Impact of Left Lane Truck Restriction Strategies on Multilane Highways in Louisiana—A Literature Review

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SUMMARY OF FINDINGS

This study examined the impact of prohibiting certain trucks from using the far left lane on all multilane state and federal highways in Louisiana. It was conducted in response to Senate Concurrent Resolution 129 sponsored by Senator Erdey during the Regular Session of the state legislature in 2008. The findings are based on a review of current practice in the U.S., theoretical and empirical studies of truck lane restriction strategies reported in the literature, a public opinion survey, and a review of highway characteristics in Louisiana.

The study showed that while 70 to 80 percent of the public are in favor of truck lane restrictions, experience and theoretical studies indicate they are only beneficial in certain circumstances and can be harmful in others. Thus, a blanket application to all multilane highways is not appropriate; each site must be evaluated independently. The key findings of the study are:

- Truck lane restrictions should not be applied to all multilane highways; sites must be evaluated individually. These locations need to be strategic.
- Prohibiting truck traffic from the left lane in multilane highway sites and at certain condition specific locations can be successful in reducing accidents and improving traffic flow.
- Restricting trucks to the right-hand lane in urban settings does not work as it impedes entering and exiting on the interstate.
- Conditions most conducive to favorable application of truck lane restrictions are freeways with three or more lanes in each direction, interchanges spaced more than two miles apart with low ramp volumes, total traffic flows greater than 1300 vehicles per hour per lane, and truck percentages between 10 and 25 percent of the total traffic stream.
- The main benefit of truck lane restrictions applied in appropriate locations is improved safety and congestion management. While widely variable, a reduction in crash rate in the order of 10 percent can be achieved under favorable conditions with truck lane restrictions.
- Marginal benefits for non-trucks are increased speed and reduced delay, but this could be at the expense of reduced speed and increased delay for trucks. Change in average speed is typically in the order of 1 or 2 miles per hour.
- Concentrating trucks into certain lanes accelerates pavement damage in those lanes. For example, on a facility with four lanes in each direction, restricting vehicles from

using the left-most lane is estimated to reduce the life of the pavement by 7 percent (i.e., from 20 years to 18.6 years), and restricting vehicles from using the two left-most lanes would reduce the life of the pavement by 34 percent, or from 20 years to 13.6 years.

- Safety is lowered the greater the differential in speed between non-trucks and trucks; therefore, uniform speed is preferential.

ABSTRACT

Truck lane restriction strategies (TLRS) are a means of managing truck traffic on highways by prohibiting trucks from using certain lanes to minimize interaction between trucks and other vehicles. The purpose of this study is to review the literature with respect to past studies of truck lane restrictions in the United States with the intention of determining whether applying them to access-controlled and non access-controlled multilane highways in Louisiana would bring any safety or operational benefits. A literature review, an opinion survey among motorists in Louisiana, and a survey of practice among state Departments of Transportation (DOTs) was conducted to establish an information base on which to base a decision.

From the results of the investigation, it is recommended that, in general, TLRS only be applied to controlled access facilities with three or more lanes in each direction, unless an engineering study can justify the application of TLRS to a particular facility. It is not recommended that truck lane restrictions be used on non controlled access highways. When applied, truck lane restrictions should prohibit trucks from using left lanes rather than restrict trucks to use right lanes only

The major advantage of TLRS appears to be in their general contribution toward improved safety, while their impact on speed, travel time, flow, speed differential, impedance, and lane changing is marginal. Some of the significant costs of introducing TLRS involve pavement damage if truck lane restrictions concentrate trucks on a limited set of lanes and the difficulty of entering a freeway where there are three or fewer lanes in each direction, high traffic volumes, and a high percentage of trucks in the traffic stream.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance provided by the Louisiana Department of Transportation (LADOTD) in allowing questions to be added to their public opinion survey and to Dr. Sharon Parsons of Southern University in conducting the survey and analyzing the results. We also acknowledge the assistance provided by the Project Review Committee in guiding the study and reviewing the report. Notwithstanding this assistance, the authors assume full and complete responsibility for the content of the report.

IMPLEMENTATION STATEMENT

This study was conducted to provide input to policy formulation on the use of truck lane restriction strategies on multilane highways in Louisiana. The information was collected at the request of the Louisiana legislature through the LADOTD. Implementation of the findings will be the prerogative of the Louisiana legislature and the LADOTD.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The growth of the United States economy is dependent on the efficiency of the transportation sector of which the trucking industry plays an important role. By 2020, it is estimated that the U.S. transportation system will carry 23 billion tons of cargo (FHWA, 2008). An increase in the number of trucks on the transportation system means more interaction between trucks and other vehicles. A potential means of reducing interaction between trucks and cars is restricting trucks from using certain lanes on multilane highways (FHWA, 1986). These so-called Truck Lane Restriction Strategies (TLRS) have been applied at individual locations in several states as reported in greater detail later in the report.

The basic idea behind TLRS is to prohibit trucks of particular configurations from using a particular lane, or lanes, for a period of time which may vary from certain hours during the day to continuously. Lane restrictions can be implemented statewide or for specific sections of highway. Truck lane restriction strategies can restrict trucks from using certain lanes or restrict trucks to certain lanes. The most common restriction is to prohibit trucks from using the left-most lane, or the two left-most lanes, depending on the number of lanes in each direction (see Figure 1).

Some factors to consider before implementing TLRS are:

1. Should it be site specific or statewide?
2. Which type of facility (access-controlled facilities vs. non access-controlled facilities and the number of lanes in each direction) should be considered for this strategy?
3. Is a left lane or right lane restriction more beneficial?
4. Should a truck lane restriction be in effect continuously or for certain periods during the day?
5. Do lane restrictions affect access and egress from facilities?
6. Do lane restrictions depend on the traffic volume of the facility?
7. Do lane restrictions affect pavement life?

This study looks for answers to these questions in the literature. The literature reports on both empirical analyses of systems in operation in the United States as well as on the findings of simulation studies investigating the impact of truck lane restriction strategies on a variety of traffic and safety features.

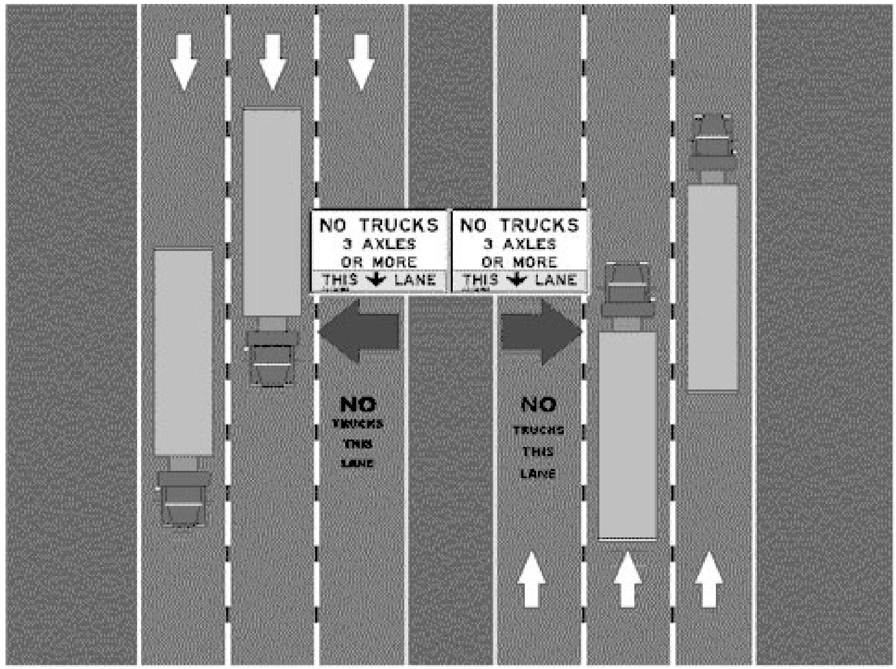
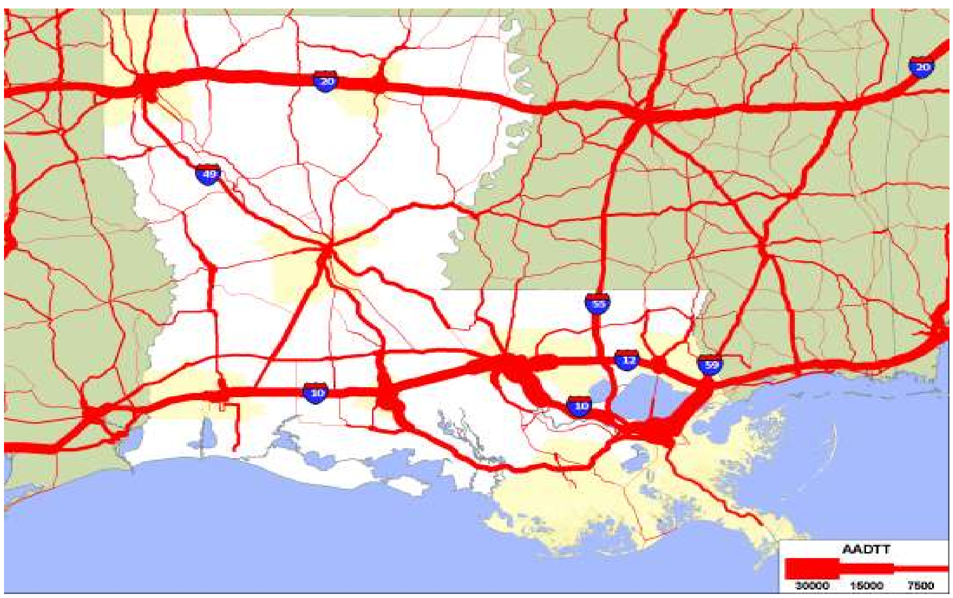


Figure 1
Left lane truck restriction on a three lane highway
(Harwood et al., 2003)

Truck Traffic in Louisiana

The Federal Highway Administration (FHWA) predicts a substantial growth in truck traffic on Interstate highways in Louisiana between 1998 and 2020 (see Figure 2) (FHWA, 2008). The FHWA predicts that truck tonnage will increase by 87 percent between 1998 and 2020 (FHWA, 2008). The FHWA document citing these statistics is attached as Appendix 1 because the URL from which it was obtained has subsequently been discontinued.

(a)



(b)

Figure 2
Estimated average annual daily truck traffic in Louisiana in (a) 1998 (b) 2020 (FHWA, 2008)

The axle weight limit for commercial vehicles on Interstate highways in Louisiana is as shown below (DOTD, 2008):

Single Axle	:	20,000 pounds
Tandem Axle	:	34,000 pounds
Tridum Axle	:	42,000 pounds
Quadrum Axle	:	50,000 pounds

On non-interstate highways, axle variance of 2,000 pounds for a single axle and 3,000 pounds for three or more axles are allowed. For vehicles with tandem axles carrying forest products in their natural state, 40,000 pound axle loads are allowed.

The legal gross weight allowed for the sum of axle weights on a vehicle or combination of vehicles (except tridum and quadrum axles) is 80,000 pounds. For tridum and quadrum axles, the legal gross weight allowed is 83,400 pounds on interstate highways and 88,000 pounds on non-interstate highways (DOTD, 2008). The DOTD issues oversize/overweight permits on a case-by-case basis for vehicles or loads that cannot conform to the statutory limitations above.

The vehicle classification system used in Louisiana is shown in Figure 3. The vehicles considered for inclusion in truck lane restriction strategies in Louisiana are vehicle configurations P, Q, and R.

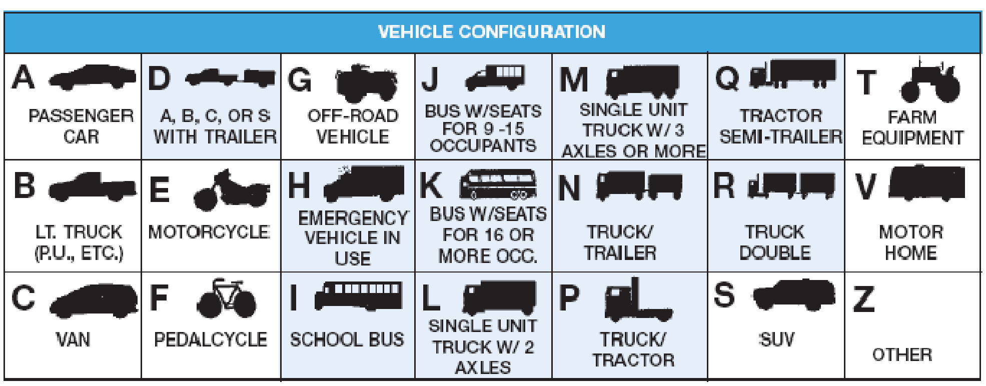


Figure 3
Vehicle classification in Louisiana
(LADOTD)

PROBLEM STATEMENT AND OBJECTIVES

State Senator Dale Erdey initiated a resolution in the 2008 session of the Louisiana Senate requesting the Secretary of the Louisiana Department of Transportation and Development to study the impact of prohibiting certain trucks from using the far left lane on all multilane state and federal highways in Louisiana. It was requested that the study include an assessment of the number of crashes that may be prevented by such action and the public perception of truck lane prohibition.

The impact of truck lane restrictions has been assessed in this study by conducting a comprehensive literature review of similar studies conducted in the United States in the past. The focus of the study was to identify the impact of truck lane restriction strategies on:

- Safety
- Vehicular flow and speed
- Speed differential among vehicles
- Lane changing behavior
- Passenger car impedance in the traffic stream
- Vehicular access and egress on controlled access highways
- Pavement damage
- Truck compliance

In addition, the opinions of motorists were obtained from surveys reported in the literature as well as from survey questions added to the LADOTD's Public Opinion Survey conducted in December 2008.

An assumption made in this study is that the findings from other studies are generally applicable in Louisiana. This is not to ignore the unique features of the state but the review has drawn from studies throughout the U.S., and general consensus among these studies is at least indicative of what would be true in Louisiana as well. In addition, many of the investigations have relied on simulation that describes conditions purely in terms of facility characteristics, such as number of lanes in one direction, access control, volume, speed, truck percentage, and grade. Thus, these theoretical analyses are considered as applicable to conditions in Louisiana as elsewhere.

