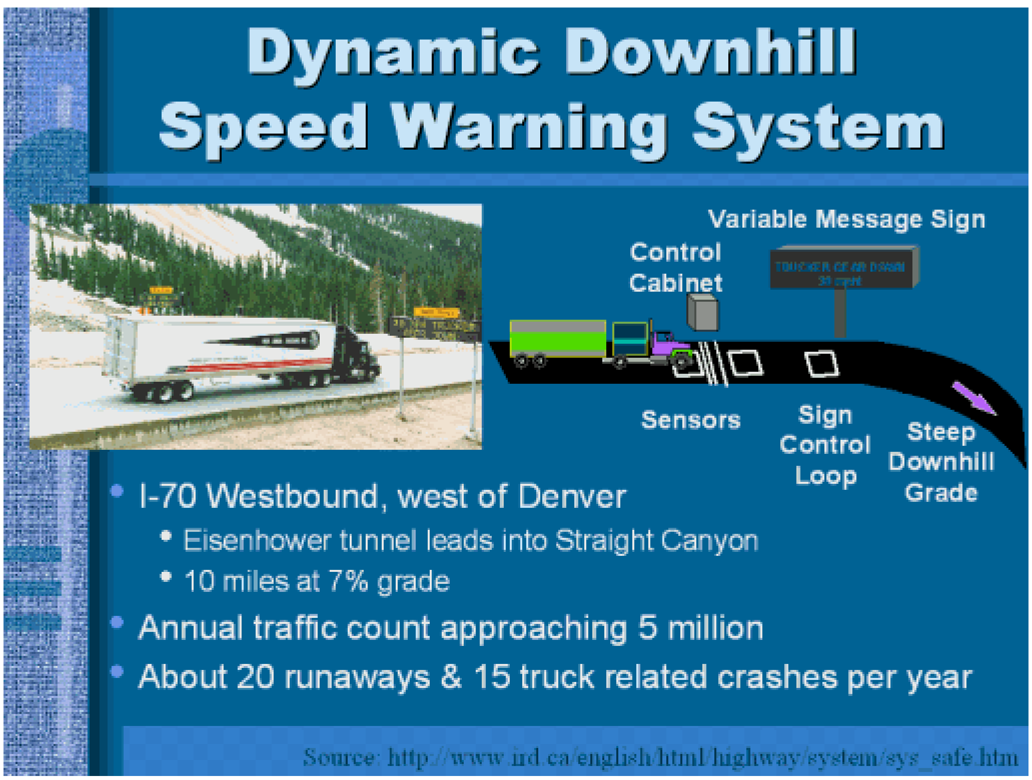
5.3.1.3 I-70 Downhill Truck Warning System

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 *(53)*. 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 ¼ mi west of the Eisenhower tunnel. It precedes a 10-mi 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 18 depicts the speed warning system and some of its components. This equipment includes a WIM 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, and 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.

5.3.1.4 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 allows 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 *(54)*.



Source: Reference *(53)*.

Figure 18. 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 recording 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 ratio 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 *(54)*.

5.3.2 Commercial Vehicle Parking

Section 4027 of the 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 NHS and determine current and projected shortages. This second stage also developed plans for action to meet the identified needs *(55)*.

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 *(55)*.

Texas is first among the states with the highest demand for truck parking, followed by California, then mid-western 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 is 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 tpd. 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 *(55)*.

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 ratio 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 *(55)*.

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APPENDIX

Presentation Materials

Project 0-4364 Objectives

- Develop profile of current Texas truck fleet
- Evaluate major truck corridors
- Identify critical design issues for trucks
  - Lane use restrictions
  - Separate truck facilities or lanes
  - Use of roadside barriers or physical separation
- Develop geometric guidelines for truck corridors
- Develop workshops for mid-level designers and policy-makers

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Designer Workshop Outline

- ➡ Introduction
- Stakeholder input
- Texas truck corridors
- Truck accommodation strategies
- Designing for trucks
- Wrap-up

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Methods to Separate Trucks

- Spatial and temporal separation
- Mixed traffic flows
- Lane restrictions
- Truck roadways
- Discussion

