Final Report
Research Project T9233, Task 22
Truck Restriction Evaluation

TRUCK RESTRICTION EVALUATION: THE PUGET SOUND EXPERIENCE

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EXECUTIVE SUMMARY

As congestion continues to build on Washington's highways, it is becoming important to improve the operational strategies of the roadway. This is especially true in urban areas. One of the strategies often promoted as a means for increasing roadway capacity is truck restrictions.

Two primary concerns exist with large trucks in the traffic stream. First, because of large trucks' operational limitations, people often perceive that they restrict the free flow of general traffic, resulting in low speeds, large headways, and ultimately, an underutilization of the facility.

Second, large trucks are thought to present a safety hazard because of their decreased stopping capabilities, their lack of maneuverability, and their large size, which occupies more lane space and blocks motorists' visibility.

Two concerns that are secondary to operational and safety levels are the detrimental economic impacts that result from the delay caused by trucks and the increased pavement deterioration caused by repetitive heavy loads.

Truck restrictions attempt to achieve one or more of four main objectives:

(1) improve highway operations,
(2) improve the level of safety,
(3) encourage more even pavement wear, and
(4) ensure better operation and safety through construction zones.

Four types of truck restrictions can be implemented for the purposes described above: (1) lane restrictions, (2) route restrictions, (3) time-of-day restrictions, and (4) speed restrictions. Lane restrictions are the only type of truck restriction that are being considered as part of this project for implementation in the Puget Sound region.

Approximately half of the states in the U.S. currently employ some type of truck lane restrictions. However, very few of these states have closely examined these lane restrictions or recorded their effect on traffic flow, safety, infrastructure maintenance, or the local economy. States that have studied some aspect of truck lane restriction impacts

include Florida, Nevada, Texas, and Virginia. In Florida, researchers considered the impacts of lane restrictions on the operation and safety of the facility and noted no change in them. In Nevada, researchers considered the impacts of lane restrictions on pavement deterioration and estimated that such restrictions allowed pavement improvements to be postponed for three to five years, extended design life by five to ten years, and reduced the need for overlays by 10 percent to 20 percent. Texas researchers examined the impacts of truck lane restrictions on facility operation and found that they produced no changes. Lastly, Virginia researchers considered safety impacts of truck lane restrictions; truck and vehicle accidents were observed to decrease slightly. In Florida, Texas, and Virginia, public support for the lane restrictions was favorable.

RESEARCH APPROACH

Three sites appeared to be suitable for the implementation of left-lane truck lane restrictions: (1) Interstate 5 (I-5) southbound on the hill from Southcenter, (2) State Route 520 westbound on the hill leading up from Redmond, and (3) I-5 southbound on the hill in Tacoma, where left-lane restrictions were already in place at the time of this study. A control site on I-5 near 185th Street in Seattle was also included in this study.

Three types of analyses were performed: (1) an in-depth analysis to determine how the implementation of a lane restriction would impact the operation, safety, and longevity of the facility, in addition to how it would economically impact the region; (2) a site comparison analysis to determine whether the results from the in-depth analysis could be applied to other areas in the region; and (3) a survey analysis to determine the opinions of truckers, motorists, and industry and enforcement officials regarding lane restrictions.

CONCLUSIONS

The results of these three analyses are summarized below. One caution should be noted when interpreting the in-depth analysis results. The lane distribution at the

Southcenter Hill site did not change significantly during the before-and-after analysis, indicating that a proportion of truck drivers were either willfully violating the lane restriction or unaware that a lane restriction existed. The lack of truck traffic redistribution throughout the facility has serious implications for this analysis. Any changes noted in the operation or safety of the Southcenter Hill site may not be attributable to the lane restriction because lane distribution conditions remained the same after the implementation of the restriction.

In-Depth Analysis

Volumes

- Trucks make up a very small percentage of the traffic in the Puget Sound region: just over 5 percent on the weekdays and just over 2 percent on the weekends.
- Unlike the volume levels for non-trucks, the volume level for trucks on the roadway does not increase significantly during the weekdays or during certain times of the day (morning and afternoon peak periods).
- The number of trucks violating the lane restriction was dependent on the level of congestion the facility experienced. The number of trucks in violation of the restriction increased greatly during the afternoon peak period.