SCOPE

This study is limited to consideration of lane restriction strategies for trucks only. Other truck management strategies such as route restrictions, time restrictions, weight restrictions, and so forth were not considered. The investigation includes consideration of restrictions from the left lane, or restriction to either the center or right lane on multilane highways. In certain cases, truck restriction from multiple lanes is considered. The literature review is limited to studies within the United States and to capturing truck lane restriction strategies that are most relevant to Louisiana. The investigation includes a survey of motorist opinions and a survey of practice among state DOTs.

LITERATURE REVIEW

From a national survey conducted in 1986 by the FHWA to evaluate the benefits of truck lane restrictions, it was found that 26 states had implemented TLRS at one or more locations in their area but most implemented them for different reasons (FHWA, 1986). Fourteen states believed lane restrictions helped improve highway operations; eight states implemented them to reduce crashes; seven states used TLRS to address pavement wear and tear; and five states used TLRS for better safety in work zones (FHWA, 1986). From the literature review, it is clear that while TLRS have a number of benefits, there are also negative aspects that need to be considered (FDOT, 1982; Moses, 2007). The positive and negative aspects of TLRS are addressed impact by impact in the sections below.

Impact of Truck Lane Restriction Strategies on Throughput

Prohibiting trucks from using certain lanes on multilane highways gives the opportunity for other vehicles to occupy and attain higher travel speeds on these restricted lanes without any interference from heavy vehicles. This can possibly lead to improved traffic flow, thereby increasing the throughput (i.e., traffic flow).

Gan and Jo (2003) developed operational performance models to study truck lane restriction policies for freeways. VISSIM, a popular simulation package, was used to develop a model to represent maximum service flow rate and minimum speed values as close to Highway Capacity Manual values as possible. The model was then used to assess the impact of prohibiting trucks from using the left most lanes on freeway sections with three, four, or five lanes in one direction. The input to the model was different combinations of number of lanes, lane restrictions, free flow speed, traffic volume, truck percentage, interchange density, and ramp volume. Table 1 shows the different input values considered for the simulation.

Table 1
Input values for Gan and Jo study

Independent Variable	Input values
Prohibiting trucks from using certain lanes	3 alternatives (no prohibition, one left-most lane prohibited, and two left-most lane prohibited to trucks) for facilities with 3 lanes in one direction, and 4 alternatives (no prohibition, one left-most lane, two left-most lanes, and three left-most lanes prohibited to trucks) for facilities with 4 lanes in one direction, and 5 alternatives (no prohibition, one left-most lane, two left-most lanes, three left-most lanes, and four left-most lanes prohibited to trucks for facilities with 5 lanes in one direction.
Number of lanes per direction	3, 4, 5
Free-flow speed (miles per hour)	55, 65, 75
Traffic flow per lane (vehicles per hour per lane)	100, 600, 1200, 1800, 2000, 2200, 2400
Truck percentage	0%, 5%, 15%, 25%
Interchange density (number/mile)	0, 0.5, 1.0, 2.0
Ramp Volume (vehicle per hour)	0, 100, 500, 1000, 1500

Throughput on three-, four-, and five-lane roadways was found to increase under low truck percentages and increased truck lane restrictions, while the opposite was true under high truck percentages. It was found that when ramp volumes increased to 1000 vehicles per hour (vph) or more, truck percentages were greater than 15 percent and interchange density was greater than two per mile; truck lane restrictions reduced throughput. The study found that TLRS increased throughput only when the number of lanes restricted were limited and truck percentages were less than 25 percent. Restricting trucks from using the two left-most lanes was recommended for four-lane or five-lane highways. For three-lane highways, it was recommended that trucks be restricted from using one left-most lane only.

Yang and Regan (2007) also studied the impact of left lane truck prohibition on urban freeways using simulation models. In this study, a pair-wise comparison of average speed, frequency of lane changes, and total volume for different values of maximum service flow rate and truck percentages were estimated. The simulation was conducted on a hypothetical five mile section having one on ramp and one off ramp and four through lanes in one direction in Case A and five through lanes in one direction in Case B (see Figure 1). Three scenarios were considered: (1) the current condition – with no truck lane restrictions, (2) alternative 1 with the left-most lane restricted, and (3) alternative 2 with the two left-most lanes restricted. Truck percentages between 5 percent and 20 percent were considered. Pair-wise comparison results indicated an increase in throughput due to truck lane prohibition provided a flow rate greater than 1300 vehicles per hour per lane (vphpl) and at least 10 percent truck traffic was present in the traffic stream. This simulation study used variable flow rates but a fixed ramp volume of 500 vehicles per hour.

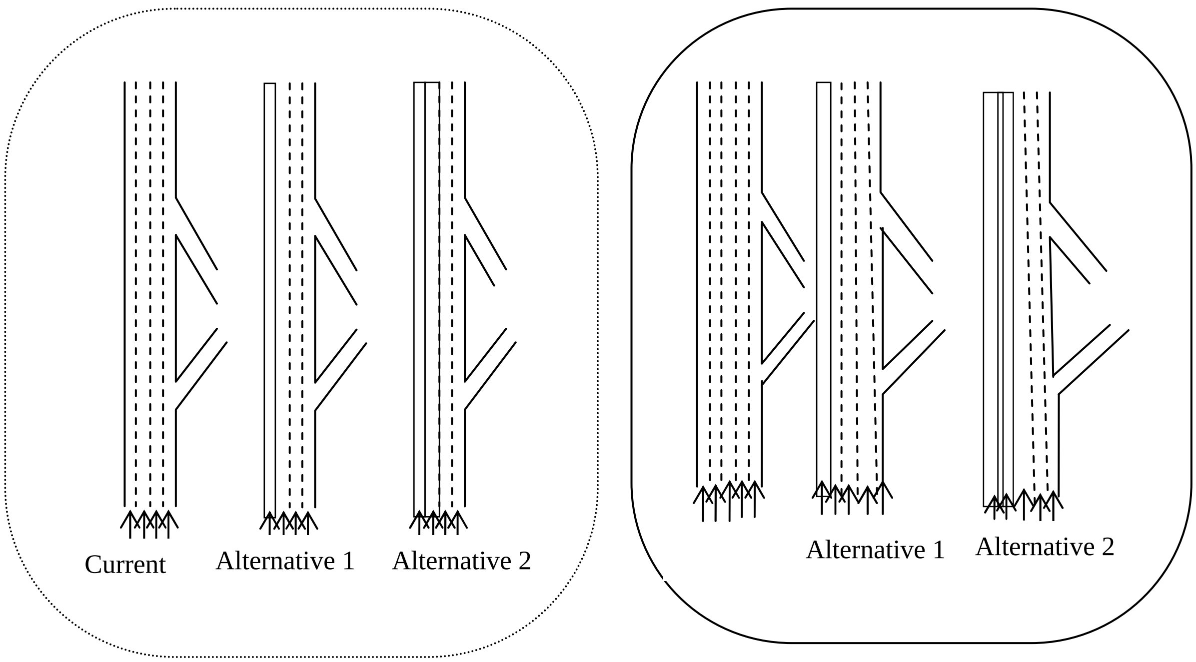


Figure 4
Hypothetical truck lane restriction strategies

Impact of Truck Lane Restriction Strategy on Speed

Prohibiting trucks from using one or more lanes on a multilane highway allows passenger cars to travel on these restricted lanes without any interference from heavy vehicles. This is expected to increase the average speed of passenger cars. In the simulation study done by Gan and Jo (2003), the average speed was reduced under high truck percentages and an increased number of restricted lanes. Ramp volume and interchange density also had a negative effect on speed. On the other hand, TLRS increased average speed under low truck percentages, i.e., less than 25 percent, low interchange density, and low ramp volumes except in the case of numerous restricted lanes.

In their simulation study, Yang and Regan (2007) showed a significant difference in average speed for all scenarios for both Case A and B shown in Figure 4. An increase in average speed was estimated for both alternative 1 and 2 with alternative 2 having a greater increase. The link speeds measured for alternative 2 (two left-most lanes restricted) showed a 19 percent increase from the existing condition and a 11 percent increase from that in alternative 1 (one left-most lane restricted).

Moses (2007) conducted a simulation study using VISSIM in which trucks were prohibited from using the left lane on an 83-mile stretch of Interstate 95 in South Florida with three lanes in each direction. The I-95 corridor was chosen because it had both High Occupancy Vehicle (HOV) lanes and truck lane restrictions implemented either independently or in combination with HOV lanes, making it possible to study the effect of each in detail. In addition to this, the corridor had closely spaced interchanges, a high percentage of trucks travelling through the corridor, and was heavily congested. Sections with an HOV lane, those with an HOV lane and adjacent truck lane restrictions, and those with left lane only truck lane restrictions were the three lane configurations analyzed on the I-95. Three types of truck restrictions (trucks prohibited from using the left lane, trucks prohibited from using the middle lane, and trucks prohibited from using the right lane) were modeled with hypothetical restrictions on the middle lane and right lane, while the left lane restriction operation was observed in segments 2 and 3 on the I-95 as shown in Table 2.

Table 2
Study corridor characteristics in Moses study

	Segment 1	Segment 2	Segment 3
	HOV Lane	HOV Lane Truck Restricted Lane	Truck Restricted Lane
Location	MP 5.48 – MP 17	MP 17- MP 61	MP 61- MP 88.75
Length (miles)	11.52	44.00	27.75
Ave. no. of through lanes	4	5	3
Ave. no. of ramp lanes	1	1	1
Speed Limit	55	65	70
Interchanges per mile	0.83	0.66	0.52
Average AADT	283,300	221,740	120,500
Ave. truck percentage	4.2	6.36	9.08

The VISSIM model was calibrated to simulate the existing traffic conditions correctly using field data. Truck traffic was simulated in 5 percent increments up to 30 percent. When speeds during peak hours were compared for the three segments for left lane restrictions, speeds were found to decrease from the leftmost lane to the rightmost lane for both north and southbound traffic. Speeds also decreased with an increase in truck percentages. For off peak hours, there was not much difference in speeds regardless of the restrictions. For the center lane restriction during peak hours, segment 1 and 2 showed a significant decrease in speeds in both directions with HOV having the highest speed followed by the center lane and then the outside lane. In segment 3, the center lane had the highest speed, then the left lane, and finally the right lane. For right lane restrictions, no significant change in speeds occurred. Also, the speeds of vehicles were considerably slower for the right lane restriction relative to the others due to fact that during peak hours it might be difficult for trucks to find sufficient gaps to change lanes. This might reduce speeds in right lanes and also hinder highway entry/exit of other vehicles at interchanges. It was found that the center lane and right lane restrictions caused spill back onto arterial roadways at interchanges due to the formation of excessive queues as entering trucks waited for long periods to get a gap to move from the restricted lane. These restrictions also caused freeway traffic flow disruption due to the queues developed at the upstream of interchanges during peak hours. Exit ramps did not generate these conditions; they were limited to entrance ramps.

Mannering et al. (1993) evaluated the impact of left lane truck restriction on safety, operation, and pavement performance of highways in the Puget Sound region. Four sites were considered as shown in Table 3 below. The study consisted of an in-depth analysis about the effect of lane restrictions on Site A followed by a site comparison study between all the four sites to evaluate whether the study results at Site A were applicable at other sites.

Table 3
Characteristics of study sites in Mannering et al. study

	Site A I-5 SB@ South Center Hill	**Site B SR 520 WB Redmond to Bellevue**	**Site C I-5 SB Puyallup River Bridge to Tacoma Mall**	**Site D I-5 SB @ 185th Street (control site)**
Grade	+ 4.0%	+ 5.1%	+ 3.0%	Negligible
Number of lanes	4 + HOV lane	3	4	3 + HOV lane
Lane width (ft.)	12	12	12	12
Restriction length (mi)	3	1	1.4	None
Number of exits	2	1	1	1
Number of entrances	1	0	1	0
Posted speed	55 mph	55 mph	55 mph	55 mph
Number of signs	4	3	2	None

Speed, traffic counts, vehicle types by lane, and accident data for Sites A-D were collected. Before and after restriction data could only be collected for Site A. For all the other sites, only after restriction data could be obtained. Lanes were numbered from the right lane toward the left lane in all the sites, i.e., the inside lane was numbered 4 and the outside lane 1. Manual traffic counts, together with videotaped data, were used at other sites to calculate length of segment under study, speed differential among lanes, average speed by vehicle type, time gaps between vehicle types, platoon length, and truck impedance time. Accident data were also collected. The Puget Sound area is mountainous and conditions there in 1993 are different to current conditions in Louisiana. However, the study illustrates how site features influence the impact of TLRS, which is of general interest.

In depth analysis at Site A illustrated that average hourly speed distributions for trucks and non-trucks showed an increase in average speeds from the outside lane to inside lane. Trucks had lower average speeds than non-trucks in all the lanes but did not seem to impede the flow of non-trucks. Since similar trends were observed in the "before" period, no conclusions were made. A statistically significant increase in average speed was obtained for both trucks and non-trucks after a lane restriction. A site comparison study revealed inconsistency in the average speed of trucks and non-trucks depending on the site characteristics, degree and length of grade, and location of exits/entrances. For instance, truck speeds on lane 4 (inside lane) were higher at the Tacoma site which had a lower grade and fewer exits than the South Center Hill site showing the effect of lane restriction strategies can vary depending on the characteristics of the site.

Liu and Garber (2007) studied the effect of truck lane restrictions on lane changes, average speed, speed distribution, volume distribution, and conflicts using PARAMICS, another popular software package. About 14,400 simulation scenarios with various traffic conditions, geometric conditions, and lane restriction strategies were analyzed with the simulation software. The Latin Hypercube Design (LHD) procedure, which reduces the various parameter combinations to a reasonable level but still is valid for the parameter surface, was used in this simulation. The parameter values which would represent the real data as closely as possible was chosen after 1000 simulation runs. The values of independent variables considered in this study are given in Table 4.

Table 4
Input values for simulation scenarios in Liu and Garber study

Independent variable	Input values
Truck lane restriction strategies	R 0/3, R 1/3 , R 2/3 R 0/4, R 1/4, R 2/4, R 3/4 R 0/5, R 1/5, R 2/5, R 3/5, R 4/5
Grade	0 %, 1 %, 3 %, 5 %
Interchange density (no/mile)	0.25, 0.50, 0.75, 1.00
Free flow speed (mph)	55, 65, 75
Main line volume (vphpl)	100, 500, 1000, 1500, 2000
Ramp volume (vphpl)	100, 500, 1000, 1500, 2000
Truck percentage	5 %, 15 %, 25 %, 40 %, 50 %

Where R *n/m* = Restriction on lane *n* given there are *m* lanes in one direction.