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Geometric Design Issues

Sight distance

- Stopping sight distance
- Decision sight distance
- Passing sight distance
- RR-hwy grade crossing SD
- Intersection sight distance

Horizontal alignment

- Curve radius
- Superelevation
- Intersection and channelization
- Pavement widening

Vertical alignment

- Critical length of grade
- Downgrades

Cross-section elements

- Lane width
- Shoulder width and composition
- Sideslopes and drainage features
- Pavement cross-slope breaks
- Vertical clearance
- Traffic barriers
- Passive signs
- Curbs
- Acceleration lanes

Designer Workshop Outline

- Introduction
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- Wrap-up

Stakeholder Input

- TxDOT
- Motor carriers
- Enforcement
- Motoring public

Truck Parking Needs

- Truck driver hours-of-service
- Existing 100 public rest areas for trucks
- TxDOT's goal: 60-90 mi. spacings
- TxDOT has $70 million program
- Current funds are insufficient

Truck Parking

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Stakeholder Input: RTI Survey

- Improvements planned or suggested
  - Implementing "Super 2" design
  - Lane and shoulder widening
  - Increased sight distance
  - Intersection improvements
  - Passing and climbing lanes
  - "Designated truck lanes"
  - Heavy-duty asphalt pavement (>5000 tpd)

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Stakeholder Input: Carriers

- Motor carriers vs. shippers
  - Pick-up and delivery schedules
  - Vehicle size issues
- Truck drivers need timely information
- Truckers want non-toll options
- Improvement needs:
  - Lengthen entry/exit ramps
  - More rest areas
- Maintain truck roadways as trucks only

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Designer Workshop Outline

- Introduction
- Stakeholder input
- ➡ Texas truck corridors
- Truck accommodation strategies
- Designing for trucks
- Wrap-up

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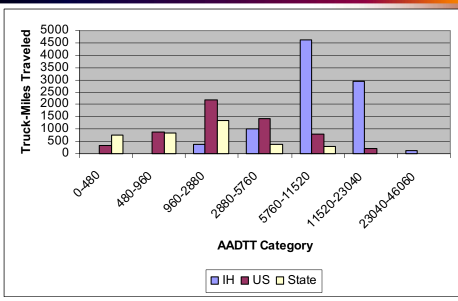
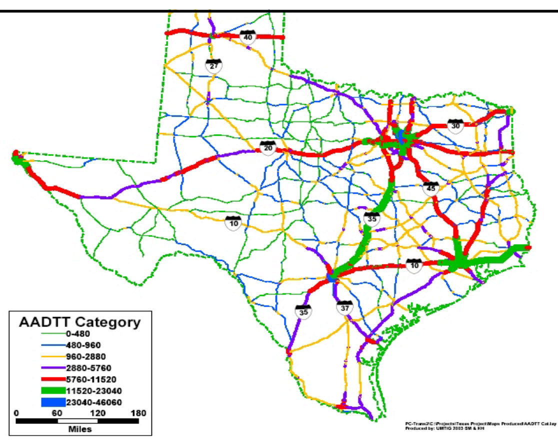
TMT by AADTT Category



Texas Truck Corridors

- I-35
- I-10
- I-69
- Ports-to-Plains Corridor
- Trans Texas Corridor



I-35 Super Highway/Truckway Concept

- I-35 Trade Corridor Study (1999)
- Design speed: 75 – 150 mph
- Separate instrumented lane for trucks
- Interchange spacing: > 20 mi
- ITS features and improved design

I-35 Super Highway/Truckway Concept

- Improved design features:
  - Heavier loads
  - Maximum grade of 3%
  - Longer acceleration/deceleration ramps
  - Wider pavement
  - Flatter turning radii at interchanges
  - Additional space at rest areas

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I-10 Study

- Covers eight states
- Criteria for truck separation
  - Total daily truck volume
  - Volume/capacity ratios
  - Total overall vehicle volume
  - Number of trucks carrying high service freight
  - Number of trucks making deliveries within 100 miles