Speeds

- Trucks and non-trucks experience similar speed distributions throughout the day, but truck speeds are substantially less, on the average, than non-truck speeds.
- Both trucks and non-trucks experienced a slight (but statistically significant) increase in average speed after implementation of the lane restriction, but it is unclear whether this increase is attributable to the lane restriction.
- The speeds of vehicle couplets may indicate that trucks are impeding the free flow of traffic because the average speeds for cars following cars and trucks following cars are greater than the speeds of cars following trucks and trucks following trucks.

- The only change in speed differential that occurred after implementation of the lane restriction took place between lanes 2 and 3, where a decrease was noted. However, this decrease does not appear to have resulted from the lane restriction.
- The number of trucks and non-trucks violating the speed limit increased substantially between 6 pm and 10 pm after implementation of the lane restriction. Again, this increase does not appear to have resulted from the lane restriction.

Occupancy

- Platoon lengths increased in lanes 2 and 3 after implementation.
- After implementation, the number of times per day trucks occupied lanes 1, 2, and 3 increased, but because there was no redistribution of trucks throughout the facility, this increase cannot be attributed to the lane restriction.

Incidents

- The proportion of truck-related accidents in each lane is similar to the proportion of trucks traveling in each lane (i.e., the majority of truck travel is in the right-most lanes; hence, the highest proportion of truck-related accidents occurs in the right-most lanes).
- The majority of accidents resulting from merging from an on-ramp, changing lanes to the left, or moving straight is initiated by vehicles other than trucks.
- The majority of accidents resulting from changing lanes to the right is initiated by trucks. This may indicate that a restriction that requires trucks to move to right-hand lanes may increase truck-involved accidents.
- The majority of truck-related accidents results only in property damage or minor injuries.

Compliance

- Restriction violation rates were only 2.1 percent. However, the proportion of trucks traveling in lane 4 prior to the restriction was also 2.1 percent, indicating that the restriction had no noticeable impact on the distribution of trucks throughout the facility. Operational characteristics at the study sites may have contributed to the lack of effect.

Economic Impacts

- Assuming 100 percent restriction compliance, the economic loss incurred by a driver who previously had traveled in lane 4 but now had to travel in lane 3 would total $4.84 per year (19.52 minutes of lost driving time). For the industry as a whole, economic losses would total $1,155 annually (82.2 hours of lost driving time).

Pavement Impacts

- Even assuming extreme conditions (i.e., 100 percent compliance with the restriction and no weather effects on the pavement), a truck lane restriction would have minimal impacts on the life of the pavement at the Southcenter Hill site.

Site Comparison Analysis

- The proportion of trucks in the traffic stream is variable, depending on site proximity to major terminals, ports, and CBDs.
- Truck distribution throughout the facilities, truck and non-truck speeds, and restriction violation rates vary depending on (1) site proximity, (2) facility size, (3) volume levels of the sites, (4) degree and length of grade, and (5) location of entrances and exits.
- Variations found in time-gap measurements could have resulted from inaccurate data collection methods.

Survey Results

- Of the motorists surveyed, 90.85 percent favored lane restrictions, while only 31.96 percent of the truckers favored lane restrictions.
- The type of trucker who is least likely to favor lane restrictions admits to violating restrictions, frequently changes lanes to avoid rough pavement, typically carries

non-perishable cargo, is between 20 and 40 years old, and has been licensed for many years.

- Truckers were more willing to favor Puget Sound truck-lane restrictions if they traveled on the I-5 Southcenter and SR-520 restricted highway sections. There was some support for restrictions in areas with few lanes and in areas that do not require merging/diverging lane changes. Lane restrictions in areas with high concentrations of merging/diverging traffic may be perceived to adversely affect the safe operation of traffic.
- The type of motorist who is most likely to favor restrictions frequently changes lanes to avoid being followed by a truck, drives a passenger car, is between 30 and 45 years old, and has been licensed for a long time.
- The motorist most likely to be aware of Puget Sound truck-lane restrictions is male, drives a passenger car, and has been licensed for a relatively short time. Motorists are more likely to be aware of restrictions when benefits are perceived (e.g., the relatively low number of lanes and merging/diverging sections on I-5 Southcenter and SR-520) and when they are not distracted by complex geometrics (e.g., the merging/diverging at the I-5 Tacoma site).