A hypothetical five mile freeway section was coded and Table 4's left lane restriction strategies were used for simulation. The PARAMICS model was embedded with the Application Program Interface to collect data on speed, density, lane changing, rear-end, and merging conflicts. Study results indicated a decrease in average speed on restricted lanes with grade, although, the decrease was less pronounced on restricted lanes than unrestricted lanes. Increase in both volumes and truck percentage lead to a decrease in average speed on both lanes but the effect was less on unrestricted lanes. Increase in interchange density also seemed to decrease average speed. It was observed that when demand volumes and truck percentages were low, the average speed on restricted lanes and unrestricted lanes decreased with an increase in the number of restricted lanes. However, when demand volume was more than 1000 vehicles per hour per lane (vphpl) and truck percentages were more than 25 percent, the average speed on restricted lanes increased with the number of restricted lanes, while that on unrestricted lanes decreased.

A North Central Texas Council of Governments (NCTCOG) study (Sims and Royester, 2006) investigated left lane restriction on two existing facilities in four phases. The detail of the facility on which the study was conducted is given in Table 5.

Table 5
Site characteristics of NCTCOG study

Location	Number of lanes	Stretch considered for study	Details of site
I-20	Four lanes in each direction	From I-45 to Cedar Ridge Road	AADT in 2005: 143,000 Peak hour LOS was C-E High volume of trucks. Presence of exits.
I-30	Four lanes in each direction	From Collins Street in Arlington to Hulen Street in Fort Worth	AADT in 2005: 174,000 Peak hour LOS was A-E Moderate truck traffic Presence of entry/exit points and also near to Central Business District.

Four phases were considered:

1. Base conditions—standard enforcement without restrictions August–September 2005
2. Increased Enforcement—included increased police patrols and commercial truck inspection units October 2005

3. Truck restrictions with increased enforcement—included left lane restriction signs in the corridors in addition to the increased police patrol and inspection units and media coverage about the restrictions November and December 2005
4. Truck restrictions with standard enforcement January 2006

To study the change in average speeds, speed data was collected in both locations 24 hours a day, 7 days a week, at 15-minute intervals for peak hours, and at one-hour intervals for off-peak periods. This data was then averaged for the period 6:00 a.m. to 8:00 p.m. each day. Table 6 shows the difference in average speed observed between phases at both sites after the imposition of truck lane restrictions with the standard level of enforcement in effect.

Table 6
Average speed before and after imposition of truck lane restrictions
(Sims and Royester, 2006)

I-20	Lane	Phase 1 Average speed (mph)	Phase 4 Average speed (mph)
Bonnie view	Left	73	74
	Left middle	68	70
	Right middle	65	65
	Right	62	63
Duncanville	Left	75	76
	Left middle	70	70
	Right middle	67	67
	Right	64	65
Hampton	Left	65	65
	Left middle	59	61
	Right middle	51	52
	Right	53	54
Houston school	Left	75	76
	Left middle	69	70
	Right middle	65	64
	Right	62	63

(continued)

I-30	Lane	Phase 1 Average speed (mph)	Phase 4 Average speed (mph)
Beach street	Left	73	73
	Left middle	70	70
	Right middle	66	66
	Right	62	62
Loop 820	Left	71	72
	Left middle	72	72
	Middle	68	68
	Right middle	66	65
	Right	60	58
Fielder	Left	71	70
	Middle	66	66
	Right	64	63
Morrison	Left	69	73
	Middle	64	67
	Right	59	62

Table 7 reports the average difference in speed between lanes at all sites on each facility where the right middle, left middle, and middle lanes were averaged and reported as middle lane speed.

Table 7
Average speed difference before and after truck lane restrictions
(Sims and Royester, 2006)

I-20			
Lane	**Phase 1 average speed (mph)**	**Phase 4 average speed (mph)**	**Difference**
Left	72	73	0.8
Middle	65	65	0.6
Right	60	61	1
I-30			
Lane	**Phase 1 average speed (mph)**	**Phase 4 average speed (mph)**	**Difference**
Left	71	72	1
Middle	67	67	0.55
Right	61	61	0

Average speed data for both corridors were aggregated to further study the impact on average speed. The composite speed differential is shown in Table 8. The results clearly indicate the increase in average speed on the restricted left lane (i.e., the lane trucks are prohibited from using).

Table 8
Composite speed differential due to truck lane restrictions
(Sims and Royester, 2006)

Lane	Overall increase in speeds from Phase 1 to Phase 4 (mph)	Overall variation from the middle lane speed in Phase 4
Left	+ 0.9	+6.125 mph faster than the middle lane(s)
Middle	+ 0.6	N/A
Right	+ 0.5	-5.00 mph slower than the middle lane(s)

Impact of Truck Lane Restriction Strategies on Travel Time

Given the general increase in speed experienced by passenger cars when TLRS are instituted, passenger cars generally experience decreased travel time. However, the converse may be true for trucks as they are restricted to certain lanes. Considering that shipper and carrier transit time is estimated to cost between $25 and $200 per hour depending on the product being transported (FHWA, 2006) and that this cost could increase by 50-250 percent in the case of unexpected delays (Jones et. al, 2006), truck travel time is an important issue.

A study conducted by Moses (2007) estimated the travel time for different vehicles on three segments with different restrictions. He found that during peak hour traffic conditions, HOV lanes and car lanes experienced better travel times than the lanes to which trucks were restricted to. During off peak hours (9:00 a.m. to 4:00 p.m. and 8:00 p.m. to 9:00 p.m.) prohibition of trucks from the left lane showed no particular difference in travel time between HOV vehicles, general cars, and trucks. When a similar lane restriction was applied on the center lane during peak hours, travel times increased for all vehicle types. Simulation of right lane restrictions during peak hours also showed an increase in travel time for all vehicle types.

Mussa and Price (2004) conducted a study to evaluate the benefits of TLRS on the inside lane (i.e., the left-most lane) of a 54-mile corridor of I-75 freeway in North Florida from milepost 374 to 428 (see Figure 5). Ten interchanges exist on this section of I-75. Level of service "B" traffic was observed during the observation period.

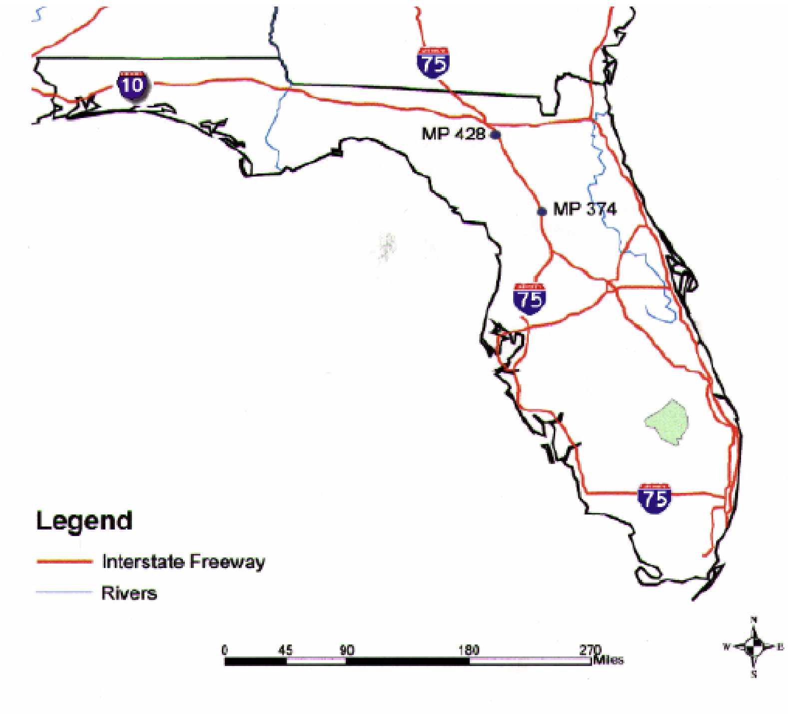


Figure 5
Study corridor for Mussa and Price truck lane restriction evaluation study

Simulation was conducted on the selected section of the I-75 corridor using a CORSIM (Corridor Simulation) model calibrated to reproduce observed travel time, speed, traffic distributions, and so forth. Different scenarios were evaluated based on vehicle type distribution, traffic volume, time of day and other factors. Results indicated that regardless of time of day, no significant difference in travel time and travel delay occurred between restricted and unrestricted conditions.

Yang and Regan (2007) studied the impact of truck lane restrictions on truck travel time and travel time variance. Travel time variance was considered important because of its impact on the reliability of travel time estimates for the trucking industry. The results showed an increase in truck travel time but a lower travel time variance when the two left-most lanes on a four- and five-lane facility in one direction are restricted from use by trucks (see alternative 2 in Figure 4).

A study by Cate and Urbanik (2004) investigated the impact of left lane truck lane restrictions on a freeway section with three or more lanes in one direction in Knoxville, Tennessee using VISSIM. Real traffic data was collected using Remote Traffic Microwave Sensors (RTMS) radar units on westbound Interstate 40/75. Real ramp data was also collected for simulation purposes. The simulation was conducted for different volumes, truck percentages, entering/exiting ramp volumes, etc. A total of thirteen scenarios were developed and two one-hour simulation runs were conducted for each scenario.

The first simulation was run without restrictions and the second simulation considered a far left lane restriction only. Speed range values of 55-85 mph were considered for passenger cars and 60-80 mph for large trucks. The scenarios were run with and without ramps. For without ramp values, a continuous stretch of five-mile roadway with three lanes in one direction was considered. For the case with ramps, an entry ramp was constructed at the two mile mark which joined to the roadway using a 0.25-mile long acceleration lane and an exit ramp was constructed at the three mile mark. No weaving sections were considered.

To quantify the effect of lane restriction, a before and after study using performance measures, such as vehicle density, travel time for vehicle types and routes, and the number of lane changes and speed differential between cars and trucks, was conducted. The values of some variables were adjusted to simulate real world traffic conditions as closely as possible.

Travel times estimated for the given scenarios showed that with an increase in grade, a left lane truck prohibition resulted in saving travel time for passenger cars and slightly increasing travel time for trucks. The travel time savings for passenger cars at level grades was minimal. Table 9 shows the values of different variables considered for the thirteen scenarios that were modeled.

Table 9
Summary of scenarios in Cate and Urbanik study

Scenario	Volume	% Trucks	Grade	Ramps?
1	High	Average	0%	No
2	Low	Average	0%	No
3	Average	Average	0%	No
4	Average	Low	0%	No
5	Average	High	0%	No
6	Average	Average	2%	No
7	Average	Average	4%	No
8*	Average	Average	0%	Yes
9	Average	High	4%	No
10	Average	Low	4%	No
11	Average	Average	0%	Yes
12	Average	High	0%	Yes
13	High	High	0%	Yes

*indicates the default VISSIM setting for lane changing behavior.

Impact on Lane Changes

Intuitively, truck lane restrictions would seem associated with increased lane changes as passenger vehicles change lanes to avoid trucks in the restricted lane. However, in the simulation study done by Mussa and Price on a 54-mile corridor on the three-lane northbound section of I-75 in Florida, a left lane restriction resulted in reduced lane changes from what it would be without truck lane restrictions.

In the simulation study done by Moses (2007) on an 83-mile corridor on the I-95 in Florida, the numbers of lane changes were modeled. The results showed that the number of lane changes increased with an increase in truck percentage, interchange density, and traffic volume. Right lane restrictions were found to increase conflicts at interchanges. The most beneficial conditions in terms of lane changes were found to be left lane truck lane restrictions on freeways with three or more lanes in one direction carrying less than 25 percent truck traffic and having interchange spacing of at least 1.5 miles.

Gan and Jo (2003) calculated lane changes per vehicle by averaging total lane changes by total volume. They found that lane changes per vehicle decreased significantly with the imposition of truck lane restriction. The greater the number of restricted lanes, the fewer the number of lane changes per vehicle. The lane changes were found to be statistically significantly lower in a restricted situation than in an unrestricted situation. Ramp volume and interchange density did not affect lane changes in the restricted case. Moreover, it was found when the flow rate was high, less lane changes occurred.

Hoel and Peek (1999) conducted a simulation study involving both right lane and left lane restrictions in Virginia. The variables considered in the simulation were uphill grades (0%, 2%, and 4%), volume distribution for left, center and right lanes respectively (33%-33%-34%, 30%-35%-35%, 25%-50%-25%, and 25%-38%-27%), traffic volumes (1000-3000 vph), percentage of trucks (10-40%) and lane restrictions (yes/no). The combination of various grades, restrictions, and volume distributions gave twenty four scenarios. For scenarios with similar characteristics in grades, distribution, and percentage of trucks but different restriction criteria, statistical tests were done to find the effect of these variables on density, lane changes, and speed differential. The scenario analysis was conducted on a hypothetical three-mile section with three through lanes in each direction using FRESIM. The scenarios simulated were leftmost lane restriction for the six-lane freeways.

Lane changes were found to significantly increase with left lane restrictions with the highest value at zero percent grades. Lane changes decreased with an increase in grade. The scenarios were applied for different volumes and truck percentages on the following three sites: (1) 10.15 km study site in Buchanan (no ramps), (2) 11.12 km site in Christiansburg, and (3) 10.2 km site in Wytheville. Truck percentages at these sites varied from 20–40 percent. Traffic data was collected at the sites using loop detectors. The volume of traffic in each of these sites were found for the current year, year 2010, and 2020 using a future volume growth rate. The purpose of this was to identify the effect of restrictions in the future. FRESIM simulation of one hour of operation was conducted at each of these sites using these volumes. The difference in simulated lane changes at three sites were compared for no restrictions with left lane and right lane restrictions. Worst case volume distribution scenarios were applied.

Simulation results showed an increase in lane changes in Buchanan and Christiansburg with a right lane restriction. In Wytheville site with entry/exit ramps, lane changes increased with left lane restriction. So site characteristics were considered to be important while considering truck lane restrictions. Left lane restrictions on steep grades decreases density and lane changes. And so was recommended for grades of 4 percent or higher.

Liu and Garber (2007) studied the effect of truck lane restrictions on lane changes using PARAMICS software. A total of 14,400 simulation scenarios with various traffic conditions, geometric arrangements, and lane restriction strategies were run using the software. A hypothetical five-mile freeway section was coded, and a left lane restriction was considered for the study. Two vehicle types considered were passenger cars and trucks. It was found that lane changes increased until truck percentages were below 25 percent after which lane changes decreased.