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I-10 Truck Bypasses

- Criteria
  - Non-circuitous route
  - >5,000 AADTT
  - 20-40% through truck percentage
  - 10-20% total truck percentage
  - No truck-only
- Two bypasses analyzed
  - Northeast Parkway Route (El Paso, TX)
  - State Route 85 (Phoenix, AZ)

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I-69

- ISTEA High-Priority Corridor No. 18
- Indianapolis – Lower Rio Grande Valley (LRGV) extension
- LRGV components:
  - US 77 Brownsville – Victoria
  - US 281 McAllen – Victoria
  - Corpus Christi Northside Highway

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Ports-to-Plains Corridor

- Ports-to-Plains Feasibility Study
- Denver – Del Rio/Eagle Pass/Laredo
- Continuous 4-lane hwy not feasible
- Truck climbing lanes
- ITS measures
- Relief routes in corridor towns/cities

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Designer Workshop Outline

- Introduction
- Stakeholder input
- Texas truck corridors
- ➡ Truck accommodation strategies
- Designing for trucks
- Wrap-up

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Truck Accommodation Strategies

- Lane restrictions (LR)
- Truck-preferred or truck-only roadways

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Lane Restriction Research

- 1989 study found that safety could improve
- 1990 Texas study did not find improvements in capacity and safety
- 2000 Texas study found crashes dropped by 68%
- A Seattle area study recommended not implementing lane restrictions
- Netherlands study found LR feasible when truck density is 600-1,000 trucks/hr
- LR can result in barrier effect in weaving areas
- Public favors LR but no special truck benefits

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Lane Restriction Applications

- Only on roadways with 6 or more lanes
- Do not restrict trucks to a single lane
- Restrict trucks
  - FROM the left lane or
  - TO the right 2 or more lanes
- LR can be used to equalize pavement wear

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Truck Roadways and Truck Bypasses

- New Jersey Turnpike
- I-5S North of Los Angeles
- SR-60 in Los Angeles
- I-710 in Los Angeles

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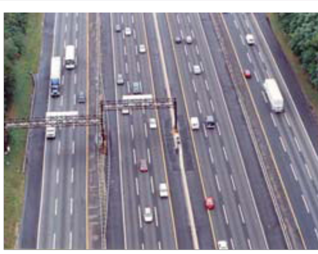
New Jersey Turnpike

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New Jersey Turnpike

- Dual-dual roadway (32 miles)
- Justification
  - To automate traffic control
  - Flexibility for maintenance and emergency management
- Separate access ramps

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New Jersey Turnpike

- Two to three outer lanes (32 miles)
- AADT 137,000 to 215,000 vpd
- Truck AADTT: 21,300 to 28,000
- Truck percent: 11.7 to 14.9%
- 62% of cars use inner roadway
- Flat grades throughout

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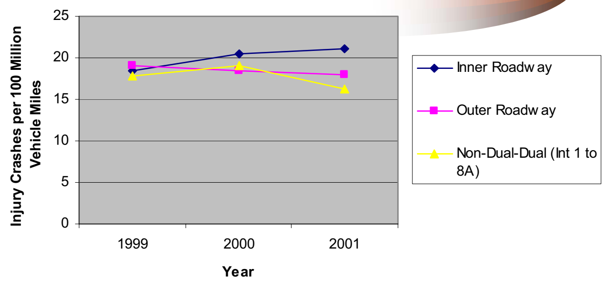
Injury Crash Rates



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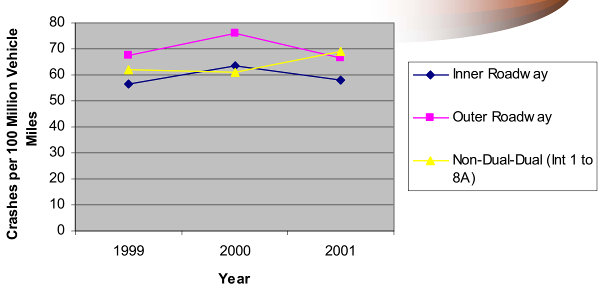
Total Crash Rates



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Cost Data

- $25-30M per mile (12 lanes)
- Interchanges
  - Urban/suburban: $100M
  - Rural: $45M