RECOMMENDATIONS

At this time, additional truck lane restrictions are not recommended for implementation in the Puget Sound region. This recommendation is based on four factors.

First, little evidence exists nationally to support the notion that truck lane restrictions improve the operation, safety, or pavement deterioration rates of a facility or that they reduce economic impacts to the users. Studies conducted in Florida, Texas, and Virginia found negligible change in the operation or safety of a facility after the implementation of a truck lane restriction.

Second, the literature indicates that a higher proportion of trucks in the traffic stream results in greater impacts when those trucks are redistributed across the facility. (1) Therefore, because the proportion of trucks in the traffic stream is very small, approximately 5 percent in the Puget Sound sites studied, the researchers suggest that any truck redistribution would result in minimal impact on the operation, safety, and pavement deterioration rates of the facility and on the economic standing of the user. (Remember that the in-depth analysis performed as part of this study was inconclusive because of a lack of truck traffic redistribution.)

Third, too much variability exists among the study sites for widespread implementation of truck lane restrictions. Again, citing from the literature, higher traffic volumes and a higher percentage of trucks in the traffic stream result in greater impacts when the truck traffic is redistributed across the facility. (1) Both of these factors, traffic volume and truck traffic proportion, varied among the sites selected for comparison. Most of this variability lay in differing facility sizes and differing proximities to major trucking origins and destinations (e.g., the ports). This variability implies that the results of a truck lane restrictions test conducted at a single site cannot be extrapolated to other sites. Instead, each site requires analysis based on its own characteristics to determine the potential impacts of a truck lane restriction.

Lastly, while the majority of motorists may favor truck lane restrictions, only a small proportion of trucking industry representatives are in favor of them. Implementation of a truck lane restriction may be viewed by the industry as an infringement of its rights to operate a business.

For the truck lane restrictions already implemented in the Puget Sound region, no additional signing efforts are recommended. The signs that are currently in place meet the state's sign specification and are felt to be adequate. However, development of an informative brochure for distribution to the trucking industry may be beneficial. A brochure that lists the facility segments in Washington that are subject to a truck-related restriction may encourage compliance.

No additional enforcement efforts are recommended to achieve higher restriction compliance. The percentage of trucks that violate the restriction is small; citing the trucks in violation would not be an efficient use of the enforcement resources.

Other types of restrictions, such as time-of-day restrictions, should not be considered for implementation in the Puget Sound region without a comprehensive survey of national experiences. (Little formal literature was found that discussed the success of time-of-day restrictions, route restrictions, and speed restrictions for improving the operation, safety, or pavement deterioration rates of a facility or the economic impacts to the user.)

Further work should instead concentrate on public education efforts. While no conclusive evidence supports the benefit of restrictions, over 90 percent of the motorists surveyed favored truck lane restrictions. Obviously, motorists' perception is that trucks cause a problem on the roadway. However, it is not fair to restrict the trucking industry on the basis of motorists' perception alone. Therefore, further research may be required (1) to determine *why* motorists perceive trucks the way they do and (2) to determine the education efforts that would be most successful in presenting the motoring public with accurate operational and safety-related information.

INTRODUCTION

As congestion continues to build on Washington highways, people are placing more and more importance on improving the operational strategies of the roadway. This is especially true in urban areas. One of the strategies often promoted to increase roadway capacity is the implementation of truck restrictions.

People often perceive that large trucks in the traffic stream restrict the free flow of traffic and present a safety problem, particularly during peak-flow periods. This perception is based on the assumption that large trucks travel more slowly than other vehicles. The large size of the truck is also intimidating to motorists and restricts their visibility. Part of the perception that large trucks restrict traffic may be due to the way the operational characteristics of large trucks differ from the operational characteristics of other vehicles, such as passenger cars, small trucks, and pick ups.

Because of their low power to weight ratio, large trucks are unable to accelerate, decelerate, or maintain speeds as well other vehicles, especially on grades. The difference, of course, depends on the truck type and weight, as well as the traffic volume and degree of grade. This factor has the potential to greatly reduce the operational efficiency of the roadway. The effects are greatest during the morning and afternoon peak periods.