Yang and Regan (2007) found similar results for lane changing behavior in their study. Frequency of lane changes measured for Case A and Case B (see Figure 4) was found to be dependent on geometric conditions. It was observed that all traffic flow components seemed to change when volume reached 1300 vphpl and truck percentages were 10 percent. However, the results did not show any significant change in frequency of lane changes between the alternative conditions and existing conditions.

Impact of Truck Lane Restrictions on Speed Differential

This section deals with the speed differential between passenger cars and trucks resulting from the implementation of a truck lane restriction. A number of studies have been carried out on the safety impact of speed differentials (Garber and Gadiraju, 1988; TRB 1998; Garber et al., 2003; Garber and Gadiraju, 1992), and it is generally accepted that a speed differential has an adverse effect on safety (Garber and Gadiraju, 1992).

Garber and Gadiraju (1991) studied sites in California, Michigan, Maryland, Virginia, and West Virginia where some sites had a uniform speed limit of 55 or 65 mph and others had a differential speed limit of 65 mph for passenger cars and 55 mph for trucks. Data were collected for the sites three years before and one year after the speed limit implementation. The results showed that truck lane restrictions might lead to a speed differential among vehicles.

Mussa and Price (2004) analyzed the speed of vehicles in the middle and outside lanes on a 54-mile section of the I-75 with left lane restrictions and found that on average the speed differential between cars and trucks were 2.7 mph in the middle and 2.6 mph in the outside lanes, respectively. Analysis of the middle and outside lanes showed a difference of 1.1 mph for cars between lanes. Similar results were found for the southbound direction as well. The speed differential between cars and trucks in the middle and outside lanes, though not significant, was 2.3 mph and 3.0 mph, respectively. The passenger cars on the inside lane traveled 5.3 mph faster than those in the middle lane though it was not statistically significant. Overall, in this corridor, both trucks and cars were found to travel above the posted speed limit, and it was claimed that lane restrictions do not negatively impact the speeds of trucks in the I-75 corridor.

The VISSIM simulation model developed by Gan and Jo (2003) estimated the speed differential for each lane and found that the speed differential remained constant while traffic conditions remained unsaturated. Under saturated conditions, a higher speed differential was predicted between the restricted and unrestricted lanes. The speed differential increased with an increase in interchange density, ramp volume, truck percentage, and number of restricted lanes. It was found that in all cases the restricted group had statistically significantly higher average speed than the unrestricted group.

FRESIM simulation study done by Hoel and Peek (1999) measured the speed differential for different scenarios at sites where truck percentages were between 20 and 40 percent and found that with left lane restrictions speed differential increased significantly with a 4 percent grade.

Cate and Urbanik (2004) used a VISSIM model to estimate the speed differential on a five-mile section before and after the implementation of a truck lane restriction strategy. The different scenarios used are shown in Table 9. Speed differential values were found to be greater on uphill grades than on level grades. This difference in speed on uphill grades with the same traffic volume was less with low truck percentages than with high truck percentages.

Impact of Truck Lane Restrictions on Crashes

A study conducted in Florida using before and after data between 2002 and 2006 showed that truck lane restrictions appear to reduce the overall number of crashes by approximately four percent (Kobelo et al., 2008).

A similar study conducted by Fontaine and Torrence (2007) studied the impact of a left lane TLRS on six-lane freeways. The study involved comparing crash data from 1998 through

2005 on six-lane freeways in Virginia with left lane restrictions to similar sites without lane restriction. The crashes considered for the study were total number of crashes and total number of fatal and injury crashes involving a truck. Twenty-three test sites and 16 comparison sites were studied. While the AADT values for the test and comparison sites were similar, truck percentages varied. Before and after comparisons of the crash rate at the test sites were found to show a general increasing trend for all sites which was suspected to be due to the increase in traffic or other factors. So as to control the influence of these extraneous factors, an Empirical-Bayes Analysis was conducted to develop a crash estimation model to predict the number of crashes which would have occurred at the test sites provided no restriction was implemented.

An "index of effectiveness," which is the ratio of the number of crashes that occurred with the truck lane restrictions to the number of crashes predicted at the test sites if no truck lane restrictions were in place, was calculated. Values less than one imply a positive benefit due to truck lane restriction. Four types of crashes were compared: all crashes, fatal/injury crashes, truck involved crashes, and truck involved fatal/injury crashes. Crash data between 1 to 5 years was used for the before period and 3 to 7 years of data for the after period, depending on the site.

A better understanding of the safety performance due to the restrictions was visible when the sites were divided into low-volume sites and high-volume sites based on their AADT values. Low-volume sites were those with less than 10,000 vehicles per day per lane. For all four types of crashes considered, analysis results showed a 10-34 percent decrease in the number of crashes at low-volume sites and a 12-37 percent increase in the number of crashes at high-volume sites. Table 10 shows the results of the Empirical-Bayes analysis for different types of crashes. For high-volume sites, trucks seemed to move to the middle and right lane of the highway due to restrictions, causing greater potential conflict among vehicles. Also the barrier effect of trucks in the right lane was more pronounced among high-volume sites.

Table 10
Analysis results for (a) total crashes, (b) fatal/injury crashes, (c) truck involved crashes, and (d) truck involved fatal/injury crashes
(Fontaine and Torrence, 2007)

Traffic volumes	**Actual crashes**	**Predicted crashes**	**Difference**	**95% CI**	**Index of effectiveness**	**95% CI**
All sites	11,188	10,372	+816	816 ± 251.7	1.08	1.08 ± 0.03
Low-volume sites	1,314	1,455	-141	-141 ± 98.1	0.90	0.90 ± 0.06
High-volume sites	9,874	8,810	+1064	1064 ± 232.97	1.12	1.12 ± 0.03

(a)

Traffic volumes	**Actual crashes**	**Predicted crashes**	**Difference**	**95% CI**	**Index of effectiveness**	**95% CI**
All sites	3,619	3,345	+274	274 ± 142.1	1.08	1.08 ± 0.04
Low-volume sites	443	536	-93	-93 ± 53.9	0.83	0.83 ± 0.09
High-volume sites	3,176	2,776	+400	400 ± 130.7	1.14	1.14 ± 0.05

(b)

Traffic volumes	**Actual crashes**	**Predicted crashes**	**Difference**	**95% CI**	**Index of effectiveness**	**95% CI**
All sites	1,725	1,368	+357	357 ± 91.8	1.26	1.26 ± 0.07
Low-volume sites	240	336	-96	-96 ± 38.8	0.71	0.71 ± 0.10
High-volume sites	1,485	1,087	+398	398 ± 84.1	1.37	1.37 ± 0.08

(c)

Traffic volumes	**Actual crashes**	**Predicted crashes**	**Difference**	**95% CI**	**Index of effectiveness**	**95% CI**
All sites	597	510	+87	87 ± 52.9	1.17	1.17 ± 0.06
Low-volume sites	86	130	-44	-44 ± 20.7	0.66	0.66 ± 0.08
High-volume sites	511	404	+107	107 ± 49.0	1.27	1.27 ± 0.13

(d)

Mannering et al. (1993) investigated the type of accidents happening in Site A (see Table 3) before the implementation of any lane restriction. It was concluded that restriction of trucks to the right lane might cause more truck-involved accidents. Crashes due to lane changes toward the left were found to be more severe. The violation rate for the restriction was high, and it was found that due to the presence of a HOV lane at the site, strict enforcement was difficult. Crash distributions before implementation of the restriction for Sites A and C were compared. The number of accidents decreased moving from right to left lanes.

Sims and Royester (2006) studied the crash rate on the I-20 and I- 30 in North Central Texas on sections with and without left lane restrictions on six- and eight-lane freeways (see Table 5). Accident data calculated for both corridors are given in Table 11 below where phase 1 is before installation of the left lane restriction, and phase 4 is after implementation of left lane restriction, both with a standard level of enforcement employed. A 64 percent reduction in crashes at the I-20 site (an eight-lane facility) and an 11 percent reduction at the I-30 site (also an eight-lane facility) were observed.

Table 11
Crash rate before and after truck lane restrictions
(Sims and Royester, 2006)

Comparison	I-20 Corridor	I-30 Corridor
Percentage of truck traffic	10%	4%
Phase 1 accidents per 1,000,000 vehicle miles travelled	0.18	0.55
Phase 4 accidents per 1,000,000 vehicle miles travelled	0.04	0.43
Statistical significance test results	Statistically different @ 90% level of significance	Not statistically different @ 90% level of significance
Average dry weather accidents per month in January	16.2	30.3
Average dry weather accidents per month in August and September	26.4	38.6
Average annual index between January and the previous August and September	0.62	0.87
Phase 1 adjusted by index	0.11	0.48
Percentage change from adjusted Phase1 to Phase 4	-64%	-11%

Crash rates during an enhanced level of enforcement were also studied. In the study, phase 2 provided conditions prior to introduction of the left lane restriction, while phase 3 provided conditions after. It was found that the enforcement level made little difference to the crash rate and compliance rate at these sites.

The Highway and Traffic Safety Division of Virginia Department of Transportation (VDOT) did a before and after study to ascertain the operational benefit of truck prohibition from the left lane on the I-95 section (four lanes in each direction) of Capital Beltway between I- 395 and the Woodrow Wilson bridge (VDOT, 1985). The comparison of accident data 2 years before and 2 years after the imposition of truck lane restrictions showed a 20 percent reduction in the rate of injury accidents. However, a follow–up study was conducted in 1987 by VDOT, and they found the crash rate had increased by 13.8 percent after the introduction of the TLRS although there was no change in fatal/injury crashes (VDOT, 1987).

A study involving restricting trucks with three or more axles from using the left lane from 7:00 A.M. to 7:00 P.M. on I-95 in Broward County, Florida, was initiated by the FDOT on May 3, 1982 (FDOT, 1982; Vargas, 1992). A twenty-five mile stretch of highway (three lanes in each direction) that prohibited trucks from using the left lane was the test site, and the control site was a similar site in Palm Beach County, Florida, without any lane restrictions. At the test site, accident data was collected for three years for the before period and for six years after the truck lane restrictions were imposed. For the control site, data were collected for the same nine years. Statistical tests were conducted to look for any significant difference in accident rates among the groups; one test compared before and after data within Broward County and the other compared Broward County with Palm County. The results showed no significant difference between before and after periods for all crashes, although, they revealed a significant decrease in the proportion of trucks to all vehicle accidents by 38.43 percent and truck injury crashes to all vehicle injury crashes by 56.81 percent in the Broward county site (Vargas, 1992). The study did not detect any impact of TLRS in reducing side-swipe or rear-end crashes. Truck lane restriction strategies were recommended as a crash reduction strategy based on this study.

In the study conducted by Mussa and Price (2004) on a 54-mile section of I-75 in northern Florida in which trucks are prohibited from using the far left lane, crash data showed that rear-end, run-off roadway, and side-swipe crashes due to lane changing were common. During a two year period from January 1, 1999 to December 31, 2000, lane changes were observed as the major cause for 48 percent of crashes involving trucks only and 28 percent of crashes involving all vehicles. A simulation study was also conducted on this section of highway and it indicated a significant increase in lane changes would likely result if the truck lane restrictions were removed. Thus, it was concluded that revoking the truck lane restriction might lead to more crashes in this corridor.

Liu and Garber (2007) used simulation to estimate conflicts between vehicles under different truck lane restriction strategies. Conflict in this case was defined as the potential collision between two vehicles. Three kinds of conflicts were studied as shown in Figure 6:

1) A *lane changing conflict* happens when Vehicle A changes lanes in front of Vehicle B
2) A *lane merging conflict* occurs when Vehicle D enters a lane from an entry ramp in front of Vehicle E
3) A *rear end conflict* occurs between Vehicle B and Vehicle C when Vehicle B reduces sped while the two vehicles are travelling in the same lane and direction.

Conflicts for this study were considered as potential collisions involving two vehicles. Conflicts were traced when lane-changing, merging, or braking maneuvers occurred; when the time of conflict exceeded a threshold value, a conflict was assumed to have occurred.

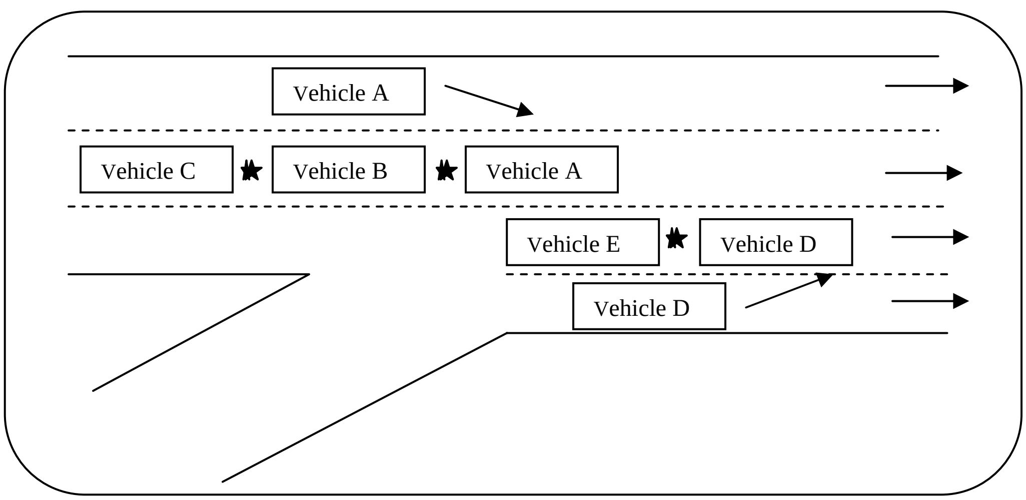


Figure 6
Layout showing conflicts
(Liu and Garber, 2007)