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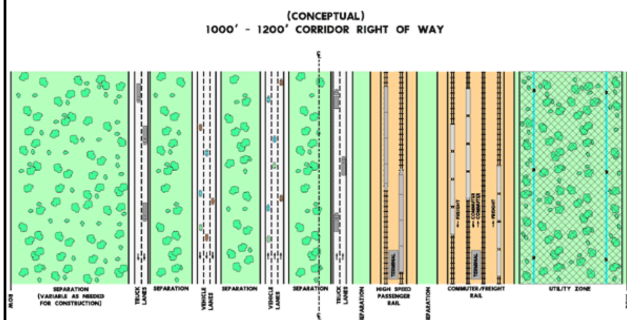
Trans Texas Corridor

- 1,200-ft ROW
- Truck lanes:
  - 13-ft lane width
  - 12-ft outside shoulder width
  - 4-ft inside shoulder
  - 80 mph on tollways
  - Significant load carrying capacity

Trans Texas Corridor ROW



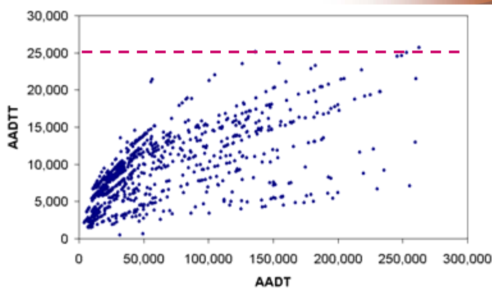
Thresholds for Truck Accommodation

- Battelle update of Exclusive Vehicle Facilities model
- Douglas criteria for truck facilities
- Truck definition
  - Battelle: Class 3 and up
  - Douglas: Class 6 and up

Battelle Study

Measure	Suggested Threshold	Remarks
AADT	≥ 100,000 vpd	Use in combination with AADTT percent
AADTT	≥ 25%	Use in combination with AADT
Level of Service (LOS)	E or lower – urban highways	To rank potential locations that satisfy traffic criteria
Truck-involved fatal crash rate	≥ national average (2.3 per 100 MVMT, 1999)	To rank potential locations that satisfy traffic criteria
Proximity to Intermodal Facilities/Processing Centers	≤ 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

AADTT vs. AADT in Texas (IH)



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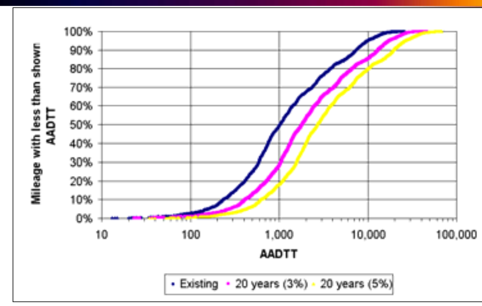
AADTT Cumulative Frequency



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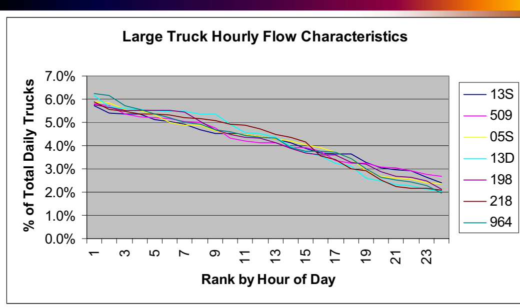
Large Truck Hourly Flow



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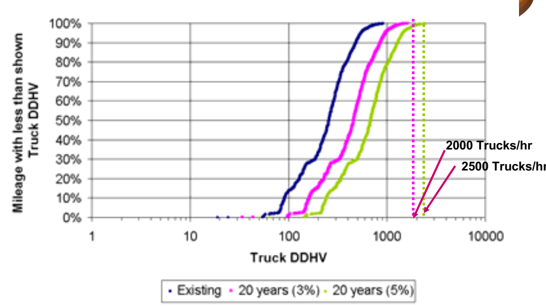
Peak-Hour Frequency Distribution (IH)



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Route-Miles and Truck-Miles Traveled