A trucks' inability to accelerate, decelerate, or maintain speed may also pose a safety risk. Because of the large trucks' great weight, they require a greater stopping distance than other vehicles. When stopping distance is constrained, severe rear-end accidents may result. The severity of these accidents usually increases as the trucks' speed increases. Trucks face a unique problem during peaks, when volumes greatly increase but speeds decrease very little. The trucks are still traveling at a relatively high speed, but they have less room to maneuver.

In addition to the operational differences between large trucks and other vehicles, visibility differences also exist. The height, width, and length dimensions of large trucks severely limit the range of vision for both the truck driver and the surrounding motorists. For the truck driver, visibility is reduced on both sides, and to the rear of the truck. These blind spots greatly increase the risk of a sideswipe accident when the truck driver is merging into the traffic stream, diverging from it, or changing lanes.

Trucks traveling next to or in front of other vehicles also reduce the distance at which motorists can see exit signs, special warning signs (e.g., "right lane closed ahead"), and unexpected stops. This impairment can lead to dangerous maneuvers that can be avoided if the motorist has adequate sight distance. In inclement weather, this visibility problem is heightened. A spray of snow or rain from the tires of the truck can temporarily block other drivers' vision, creating the potential for rear-end accidents.

Large trucks also create physical disturbances in the traffic stream. (1) When traveling at high speeds, trucks create powerful air disturbances that can cause unsuspecting motorists to temporarily lose control of their relatively lightweight automobiles.

Lastly, large trucks are psychologically intimidating to other motorists. Trucks occupy more length and width of a lane than a typical vehicle. Motorists often feel threatened by the closeness of a truck in the adjacent lane. This is becoming an even greater problem because of the trend to manufacture larger trucks and smaller cars.

The preceding paragraphs have discussed how large trucks in the traffic stream can potentially impact day-to-day roadway operations and also decrease roadway safety. But what are the impacts when an accident involving a truck occurs?

If a truck driver makes a sudden or evasive motion, the danger to other motorists stems not only from the truck itself but also from the load it is carrying. For any type of non-containerized transport, the potential for a dumped load during an accident is great, and by dumping its load, a single disabled truck can impact several lanes of travel. Also, some trucks may contain hazardous or explosive materials that can endanger a much greater area than the impacted lane.

Not only are incidents involving large trucks more severe and a greater hazard than vehicle accidents, they are also much more costly. Impaired trucks often block multiple lanes and require more time to be cleared. This delay results in a greater cost.

The problem can not simply be solved by restricting trucks from the traffic stream. The trucking industry carries more freight, employs more people, and generates more revenue than any other transportation mode. In addition, the trucking industry has a legal right to use the roadway. Wide implementation of exclusive truck routes is costly. Thus, it is necessary to examine the success of less drastic measures, such as trucking restrictions, that can be implemented on existing facilities.

BACKGROUND

Truck restrictions attempt to achieve one or more of the following four objectives:

- to improve highway operations,
- to improve the level of safety,
- to provide for more even pavement wear, and
- to ensure better operation and safety through construction zones.

Four types of truck restrictions can be implemented for the purposes described above: lane restrictions, route restrictions, time-of-day restrictions, and speed restrictions. These restrictions are more fully defined below.

- Lane restrictions - all trucks, or trucks of a specific size, weight, or axle configuration, are restricted from traveling in specified lanes on the facility.

- Route restrictions - all trucks, or trucks of a specific size, weight, or axle configuration, are restricted from traveling on certain routes.

- Time-of-day restrictions - all trucks, or trucks of a specific size, weight, or axle configuration, are restricted from specific lanes or specific routes at specified times of the day, usually during peak hours.

- Speed restrictions - all trucks, or trucks of a specific size, weight, or axle configuration, are restricted to traveling at lower speeds than the rest of the traffic stream.

Lane restriction is the only type of restriction under consideration as part of this project for implementation in the Puget Sound region. The following issues should be considered before the implementation of lane restrictions.

- Should the restriction be implemented statewide or on a site-specific basis?
- How many lanes should be included in the restriction?
- Which lanes should be included in the restriction?
- Will the access/egress areas (on/off ramps) along the facility be affected by the restriction?
- How will the restriction impacts differ for different freeway orientations (radial or circumferential) that have different levels of facility entrance/exit activity?
- How great will the impacts be, given the volume of traffic on the roadway?
- Should the lane restriction be implemented on a continual basis or only during peak periods or other times of the day?
- Will concentrating trucks in the remaining lanes present safety problems?
- Will concentrating trucks in the remaining lanes result in accelerated pavement wear?