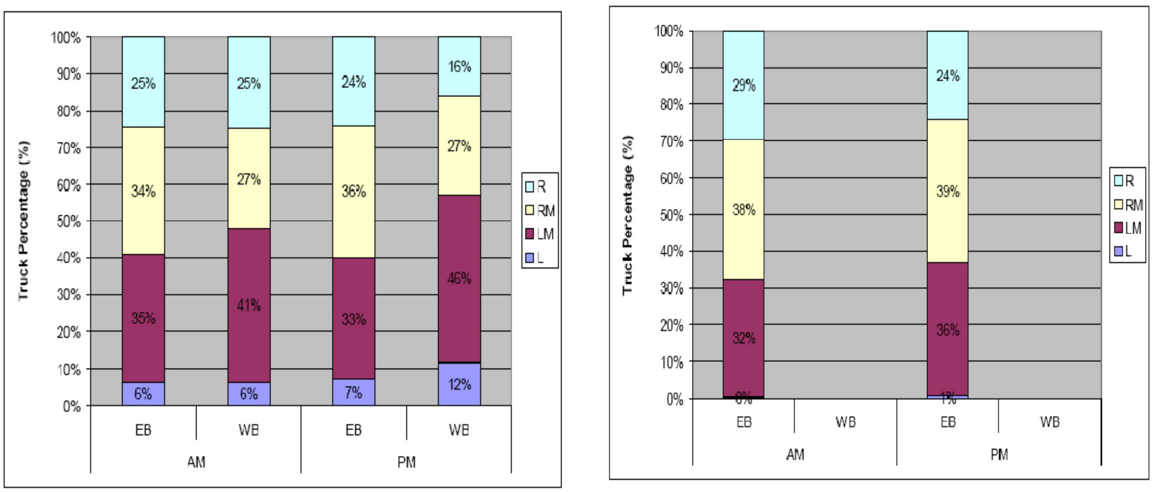
Various TLRS were tested using different values of volume, truck percentage, number of lanes, etc. The results showed a decrease in the frequency of lane changing conflicts with an increase in the number of lanes restricted at low truck percentages and for volumes below 1500 vphpl. However, the opposite trend was observed when traffic volume was above 1500 vphpl. A similar analysis was conducted for merging conflicts. The frequency of merging conflicts for trucks increased and car-car merging conflicts decreased with the number of restricted lanes and for volumes less than 1500 vphpl. However, when demand volume was more than 1500 vphpl, truck merging conflicts decreased with an increase in restricted lanes. For rear-end conflicts, frequencies increase with an increase in the number of restricted lanes when truck percentages are below 40 percent and volume above 1000 vphpl. Lane restrictions were determined to be beneficial on high volume, high truck percentage roads.

Compliance with Truck Lane Restriction Strategies

The benefit of any lane restriction strategy is dependent on the level of compliance with the restriction. The compliance rate is defined as the percentage of trucks complying with the restriction. Several studies have measured compliance and show that on facilities with three or more lanes in one direction, compliance is generally high. For example, in Virginia, Fontaine and Torrence (2007) found that on freeways with three lanes in each direction, over 30 percent of trucks used the left lane when there were no truck lane restrictions but between 2.4 and 5.1 percent of trucks used the left lane when left lane restriction policies were in force.

Texas Transportation Institute (TTI) did a 36-week evaluation of compliance of a left lane restriction on an 8-mile section of the I-10 freeway between Waco and Uvalde Streets in Houston (TTI, 2002). The site was chosen based on the criteria of having at least four percent truck volume and a minimum length of six miles. Compliance was measured by comparing the traffic volume data collected at three locations in the test section and also at a location before and after the restriction. The compliance rate was found to be 70-80 percent due to strict enforcement.

In a study conducted in North Central Texas (Sims and Royester, 2006), the distribution of trucks on the lanes before and after a restriction on I-20 (see Table 5) was found using video data collected at I-35 due to unavailability of data at I-20 for eight separate two-hour sessions for Phase 1 (no truck lane restrictions and standard level of enforcement) and two separate hour sessions for Phase 3 (truck lane restrictions with increased enforcement). The lane distribution of trucks for these two conditions is shown in Figure 7. The compliance rate for different levels of enforcement is shown in Table 12.



(a) Before introduction of TLRS and standard level of enforcement

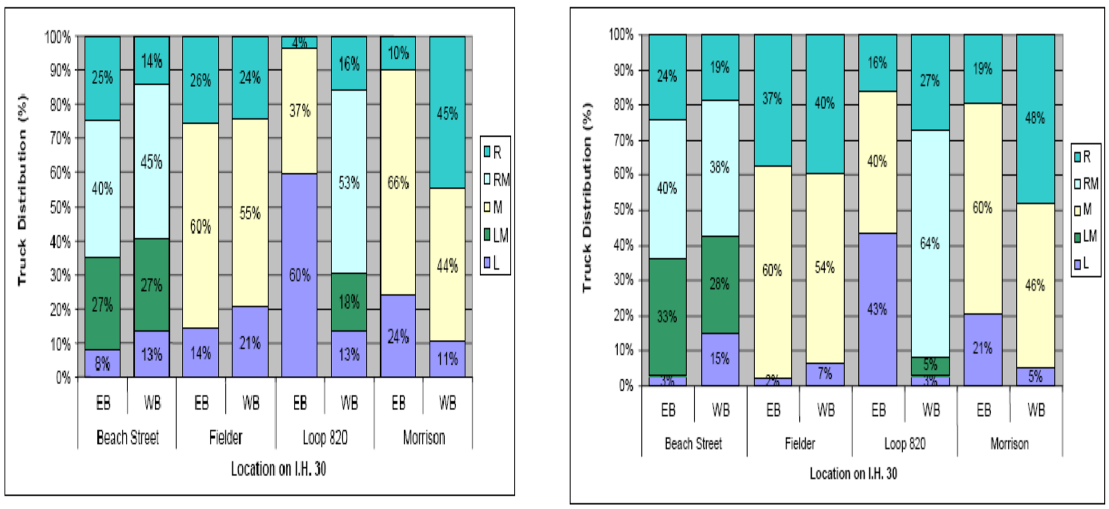
(b) After introduction of TLRS and increased level of enforcement

Figure 7
Impact of TLRS and enforcement on lane distributions of trucks on I-20
(Sims and Royester, 2006)

Table 12
Compliance on I-20 with increased level of enforcement
(Sims and Royester, 2006)

Phase	**Percentage of trucks in left lane**	**Compliance rate**
Phase 1: Before introduction of TLRS and with standard level of enforcement	6.7%	N/A
Phase 3: After introduction of TLRS and with increased level of enforcement	0.5%	99.5%

In the same study, Intelligent Transportation Systems (ITS) data was used to calculate the lane distributions on I-30 at 4 different locations, 24 hours a day, 7 days a week at 15-minute intervals for peak hours, and at 1-hour interval for off-peak hours for Phase 1 and Phase 4 as shown below in Figure 8. Phase 1 was before introduction of TLRS and Phase 4 after. For both phases, a standard level of enforcement was in effect. The compliance rates for different phases are shown in Table 13.



(a) Standard level of enforcement **(b) Enhanced level of enforcement**

Figure 8
Impact of TLRS and enforcement on lane distributions of trucks on I-30
(Sims and Royester, 2006)

Table 13
Compliance on I-30 with standard level of enforcement
(Sims and Royester, 2006)

Phase	**Percentage of trucks in left lane**	**Compliance rate**
Phase 1	20.5%	N/A
Phase 4	12.4%	87.6%

It is observed in Table 12 that with introduction of TLRS and an increased level of enforcement, the use of the left lane by trucks decreased by 94 percent and the compliance rate was 99.5 percent. On I-30, truck use of the left lane reduced by 40 percent with the introduction of the TLRS and a standard level of enforcement, resulting in a compliance rate of 87.6 percent.

Hanscom (1990) measured truck lane occupancy using manual counts before and after introduction of a truck lane restriction for matching time-of-day and day-of-week at three study sites. On I-290, a six-lane facility, truck occupancy of the left lane at the control site increased from 3.8 to 5.4 percent, whereas in the study sites, truck lane occupancy reduced from 6.7 to 0.8 percent due to the lane restriction. On I-55 in Chicago which is a six-lane facility, the probability of a truck using the left lane at the study site was only 0.43 of that in the left lane at the control site. On I-90/I-94 in Wisconsin, which has two-lanes in each direction with right lane restriction, a reduction in truck lane occupancy from 87.4 percent to 10.2 percent was observed at the study site, and no significant reduction was observed for the control site. The lower compliance rates in Chicago were attributed to the geometry at the test site.

Passenger Car Flow Impeded by Truck Lane Restriction Strategies

Mannering et al. (1993) found that after a left lane restriction was implemented, car-following-car and truck-following-car average speeds were greater than car-following-truck and truck-following-truck average speeds. This suggested that trucks were impeding flow.

Hanscom (1990) also measured the proportion of trucks impeding followers by determining the proportion of trucks associated with zero queue lengths. On I-290, 37.2 percent of trucks had a zero length following queue (no impedance) at the control site, whereas 45.4 percent of the trucks had a zero length following queue at the test site. On I-55 in Chicago, the proportion of trucks not impeding flow increased from 44.9 percent to 51.4 with introduction of a truck lane restriction strategy. On I-90/I-94 in Wisconsin (two-lanes in each direction with right lane restriction), the percentage of trucks not impeding following vehicles increased from 72.1 percent in the before condition to 79.7 percent in the after condition at the test site and, similarly, from 72.6 to 79 percent in the control site which might have been due to the lower truck volumes at the site.

Fontaine and Torrence (2007) also investigated the impedance of truck lane restrictions to traffic flow by looking at the headways. If the headways of following vehicles were less than 3 seconds in a platoon of vehicles and the lead vehicle had headway of at least 3 seconds, then the lead vehicle was considered to impede traffic. At sites with three lanes in each direction, trucks in the left lane impeding flow were analyzed, and it was found that a lower number of trucks impeded the flow at sites with truck lane restrictions. However, overall, trucks did not impede faster vehicles in both test and control sites. At sites with two lanes in each direction, the number of trucks impeding flow in the left lane was analyzed, and it was found that 34 percent of trucks and 13 percent of passenger vehicles were impeding at least one vehicle.

Impact of Truck Lane Restrictions on Access/Egress Points

In the case of right lane restrictions, increased truck traffic on right lanes makes it difficult for vehicles to enter or exit the facility. Vehicles entering on-ramps have to wait for a space between the slow-moving trucks and then must travel sandwiched between the trucks before they can change lanes. Also, vehicles exiting the freeway have to find a gap in the right lane before exiting. This kind of hindrance near exit/entry ramps is called the “barrier effect” and often manifests itself in the form of a heightened involvement of trucks in rear-end and side-swipe collisions (Gan and Jo, 2003). Another issue at exit/entry points is low visibility of signs. While travelling behind the trucks, traffic signs are generally less visible to following passenger cars, making travel inconvenient and unsafe.

Moses (2007) simulated left lane, center lane, and right lane restrictions on facilities with three, four, and five lanes in each direction (see Table 2). He found that center lane and right lane restrictions caused spill back onto arterial roadways at interchanges due to the difficulty of entering trucks to get an acceptable gap on the facility during peak hours. Exiting vehicles did not generate similar delays; they were limited to entrance ramps.

In the NCTCOG study (Sims and Royester, 2006), the following data was collected: (a) cars in outside lane blocking exit/entry ramps, (b) trucks in the outside lane blocking exit/entry ramps, (c) near collisions (no truck involved), (d) near collisions (truck involved), (e) queues on the entrance ramp, (f) queues on the exit ramp, (g) queues on the freeway, (h) trucks in the inside lane not passing, and, (i) wall of trucks. The results indicated a wall of trucks (i.e., an unbroken line of trucks) at both locations, but it was not concluded that truck restrictions had a negative impact on access/egress.

TTI recommends the guideline that the stretch of roadway incorporating a truck lane restriction should be one mile beyond any entry/exit ramp for easy access/egress of vehicles in Texas (TTI, 2002).

Impact of Truck Lane Restriction on Pavement Damage

In most states, slow-moving traffic is restricted to rightmost lanes. Trucks are considered to be slow-moving vehicles due to their mass and lower acceleration and deceleration abilities, thus they tend to travel in the slower lanes. This causes uneven wear of the pavement. However, when trucks are further concentrated on the slower lanes through truck lane restrictions, uneven wear of the pavement is exacerbated.

Mannering et al. (1993) studied the impact that a prohibition on trucks from the left lane on highways has on pavement deterioration in the Puget Sound region. Pavement curves showing the relationship between Present Serviceability Index and equivalent axle loads for lane 3 (the lane adjacent to the inside lane) and lane 4 (the inside lane) were developed using soil and water conditions in the Puget Sound Region. Pavement deterioration was measured assuming 100 percent compliance and no weather impact on the pavement. Improved pavement conditions on lane 4 (the restricted lane) and reduced pavement life on lane 3 was observed after left lane restriction.

Pavement deterioration was estimated using the concept of Equivalent Single Axle Loads (ESALs) by Yang and Regan (2007) in their simulation study. The sum of ESAL values on all lanes was used to determine pavement deterioration assuming 100 percent compliance. Damage was assessed using the standard damage equation in AASHTO (1993) (Christopher et.al, 2006). For the case where there are four lanes in each direction and trucks are prohibited from the left-most lane (alternative 1), or from the two left-most lanes (alternative 2), the results are shown in Figure 9. As can be seen, the total ESALs increase from approximately 290,000 to approximately 310,000 when moving from no truck lane restrictions to prohibiting trucks from the left-most lane only (alternative 1). This approximately 7 percent increase in total pavement damage is, however, increases by approximately 34 percent as the total ESALs increase to approximately 390,000 when trucks are prohibited from using the two left-most lanes (alternative 2). The total ESALs reflect the total loading the pavement is subjected to and are therefore indicative of the wear the pavement experiences. Pavements are designed for a total number of ESALS so any accelerated consumption of ESALs represents a direct reduction in the life of the pavement. Thus, given the assumption of 100 percent compliance in this study, the pavement is estimated to fail 34 percent earlier if trucks are restricted from using the two left-most lanes in a four-lane in one direction facility and 7 percent earlier if trucks are restricted from using the left-most lane only in the same facility. If a pavement is designed for 20 years, this would represent a 6.4 year and 1.4 year shortening in the life of the facility, respectively.