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%

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Truck Growth for Four Lanes

- Build truck roads based upon predicted reasonably full utilization of minimum two lanes
- Roadway capacity is based upon terrain
- Capacity of truck roadway is 1600 trucks/ln/hr in flat terrain and 800 in rolling terrain
- For flat terrain, the corresponding AADTT for four lanes is 106,600 trucks per day
- For rolling terrain, the corresponding AADTT for four lanes is 53,300 trucks per day
- Even on high-growth corridors in flat terrain in Texas, 100% of the highway mileage can handle this volume

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Threshold Summary

AADTT	Design Hour Volume	Truck Treatment
0 – 1000	0 – 60	Truck-friendly design
1000 – 5000	60 – 300	Some design for trucks
5000 – 25,000	300 – 1500	All design for trucks
Over 25,000	Over 1500	Two-lane truck roadway

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Designer Workshop Outline

- Introduction
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- ➡ Designing for trucks
- Wrap-up

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Current Design Adequacy

Design Element	Relevant?	Current Guidelines Adequate?
Stopping Sight Distance	Y	Y
Decision Sight Distance	Y	N
Passing Sight Distance	N	N
RR-Hwy Grade Crossing Sight Distance	Y	Y
Intersection Sight Distance	Y	Y
Curve Radius	Y	Y
Superelevation	Y	Y
Intersection & Channelization Geometrics	Y	N [a]
Pavement Widening	N	Y
Critical Length of Grade	Y	Y
Downgrades	N [b]	Y

[a] TRDM does not include WB-65

[b] Does not apply to controlled-access facilities in Texas

Current Design Adequacy

Cross-Section Elements	Relevant?	Current Guidelines Adequate?
Lane Width	Y	N
Shoulder Width & Composition	Y	N
Sideslopes & Drainage Features	Y	N [a]
Pavement Cross-Slope Breaks	Y	Y
Vertical Clearance	Y	Y
Longitudianl/Bridge Barrier	Y	N [a]
Passive Signs	Y	N
Curbs	Y	Y
Acceleration Lanes	Y	N
Intelligent Transportation Systems	Y	N

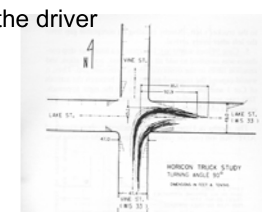
[a] NCHRP 22-12 will address design for trucks, but it is not finished

Decision Sight Distance

- Green Book criteria do not explicitly consider trucks
- Designing for trucks would not be cost-effective based on FHWA study

Intersection and Channelization Geometrics

- Add WB-65 vehicle to Texas Roadway Design Manual
- Consider the input of the driver



Use Truck-Friendly Design

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Monitor Vehicle Trends

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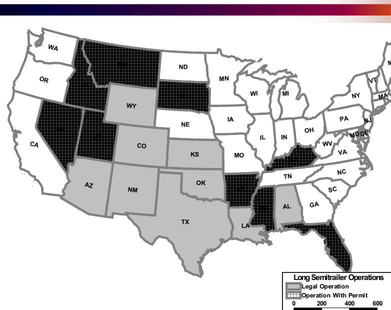
States Allowing Long Semitrailers



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Lane Width

- From an earlier TTI report:
  - Lane width: $W = W_v + 4.5$ ft
  - Where W_v = vehicle width = 8.5 ft
- Proposed lane width for Trans Texas Corridor is 13 ft

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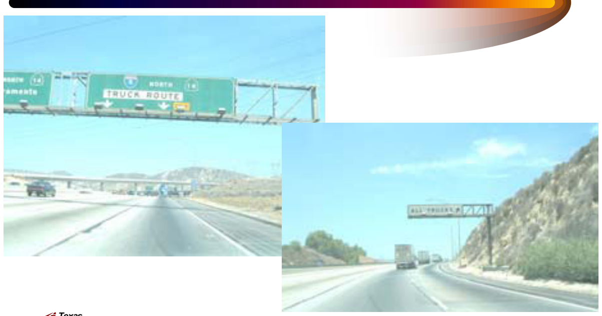
Shoulder Width

- Green Book for high-speed, high-volume highways
  - Right shoulder 10 ft, preferably 12 ft
  - Offset vertical elements 2 ft
- TxDOT Roadway Design Manual
  - Right shoulder 10 ft
- TTI recommends increasing to 12 ft