These issues in general, and how they apply specifically to the Puget Sound region, will be considered and discussed in later sections of this report.

PROBLEM DEFINITION

Large trucks in the traffic stream raise two primary concerns. First, because of large trucks' operational limitations, people perceive that they restrict the free flow capabilities of the general traffic, which results in lower speeds, larger headways, and ultimately, an underutilization of the facility.

Second, large trucks are thought to present a safety hazard because of their decreased stopping capabilities, their lack of maneuverability, and their large size, which occupies more lane space and blocks motorists' visibility.

Two additional concerns, which are secondary to operational and safety levels, are the detrimental economic impacts that result from traffic delays caused by trucks and the increased pavement deterioration from continual heavy loads.

Because few studies have been conducted to determine the consequences of truck restrictions or, more specifically, truck lane restrictions, little is known about their effect on the operation, safety, economy, or pavement deterioration rate of a roadway. The purpose of this study is to more fully investigate the consequences of implementing truck lane restrictions and their applicability to other regions.

GOALS AND OBJECTIVES

The overall goal of this truck lane restriction evaluation is to improve the operational efficiency, safety, and design life of the facility, while maintaining an adequate level of economic prosperity.

Several objectives for the ultimate attainment of this goal are as follows.

- Determine changes in traffic flow rate, vehicle speeds, and vehicle spacing after the truck restriction is operational.
- Examine changes in accident rates, accident types, and accident severities.
- Estimate violation rates.
- Estimate changes in pavement deterioration rates.
- Estimate the economic impacts of the restrictions.

Less quantifiable objectives that should be addressed include providing an overview of truck restriction use in the U.S.; analyzing the opinions of motorists, truckers, and the trucking industry regarding truck restrictions; and making recommendations for their future use.

DESCRIPTION OF THE STUDY AREA

When the effects of truck lane restrictions are examined, the trucking industry's importance to a region, as well as the location of the major trucking routes in relation to the rest of the region, should be taken into account.

Two major trucking corridors exist in the Puget Sound region: Interstate 5 runs north to south from the Canadian border, through the Seattle central business district, and through Oregon and California, where it joins Interstate 10 and heads east through Arizona, New Mexico, and Texas (see Figure 1). Interstate 90, the major east to west route in this region, originates in the Seattle central business district and runs east, through the eastern half of Washington State, Idaho, and Montana.

Both Interstate 5 and Interstate 90 provide convenient routes for transporting goods that arrive at the Port of Seattle for shipment to other parts of the nation. In addition, Interstate 5 is a convenient route for transporting goods that arrive at the Port of Tacoma (see Figure 2).

SITE SELECTION

The sites for the study were selected before the data collection process. The selection of freeway sections in the Puget Sound region suitable for the analysis of truck lane restrictions was based on a number of key factors:

- geometric considerations (grades and number of lanes),
- availability of traffic and accident data,
- potential benefits, and
- feasibility of implementation.

Given these factors, the following three sites seemed suitable for the implementation of left-lane truck lane restrictions: (1) Interstate 5, southbound, on the hill from Southcenter, (2) State Route 520, westbound, on the hill leading up from Redmond, and (3) Interstate 5, southbound, on the hill in Tacoma, where lane restrictions were already in force (see Figure 3). A control site on I-5 near 185th Street in Seattle was also considered in this study because an automatic data collection system was already in place there. A more detailed description of each site is given below. Plan and profile views of the sites are also provided in Figure 4. In addition, a summary of the facility characteristics at each site is given in Table 1. For convenience, the sites have been labeled A, B, C, and D and

Figure 1. Major Trucking Routes in the Western U.S.