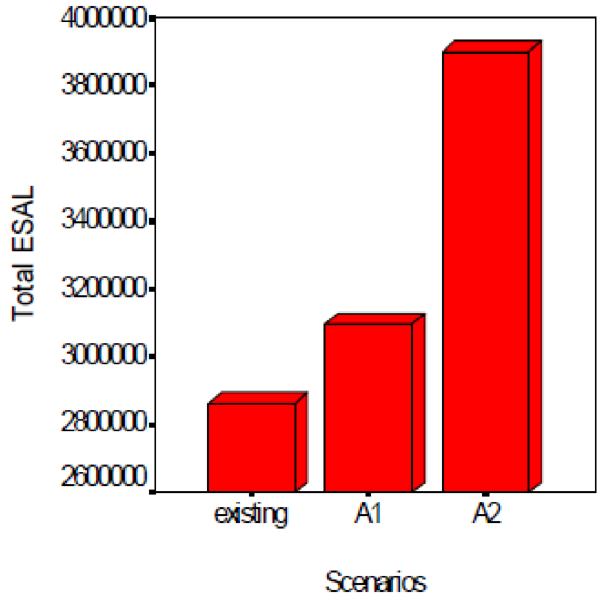


Figure 9
Impact of TLRS on pavement damage
(Yang and Regan, 2007)

Recommendations for Implementation of Truck Lane Restriction Strategy from Other Studies

A study by Jasek et al. (1997) at TTI recommended that approval of any truck lane restriction application requires that the following conditions be satisfied:

- On roads within the State Highway System
- Applicable on access-controlled highways
- Highways with three or more travel lanes in one direction
- Highways where trucks have at least two through lanes for travel

- No time of day restriction
- Restricted vehicles should be allowed to use any lane to pass or exit/enter the highway
- A traffic study should be done in the location to know whether the geometrics, traffic control devices, and site characteristics warrant lane restriction
- Lane restrictions should not end and begin frequently
- Within and between municipalities, lane restrictions should be continuous
- Following the approval of the application, installation of proper signs and a periodic review of the change in traffic conditions at the site change, or change in pavement condition or roadway configuration is required

In a similar vein, a more recent TTI study recommended the following guidelines for truck lane restriction in Texas (Borchardt et al., 2008):

- A minimum of 4 percent truck traffic should be on the roadway for a consecutive 24 hour period
- The roadway should have approximately 10 percent of total truck traffic using left lane or inside lanes of the roadways
- The stretch of roadway should be one mile beyond any entry/exit ramps in the restricted lane for easy access/egress of vehicles
- The roadway considered for restriction should be at least six continuous miles long
- Routine enforcement and traffic patrols should be enforced
- Proper signs specifying the class of vehicle restricted and the type of restriction should be installed at 1-mile intervals throughout the restricted area
- A public information campaign should be conducted to inform the public about the kind of restriction to be implemented

OPINION SURVEYS REGARDING TRUCK LANE RESTRICTIONS

Opinion Surveys Conducted in Other States

An opinion survey was conducted among truckers in the Puget Sound region regarding their opinion of the truck lane restrictions (Mannering et al., 1993). A similar survey was conducted among 400 motorists. An informal survey was also conducted among state troopers.

The trucker survey showed that truckers opposed truck lane restrictions in the Puget Sound region. On the other hand, the motorist survey indicated that over 90 percent of motorists were in favor of truck lane restrictions. The motorist survey indicated that 70 percent of motorists changed lanes to avoid following a truck, 78 percent reported seeing violation of truck lane restrictions, and 74 percent expressed the need for restrictions to apply to buses as well. The state trooper survey was too small and informal to provide reliable results, but they generally favored left lane truck restrictions during peak hours. The study sites had low truck percentages and traffic volumes and a high variability of conditions; therefore, the survey was not considered indicative of the merit of truck lane restrictions in general.

The Highway and Traffic Safety Division of Virginia Department of Transportation (VDOT) conducted a similar public opinion survey (VDOT, 1985). The survey showed significant support among motorists for truck lane restrictions. A 36-week evaluation study conducted by TTI reports that 90 percent of the motorists favored prohibiting trucks from the far left lane on the I-10 East freeway in Texas (Texas Transportation Researcher, 2002).

The Preusser Research Group conducted a focus group study to assess the safety issues on the Capital Beltway (USDOT, 1998). The focus group consisted of three groups representing regular private passenger vehicle drivers, aggressive passenger vehicle drivers, and commercial truck drivers. The truck drivers were found to be aware of the left lane prohibition on the Capital Beltway. Some members of the aggressive driver group felt that trucks should be restricted to the two rightmost lanes on the Beltway. Truck drivers reported the right lane to be dangerous due to merging/exiting activity of cars in this lane.

Opinion Surveys Conducted in Louisiana

Wolshon et al. (2008) report on a mail-in survey conducted among truckers in 2008 in Louisiana. Respondents were recruited from trucking companies that had been cited for overloading at a weigh station between Baton Rouge and Lafayette on I-10. The weigh station is close to the site of the truck lane restriction system on an 18-mile elevated section over the Atchafalaya Basin. The facility has two lanes in each direction and has a differential speed limit of 55 mph for trucks and 60 mph for passenger vehicles. The questionnaire contained questions about drivers, their travel frequency, awareness of the restrictions, opinions, and proposed strategies for improvements. Sixty-three percent of the truck drivers had more than 10 years of driving experience and 54 percent had frequently driven through the test section. Ninety-four percent of the respondents were aware of the differential speed limit and 95 percent were aware of the lane restriction. Most respondents thought that warning signs ahead of the section were adequate. Fifty-seven percent did not favor the differential speed limit for trucks and 58 percent considered truck lane restrictions to have reduced safety in the test section. While the sample was not random and may be biased due to the selection of cited trucking companies, the findings are similar to the opinion of truckers in other surveys.

LADOTD conducted an opinion poll in late 2008 among Louisiana residents as part of a routine Public Opinion survey. Respondents were selected through a random sample of phone numbers and resulted in a sample of 198 respondents. The majority of respondents were white (59%), female (60%), and licensed drivers (93%). Thirty-six percent of the respondents had finished college. The respondents were fairly well distributed by telephone area code with the majority from the 225 (25%) and 318 (26%) area codes (337 = 18%, 504 = 19%, and 985 = 12%). Twenty-one percent of respondents indicated that they or someone in their household was in the trucking business.

Respondents were asked to provide their opinion on prohibiting trucks from using specified lanes on different classifications of multilane highways in the state. The full set of questions on truck lane restrictions is included in Appendix 2. Responses to the questions were as follows:

- Less than three-fourths (73.5%) of respondents supported keeping trucks out of the far left lane for regular four-lane freeways
- 70.1% supported keeping trucks out of the far left lane on four-lane freeways on bridges

- 74.1% supported keeping trucks out of the far left lane on regular six-lane freeways
- 74.5% supported keeping trucks out of the far left lane on six-lane freeways on bridges
- Fewer, but still a large majority (69.2%), supported keeping trucks out of the far left lane on four-lane divided highways
- 68.6% supported keeping trucks out of the far left lane on four-lane undivided highways
- 70.9% supported keeping trucks out of the far left lane on six-lane divided highways (that are not freeways)
- 72.6% agreed that keeping trucks out of the far left lane of any four-lane or six-lane road would improve safety
- A slight majority (53.7%) disagreed that keeping trucks out of the far left lane on the four-lane or six-lane roads would cause congestion in the other lanes
- A slight majority (56.4%) agreed that keeping trucks out of the far left lane on four-lane or six-lane roads would make it more difficult to get on to and off the road

PRACTICE IN OTHER STATES

The Louisiana Department of Transportation and Development issued a request for information from other states on their use of truck lane restriction strategies in February 2009. The responses are summarized below.

Table 14
Summary of state responses

STATE	**Does your state have any truck lane restrictions? If yes, explain policies/practices. If no, have they been considered and why they were not implemented**	**If your state has truck lane restrictions, on what type highways are they being implemented; fully controlled access/ partially controlled access or non-controlled access?**	**If your state has truck lane restrictions, do you have any implemented on four-lane facilities (two lanes in each direction)?**
Arkansas	Yes, left lane truck restriction on six-lane sections of urban interstates	Fully controlled access highways	None
California	Yes, motor truck or truck-tractor with three or more axles is restricted to designated lanes on locations where signs are erected. At other locations trucks should keep to the right hand lane and on highways with four or more lanes without designated lanes, trucks should keep to the two right-most lanes except to pass other vehicles. Truck drivers who have to make a left-turn or use entrance/exit points are exempt from the designated lane restriction.	Fully controlled access highways	Yes, restriction to designated lanes where signs are erected and at other locations to the right-most lane.
Colorado	Yes, trucks restricted to the right lane at some locations with steep downhill grades.	Primarily on mountainous four-lane interstates.	Yes, we have some truck lane restrictions on four-lane, five-lane and six-lane facilities.

STATE	Does your state have any truck lane restrictions? If yes, explain policies/practices. If no, have they been considered and why they were not implemented	If your state has truck lane restrictions, on what type highways are they being implemented; fully controlled access/ partially controlled access or non-controlled access?	If your state has truck lane restrictions, do you have any implemented on four-lane facilities (two lanes in each direction)?
Florida	Yes, left-most lane restrictions for trucks over three or more axles on roadways with six or more lanes for twenty four hours a day. Restrictions are applied depending on the amount of truck traffic, interchange spacing and other operational considerations.	Fully-controlled access highways	Restrictions are applied on six or more lane highways not including HOV lanes and none on four-lane facilities.
Iowa	No, it was not implemented because lane restrictions were not considered appropriate for four-lane interstates.	None	None
Kansas	None	—	—
Kentucky	Yes, trucks with more than six wheels are restricted to the two right-most lanes on rural interstates with three or more lanes in each direction	Fully controlled access highways	None
Maine	Yes, median lane(left-most) restriction for trucks on 40 miles of six-lane highway on Maine Turnpike	Fully controlled access highways	None on four-lane facilities.
Maryland	Yes, left lane truck lane restrictions for trucks over five tons GVW on all freeways with four or more lanes in one direction	Fully-controlled access highways	None on four lane facilities except on hilly areas.
Mississippi	None	—	—

STATE	Does your state have any truck lane restrictions? If yes, explain policies/practices. If no, have they been considered and why they were not implemented	If your state has truck lane restrictions, on what type highways are they being implemented; fully controlled access/ partially controlled access or non-controlled access?	If your state has truck lane restrictions, do you have any implemented on four-lane facilities (two lanes in each direction)?
Missouri	Yes, left-most lane restriction for trucks with a gross weight of 48,000 pounds or more on interstate highways, freeways or expressways in urban areas with three or more lanes in the same direction. Exceptions are allowed if a truck wants to make a left-hand exit and when right lane is closed for construction or repair on a case-by-case basis.	Fully controlled access highway	None
New Hampshire	None	—	—
New Jersey	Yes, trucks weighing 10,000 pounds or more gross weight are restricted from the left-most lane on highways with three or more lanes in one direction. Restricted trucks can use the left lane to make a left turn, to use an entrance/ exit point or in case of emergency. Restriction on trucks from driving on the farthest two left lanes on New Jersey Turnpike with four lanes in one direction of which the left-most lane is a HOV lane.	Non-controlled access ways and fully controlled access ways	None

STATE	Does your state have any truck lane restrictions? If yes, explain policies/practices. If no, have they been considered and why they were not implemented	If your state has truck lane restrictions, on what type highways are they being implemented; fully controlled access/ partially controlled access or non-controlled access?	If your state has truck lane restrictions, do you have any implemented on four-lane facilities (two lanes in each direction)?
New York	Yes, on a case-by-case basis. There is a left lane restriction for a ten mile distance between Exits 24 (Albany) and Exit 26 (Schenectady) on New York State Thruway which has a minimum of three lanes (single direction). All the vehicles on this facility are also restricted to the right except to pass. Left lane restriction on I-495 (Long Island Expressway) which has a HOV lane in each direction with parallel service road and four to six lanes in one direction on some sections. No left-lane restrictions on State Highway system.	Fully controlled access highways	On the New York State Thruway all vehicles are to keep right except to pass and this applies to two-lane sections (in one direction) on the facility as well. In general state highway system does not have left lane truck restrictions and do not require vehicles to stay in the right lane.
North Carolina	Yes. The majority of these were implemented as part of a “pilot” effort initially limited to approximately 123 miles of six-lane interstates. These restrictions (plus a few additional segments) are still in place	All “pilot” lane restrictions are on fully controlled access highways. Only a couple of specialized lane restrictions on non-freeway routes with partial control of access (US 74 Shelby, NC) and no control of (US 17 Jacksonville, NC).	Yes, some lane restrictions on four-lane freeway segments due to specific alignment and terrain issues; for example, on I-40 (through the Gorge) and on I-26 (EB Saluda Grade)

STATE	Does your state have any truck lane restrictions? If yes, explain policies/practices. If no, have they been considered and why they were not implemented	If your state has truck lane restrictions, on what type highways are they being implemented; fully controlled access/ partially controlled access or non-controlled access?	If your state has truck lane restrictions, do you have any implemented on four-lane facilities (two lanes in each direction)?
North Dakota	Yes, lane restriction on Hwy 2 (four-lane) where slower traffic is restricted to right lane on some upgrades. Practice is to restrict trucks on three or more lane (single direction) interstates to the two right most lanes.	Slower traffic restriction is on uncontrolled access highways. Lane restriction on fully controlled access highways	None
South Carolina	Yes, practice is to apply truck lane restriction to the two rightmost lanes on interstate facilities with three or more lanes in one direction	Fully controlled access	None
South Dakota	No specific lane restrictions for trucks. However, for climbing lanes on long hills, slower traffic has to keep right.	—	—
Texas	Yes, left lane truck lane restrictions on I-10E, SH 225, I-45N and US 290 in Houston area, I 10/US 90 and I-35 in San Antonio area, I-20 and I-30 in Dallas-Fort Worth area and I-35 in Austin area for trucks with three or more axles.	Fully controlled access highways	None on four lane facilities because such restrictions are not permitted on highways with less than three lanes in each direction by the TxDOT.