Roadside Safety Features

- Longitudinal/bridge barrier
- Sideslopes and drainage features
- Crash cushions
- NCHRP 22-12 will investigate

Static Signs



Static Signs

- Typical ground-mounted signs may be inadequate in high truck flows
- NJTA uses overhead guide signs at two miles, one mile, ¼ mile over both roadways
- Consider truck driver eye-height

Technology Solutions

- Components
  - Weigh-in-motion, classification devices, static signs, changeable message signs
- Warning systems
- On-board systems
  - AVL, AVI, on-board computers, weight sensors

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Weigh-in-Motion

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Weigh-in-Motion

- Critical in rollover warning applications
- Enforcement application
  - Overweight sorting system
  - High-speed roadway approaching station
  - Slow-speed ramp at enforcement site
- Types
  - Piezoelectric, bending plate, load cell

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Rollover Warning Systems

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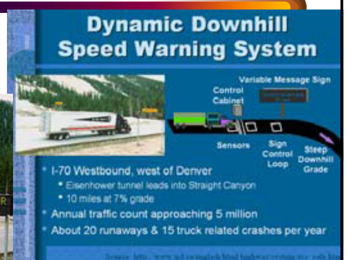
Downhill Warning Systems



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Changeable Message Signs

- Divert traffic from one roadway to another
- Integral warning system component

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Designer Workshop Outline

- Introduction
- Stakeholder input
- Texas truck corridors
- Truck accommodation strategies
- Designing for trucks
- ➡ Wrap-up

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Wrap-Up

- Design Element Summary
- Discussion

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Design Element Summary

Design Element	Design Year AADTT		
	1000 to 5000	5001 to 25,000	Over 25,000
Stopping Sight Distance	* [a]	* [a]	* [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

[a] Only a wording change in TRDM.

NA: Not applicable to high-volume, controlled-access roadways for trucks.

NC: No change from current design practice.

Texas Transportation Institute

Transportation Operations Group

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Design Element Summary

Design Element	Design Year AADTT		
	1000 to 5000	5001 to 25,000	Over 25,000
Curve R and Superelev.	NC	NC	NC
Int. and Channelization	NC	*	*
Pavement Widening	NC [a]	NC [a]	NC [a]
Critical Length of Grade	NC	NC	NC
Downgrades	NC	NC	NC

[a] For design speeds over 60 mph.

NC: No change from current design practice.

* Special design considerations for trucks.

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Design Element Summary

Design Element	Design Year AADTT		
	1000 to 5000	5001 to 25,000	Over 25,000
Lane Width	NC	NC	*
Shldr. Width and Comp.	NC	*	*
Sideslopes & Drainage	NC [b]	NC [b]	NC [b]
Pavement X-Slope Breaks	NC	NC	NC
Vertical Clearance	NC	NC	NC

NC: No change from current design practice.

* Special design considerations for trucks.

[b] Apply findings of NCHRP 22-12 as appropriate to Texas Roadways.

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Design Element Summary

Design Element	Design Year AADTT (DHV)		
	1000 to 5000	5001 to 25,000	Over 25,000
Traffic Barrier	NC	* [b]	* [b]
Passive Signs	NC	* [c]	* [c]
Curbs	NC	NC	NC
Acceleration Lanes	NC	*	*

NC: No change from current design practice.

[b] Apply findings of NCHRP 22-12 as appropriate to Texas Roadways.

[c] 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.

* Special design considerations for trucks.

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Project Personnel

- Rick Collins, PC
- Gus Lopez, PD
- Dan Middleton, RS
  - Cesar Quiroga
  - Debbie Jasek
  - Mark Wooldridge
- University of Manitoba
  - Alan Clayton
  - Kai Han
  - Scott Minty

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Contact Information

- Gus Lopez (Project Director)
  - TxDOT Pharr District
  - (956) 702-6100 glopez@dot.state.tx.us
- Dan Middleton (Research Supervisor)
  - Texas Transportation Institute
  - (979) 845-7196 d-middleton@tamu.edu

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