STATE	Does your state have any truck lane restrictions? If yes, explain policies/practices. If no, have they been considered and why they were not implemented	If your state has truck lane restrictions, on what type highways are they being implemented; fully controlled access/ partially controlled access or non-controlled access?	If your state has truck lane restrictions, do you have any implemented on four-lane facilities (two lanes in each direction)?
Virginia	Yes, commercial motor vehicles are restricted from the left-most lane of any interstate highway having more than two lanes in each direction and also where posted speed limit is 65 mph or more. On Interstate 81 and also in the Northern Virginia area, this restriction is applicable regardless of the posted speed limit.	Fully controlled access Interstate Highways	Yes, restriction to the right-most lanes for commercial motor vehicles travelling at less than 15 mph from the posted speed limit on interstate highways with not more than two lanes in each direction
Wisconsin	None	—	—

Reviewing the information from the 21 responding states in Table 14, it is interesting to note that only two states (California and Colorado) apply truck lane restrictions to four-lane facilities (two lanes in each direction), and one of them (Colorado) applies it only for steep downhill grades. Also, only two states (New Jersey and North Carolina) apply truck lane restrictions to non-controlled access facilities and then only in isolated applications. On the other hand, it is noteworthy how many states apply truck lane restriction strategies (16 of the 21 in this survey). The majority prohibit trucks from using the left-most lane on facilities with three lanes in each direction and the left-most or the two left-most lanes on facilities with four or more lanes in each direction. Those that restrict trucks to use of the right-most or two right-most lanes are in the minority (California, Colorado, New York, North Dakota, and South Dakota).

SUMMARY AND CONCLUSIONS

Summary

The literature is generally consistent in finding that flow on a facility is increased by the introduction of TLRS only when the number of lanes that are restricted are limited (i.e., one lane with three lanes in one direction or at most two lanes restricted with four or five lanes in one direction), truck percentage is between 10 and 15 percent, total flow is relatively heavy (> 1300 vphpl), interchange spacing is greater than approximately 2 miles, and ramp volumes are less than, say, 1000 vph. In contrast, when these conditions are exceeded, flow on the facility is generally reduced by the introduction of TLRS.

The impact of TLRS on speed is influenced by similar conditions to those described as affecting flow in the previous paragraph with the added observation that left lane restrictions are clearly better than right lane restrictions. Generally, a small increase in speed can be expected to follow introduction of TLRS with a limited number of restricted lanes, low truck percentage (< 25%), peak hour flow, low interchange density, and low ramp volumes. In off-peak periods, speed change is negligible.

The impact TLRS is expected to have on travel time is limited and is primarily related to a difference in travel time among passenger vehicles and trucks. Generally, passenger vehicles experience a slight reduction in travel time and trucks a slight increase in travel time provided a left lane restriction is applied. If a center or right lane restriction is applied, then travel time generally increases for all vehicles.

Lane changing is observed to increase with TLRS when truck percentages, interchange density, and traffic volume increases. Left lane restrictions generate the lowest number of lane changes.

TLRS generally increase speed differential among vehicles although there is generally a lower speed differential among trucks. Speed differentials in normal traffic streams generally imply reduced safety, but it is not known what impact truck lane restrictions have on this observation.

The literature is relatively consistent in reporting that TLRS reduce crashes. Estimates vary from site to site but most suggest a reduction in crashes in the order of 10 percent from prior levels. The reports indicate that crash reduction may be higher among more severe crashes (fatalities and injuries) than among the less severe crashes.

The literature indicates that for three or more lanes per direction, the increase in vehicles impeded by the introduction of TLRS is in the order of five percent. However, when there are only two lanes in each direction, the introduction of TLRS has a much greater impact, increasing the number of trucks experiencing impedance by 33 percent and passenger cars by 12 percent.

The impact that TLRS can have on the ease of vehicles entering and exiting a freeway is dependent on which lane the truck lane restrictions are imposed, truck volumes, interchange density, and vehicular flow on the facility. Generally, it is more severe for vehicles entering the freeway than those exiting, and it is a greater problem for trucks than for passenger vehicles. Left lane truck restrictions are decidedly better than truck lane restrictions on other lanes.

The impact that TLRS has on pavement damage is significant depending on the type of lane restriction, number of lanes, and truck percentages. On a facility with four lanes in each direction, prohibiting trucks from the leftmost lane increases pavement damage overall by approximately seven percent. However, if trucks are prohibited from using the two left-most lanes of the same facility, the damage to the pavement is increased by 34 percent. Thus, the more trucks are restricted to certain lanes, the greater the damage to the pavement and the increase in damage is dramatic as shown by the percentages just quoted. The shorter life of the existing pavement will result in a significant increase in construction and maintenance cost to the state.

Public opinion regarding TLRS is divided among motorists and truckers. Between 74 and 90 percent of the public are in favor of TLRS on controlled access facilities. In contrast, the majority of truckers do not believe that it improves safety and do not support it. Generally, compliance with TLRS among truckers is high with compliance ranging from 88 percent in one study with a standard level of enforcement to 99.5 percent with increased enforcement.

Conclusions

Considering the outcome of the literature review, the opinion survey, and the survey of practice, it is clear that TLRS are most applicable to controlled access facilities with three or more lanes per direction, and are seldom applied to non controlled access facilities. TLRS are most applicable when the lanes they are prohibited from using are a small proportion of the total lanes available, thus providing them with sufficient freedom to overtake other vehicles and choose their own speed. Other conditions are that the volume of traffic on the facility should be sufficient to warrant reducing the interaction between trucks and passenger cars, there should be a low level of on and off ramp traffic, and the percentage of truck traffic in the traffic stream should at once be sufficient to warrant action but not cause increased congestion in the unrestricted lanes. The literature suggests typical values for these conditions are that total traffic flow should be in excess of approximately 1300 vphpl, interchanges should preferably be spaced more than two miles apart where TLRS are implemented, ramp volumes should be less than approximately 1000 vph, and truck percentages should, on the one hand, be higher than approximately 10 percent of the traffic stream, but preferably not much higher than approximately 25 percent. Truck lane restrictions should be targeted to left lanes (i.e., trucks prohibited from using left lanes), and the number of restricted lanes should be limited to one or two. Restricting trucks to using the right lane, or the two rightmost lanes is an inferior truck lane restriction strategy on every measure of effectiveness, and its negative impact on ease of entry and exit to a freeway, and its impact on pavement damage is significant. Past studies have shown that limiting trucks from using the left two lanes on a facility with four lanes in each direction increases pavement wear by 34 percent, but limiting trucks from using the leftmost lane on facilities with two or three lanes in each direction will have a significantly larger impact resulting in a considerable increase in construction and maintenance costs.

The major advantage of TLRS appears to be in its contribution toward improved safety, although reported safety impacts vary from isolated cases of small deterioration in crash rates to cases where improvements of over 60 percent were observed. The majority of cases report an improvement in overall crash rates with the introduction of TLRS in the order of 10 percent. The impact of TLRS on speed, travel time, flow, speed differential, impedance, and lane changing appear to be marginal. Some of the significant costs of introducing TLRS are in pavement damage if the restrictions concentrate trucks to a limited set of lanes, difficulty in entering a freeway where traffic volumes are high, and when there is a high percentage of trucks in the traffic stream. However, since TLRS are not recommended in urban areas with high interchange density and high ramp volumes, these problems are not likely to arise.

Highways with two lanes in each direction are not suitable for TLRS because they concentrate trucks in the right lane with the resulting problems of increased pavement damage, difficult entry/exit via ramps, and negative impact on every MOE mentioned above. They are hard to police because overtaking needs to be allowed and is difficult to distinguish from a violation.

The number of controlled access facilities with three or more lanes in one direction in Louisiana is limited. Figure 10 shows a map of highways in Louisiana with more than two lanes in each direction for a distance of more than one-half mile. Interstate routes are, of course, controlled access facilities, while the US and state routes shown in the map are not. There are a total of 184 miles of highway with three lanes in one direction in Louisiana, of which only 36 miles are in rural areas. There are only just over 4 miles of highway with four lanes in each direction in Louisiana. Since three or more lanes per direction in a rural area are needed for effective application of TLRS, the map shows with red lines in Figure 10 the limited options for the implementation of truck lane restrictions in the state.

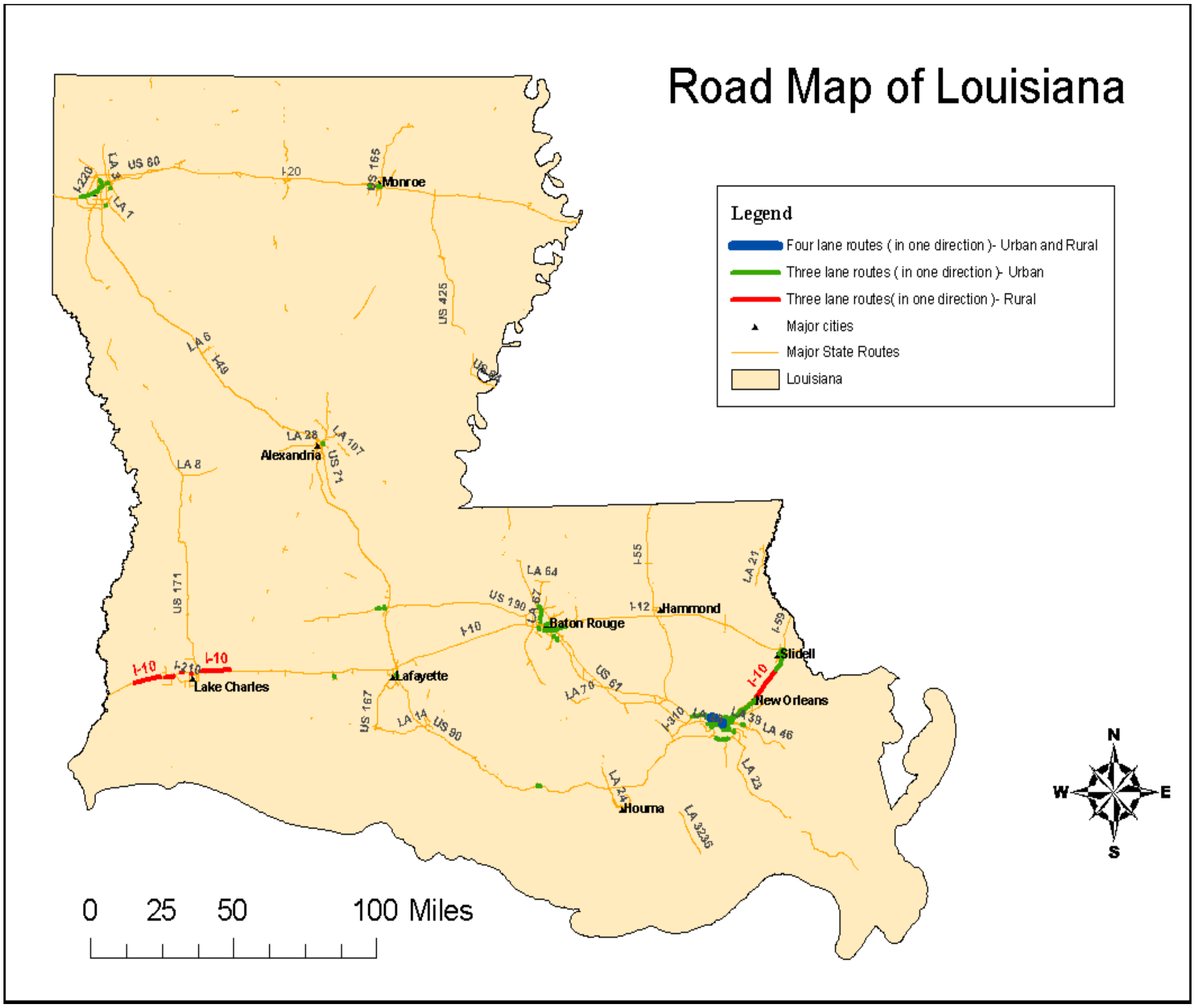


Figure 10

Routes in Louisiana with more than two lanes in each direction

(Note: Only red sections represent candidate sites for TLRS implementation and all require thorough analysis before implementation)

RECOMMENDATIONS

Based on the recommendations from other studies explained in last section of the literature review and surveys conducted in this study, it is recommended that the application of TLRS in Louisiana abide by the following guidelines, unless an engineering study can justify an application at a particular location:

- TLRS should only be considered on controlled access facilities with three or more lanes in one direction
- Where TLRS are applied, trucks should be prohibited from using the leftmost lane on facilities with three or four lanes in each direction, and from no more than the two leftmost lanes on facilities with five or more lanes in each direction
- TLRS where trucks are restricted to using right lanes are not recommended
- TLRS applications should be at least 6 miles long and should not end and begin frequently unless a study of the site suggests otherwise
- There should no time restriction on the applicability of TLRS; it should be operative continuously
- Each site should be studied to confirm the geometrics, traffic control, and site characteristics are conducive to introduction of a TLRS
- Truck traffic should preferably constitute between 10 and 25 percent of the vehicle composition in the traffic stream to ensure, on one hand, that there are sufficient trucks to justify special treatment and, on the other hand, that there are not too many to cause undue congestion in the truck lanes
- Truck lane restrictions should not be introduced where interchanges are closer than 2 miles apart or where ramp volumes exceed 1000 vehicles per hour
- Signs specifying the class of vehicle restricted and the type of restriction should be installed at 1-mile intervals throughout the restricted area

Considering the guidelines above, highway conditions in Louisiana present limited opportunities for introduction of TLRS. Among candidate sites, an engineering study should be conducted to verify the suitability and benefit of TLRS before implementation.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
AADT	Average Annual Daily Traffic
AADTT	Average Annual Daily Truck Traffic
ADT	Average Daily Traffic
ATA	American Trucking Association
BTS	Bureau of Transportation Statistics
DSL	Differential Speed Limit
DOT	Department of Transportation
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
FDOT	Florida Department of Transportation
HOV	High Occupancy Vehicle
I-20	Interstate Highway 20
ITS	Intelligent Transportation Systems
LADOTD	Louisiana Department of Transportation and Development
LHD	Latin Hypercube Design
LOS	Level of Service
MOE	Measure of Effectiveness
mph	Miles per hour
NAFTA	North American Free Trade Agreement
NCTCOG	North Central Texas Council of Governments
RTMS	Remote Traffic Microwave Sensors
S.R.	State Route
TXDOT	Texas Department of Transportation
TTI	Texas Transportation Institute
TLRS	Truck Lane Restriction Strategies
URL	Uniform Resource Locator
USDOT	United States Department of Transportation
vphpl	Vehicles per hour per lane
vph	Vehicles per hour
vpdpl	Vehicles per day per lane
VTRC	Virginia Transportation Research Center
WTA	Washington State Trucking Association

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APPENDIX-1

Federal Highway Administration Document on Truck Traffic Growth in Louisiana

State Profile—Louisiana: 1998, 2010, and 2020

Understanding future freight activity is important for matching infrastructure supply to demand and for assessing potential investment and operational strategies. To help decision-makers identify areas in need of capacity improvements, the U.S. Department of Transportation developed the Freight Analysis Framework (FAF), a comprehensive national data and analysis tool, including county-to-county freight flows for the truck, rail, water, and air modes. FAF also forecasts freight activity in 2010 and 2020 for each of these modes.

The U.S. freight transportation network moves a staggering volume of goods each year. Over 15 billion tons of goods, worth over $9 trillion, were moved in 1998. The movement of bulk goods, such as grains, coal, and ores, still comprises a large share of the tonnage moved on the U.S. freight network. However, lighter and more valuable goods, such as computers and office equipment, now make up an increasing proportion of what is moved. FAF estimates that trucks carried about 71 percent of the total tonnage and 80 percent of the total value of U.S. shipments in 1998. By 2020, the U.S. transportation system is expected to handle about 23 billion tons of cargo valued at nearly $30 trillion.

Louisiana

Table 15 presents information on freight shipments that have either an origin or a destination in Louisiana. As shown in the table, trucks moved a large percentage of the tonnage and value of shipments. Figures 11 and 12 show freight flows on the highway and rail modes. Louisiana also handles significant freight activity on its waterway system.

Truck traffic is expected to grow throughout the state over the next 20 years. Much of the growth will occur in urban areas and on the Interstate highway system (Figures 13 and 14). Truck traffic moving to and from Louisiana accounted for 17 percent of the average annual daily truck traffic (AADTT) on the FAF road network. Nearly 16 percent of truck traffic involved in-state shipments, and 18 percent involved trucks traveling across the state to other markets. Approximately 49 percent of the AADTT were not identified with a route-specific origin or destination.

Table 16 shows the top five commodity groups shipped to, from, and within Louisiana by all modes. The top commodities by weight are crude petroleum or natural gas, farm products, and petroleum or coal products. By value, the top commodities are chemicals or allied products and transportation equipment.

Table 15
Freight shipments to, from, and within Louisiana 1998, 2010, and 2020

	Tons (millions)			Value (billions $)		
	1998	**2010**	**2020**	**1998**	**2010**	**2020**
State Total	**972**	**1,374**	**1,703**	**440**	**798**	**1,238**
By Mode						
Air	<1	<1	<1	9	20	34
Highway	371	548	693	321	590	919
Other [a]	187	230	261	24	34	48
Rail	113	171	223	39	69	106
Water	302	424	526	47	85	131
By Destination/Market						
Domestic	651	916	1,112	361	655	998
International	322	457	591	78	143	240

Note: Modal numbers may not add to totals due to rounding.
[a] The "Other" category includes international shipments that moved via pipeline or by an unspecified mode.

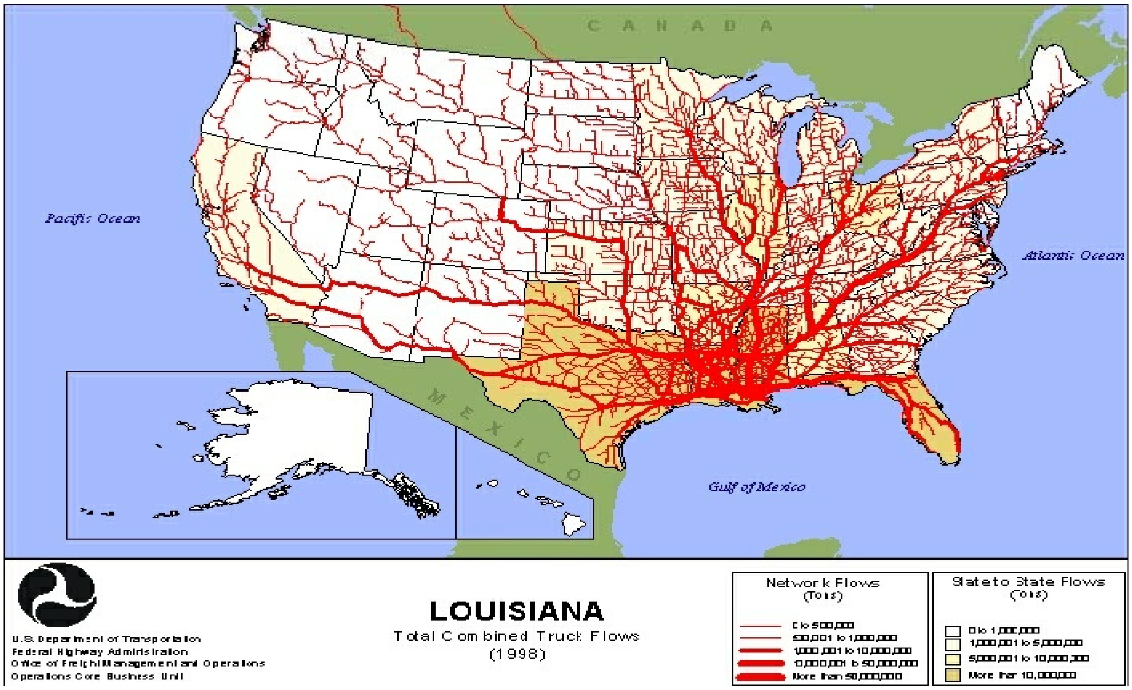

Figure 11
Freight flows to, from, and within Louisiana by truck: 1998 (tons)

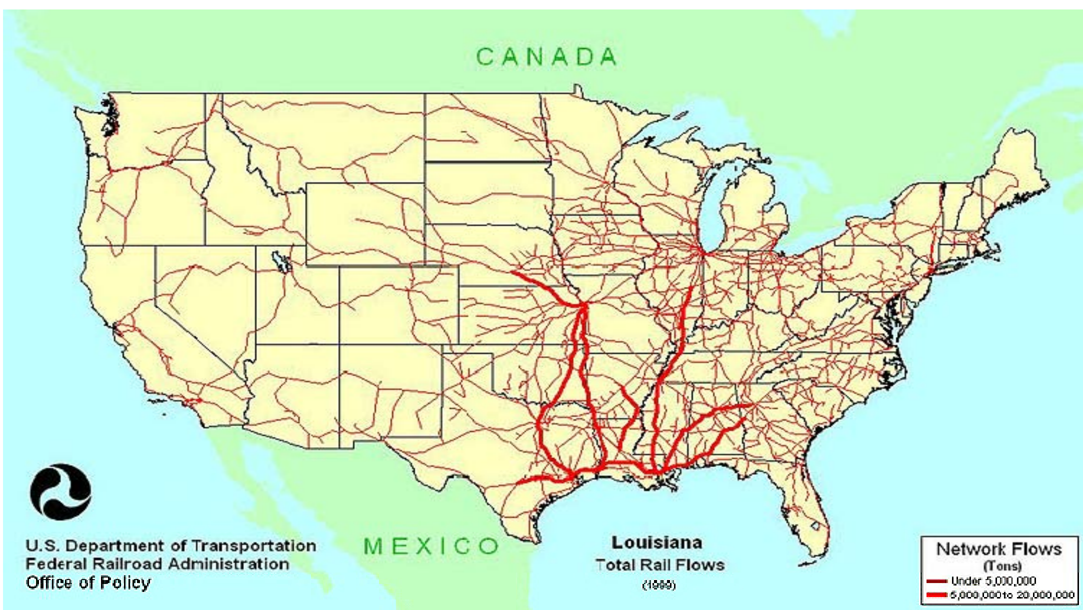

Figure 12
Freight flows to, from, and within Louisiana by rail: 1998 (tons)

Figure 13
Estimated average annual daily truck traffic: 1998

Figure 14
Estimated average annual daily truck traffic: 2020

Table 16
Top five commodities shipped to, from, and within Louisiana

Commodity	Tons (millions) 1998	Tons (millions) 2020	Commodity	Value (billions $) 1998	Value (billions $) 2020
Crude Petroleum/Natural Gas	183	235	Chemicals/Allied Products	94	250
Farm Products	159	314	Transportation Equipment	59	113
Petroleum/Coal Products	141	249	Food/Kindred Products	43	164
Chemicals/Allied Products	114	196	Primary Metal Products	33	81
Food/Kindred Products	60	140	Farm Products	33	75

More Information

A series of FAF products are available on the website noted below. FAF outputs include freight flow maps for states, modes, and gateways; detailed databases on traffic flows and commodity movements; information on the methodologies used to develop FAF; and forecast assumptions.

The U.S. Department of Transportation's Bureau of Transportation Statistics (BTS) is also developing a series of state transportation profiles. For more information and to obtain a copy of the BTS reports, please call 202-366-DATA.

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APPENDIX-2

Survey Questions on Trucking

The Louisiana Department of Transportation and Development is looking into keeping trucks out of the far left lane of major highways. As part of the study, we are getting public opinion; please indicate whether <u>you support keeping trucks out of the far left lane of the following highways in Louisiana.</u>

1. A. Regular four-lane freeways (i.e., two lanes in each direction) ❒ Yes ❒ No

   B. Four-lane freeways on bridges ❒ Yes ❒ No

   C. Regular six (or more) lane freeways ❒ Yes ❒ No

   D. Six (or more) lane freeways on bridges ❒ Yes ❒ No

   E. Four-lane divided highways (i.e., with island) that are not freeways ❒ Yes ❒ No

   F. Four-lane undivided highways ❒ Yes ❒ No

   G. Six (or more) lane divided highways that are not freeways ❒ Yes ❒ No

2. Do you think that keeping trucks out of the far left lane on any of the four lane or six lane roads would improve safety? ❒ Yes ❒ No

3. Do you think that keeping trucks out of the far left lane on the four and six lane roads would cause congestion in the other lanes? ❒ Yes ❒ No

4. Do you think that keeping trucks out of the far left lane on the four and six lane roads would make it more difficult to get onto and off of the road? ❒ Yes ❒ No

1. Area Code

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**225**	49	24.7	24.9	24.9
	318	52	26.3	26.4	51.3
	337	35	17.7	17.8	69.0
	504	37	18.7	18.8	87.8
	985	24	12.1	12.2	100.0
	Total	197	99.5	100.0	
Missing	**System**	1	.5		
	Total	198	100.0		

2. What is your gender?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Male**	86	43.4	44.1	44.1
	Female	109	55.1	55.9	100.0
	Total	195	98.5	100.0	
Missing	**System**	3	1.5		
	Total	198	100.0		

3. Highest grade you have completed?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**10th grade or less**	8	4.0	4.1	4.1
	12th grade or GED	70	35.4	35.7	39.8
	some college/technical school	45	22.7	23.0	62.8
	college graduate	71	35.9	36.2	99.0
		2	1.0	1.0	100.0
	Total	196	99.0	100.0	
Missing	**System**	2	1.0		
	Total	198	100.0		

4. Which racial or ethnic group do you best identify?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**white**	115	58.1	58.7	58.7
	african american, etc	69	34.8	35.2	93.9
	hispanic, etc	6	3.0	3.1	96.9
	asian, etc	4	2.0	2.0	99.0
	other	2	1.0	1.0	100.0
	Total	196	99.0	100.0	
Missing	**System**	2	1.0		
	Total	198	100.0		

5. Are you a licensed driver?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	178	89.9	92.7	92.7
	No	13	6.6	6.8	99.5
	4.00	1	.5	.5	100.0
	Total	192	97.0	100.0	
Missing	**System**	6	3.0		
	Total	198	100.0		

6. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Regular four-lane freeways

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	136	68.7	73.5	73.5
	No	49	24.7	26.5	100.0
	Total	185	93.4	100.0	
Missing	**System**	13	6.6		
	Total	198	100.0		

7. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Four-lane freeways on bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	129	65.2	70.1	70.1
	No	55	27.8	29.9	100.0
	Total	184	92.9	100.0	
Missing	**System**	14	7.1		
	Total	198	100.0		

8. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Regular six-lane freeways

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	140	70.7	74.1	74.1
	No	49	24.7	25.9	100.0
	Total	189	95.5	100.0	
Missing	**System**	9	4.5		
	Total	198	100.0		

9. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Six-lane freeways on bridges

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	140	70.7	74.5	74.5
	No	48	24.2	25.5	100.0
	Total	188	94.9	100.0	
Missing	**System**	10	5.1		
	Total	198	100.0		

10. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Four-lane divided highways

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	128	64.6	69.2	69.2
	No	57	28.8	30.8	100.0
	Total	185	93.4	100.0	
Missing	**System**	13	6.6		
	Total	198	100.0		

11. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Four-lane undivided highways

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	129	65.2	68.6	68.6
	No	59	29.8	31.4	100.0
	Total	188	94.9	100.0	
Missing	System	10	5.1		
	Total	198	100.0		

12. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Six-lane divided highways not freeways

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	134	67.7	70.9	70.9
	No	55	27.8	29.1	100.0
	Total	189	95.5	100.0	
Missing	System	9	4.5		
	Total	198	100.0		

13. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Six-lane divided highways

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	137	69.2	72.5	72.5
	No	52	26.3	27.5	100.0
	Total	189	95.5	100.0	
Missing	System	9	4.5		
	Total	198	100.0		

14. Your support in keeping trucks out of the far left lane of the following highways in Louisiana. Six-lane divided highways not freeways

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	134	67.7	70.9	70.9
	No	55	27.8	29.1	100.0
	Total	189	95.5	100.0	
Missing	System	9	4.5		
	Total	198	100.0		

15. Do you think that keeping truck out of the far left lane on any of the four lane or six lane roads would improve safety?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	135	68.2	72.6	72.6
	No	51	25.8	27.4	100.0
	Total	186	93.9	100.0	
Missing	System	12	6.1		
	Total	198	100.0		

16. Do you think that keeping truck out of the far left lane on the four lane or six lane roads would cause congestion in the other lanes?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	87	43.9	46.3	46.3
	No	101	51.0	53.7	100.0
	Total	188	94.9	100.0	
Missing	System	10	5.1		
	Total	198	100.0		

17. Do you think that keeping truck out of the far left lane on the four lane or six lane roads would make it more difficult to get onto & off of the road?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	106	53.5	56.4	56.4
	No	82	41.4	43.6	100.0
	Total	188	94.9	100.0	
Missing	**System**	10	5.1		
	Total	198	100.0		

18. Are you or someone in your household in the trucking business?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Yes**	41	20.7	21.4	21.4
	No	151	76.3	78.6	100.0
	Total	192	97.0	100.0	
Missing	**System**	6	3.0		
	Total	198	100.0		