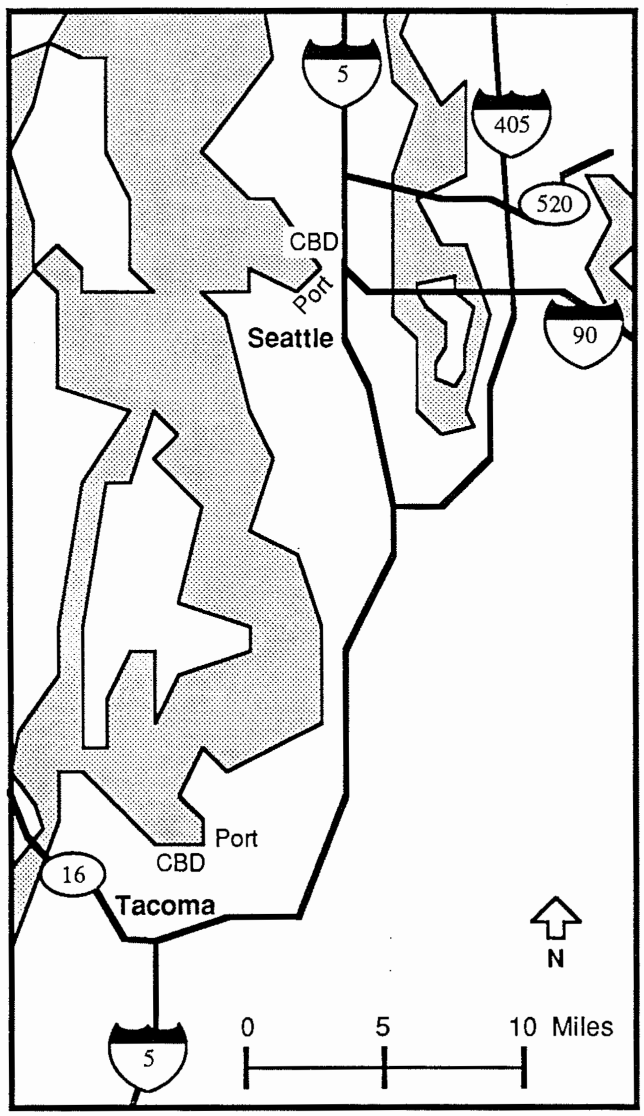
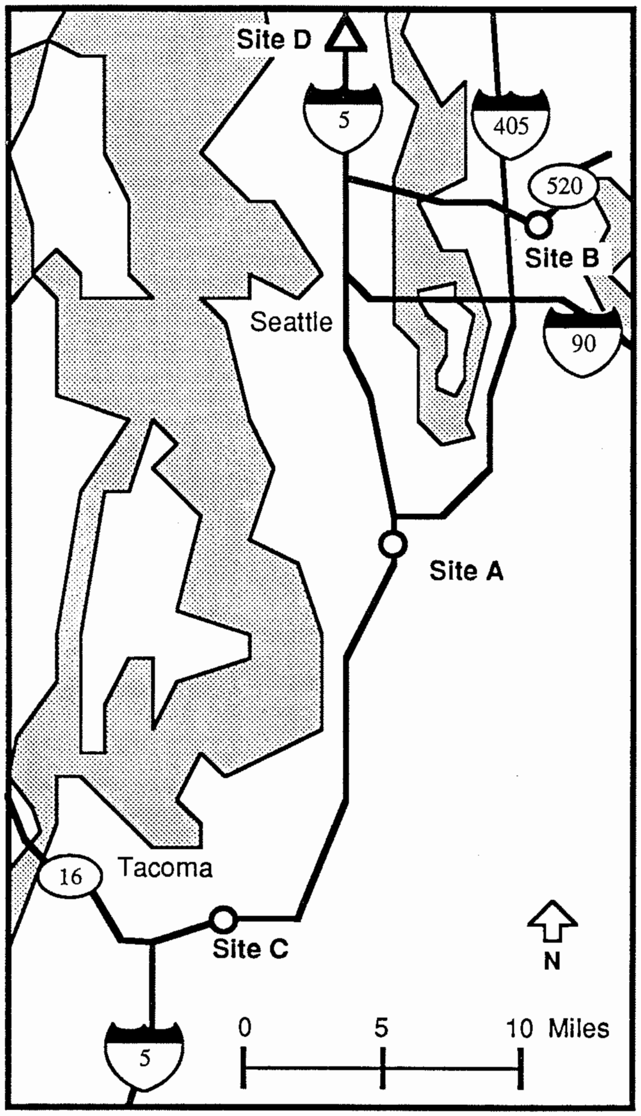


Figure 2. Proximity of Ports and CBDs to Major Puget Sound Truck Routes



O = Truck Lane Restriction Sites
Δ = Control Site

Figure 3. Study Sites in the Puget Sound Region

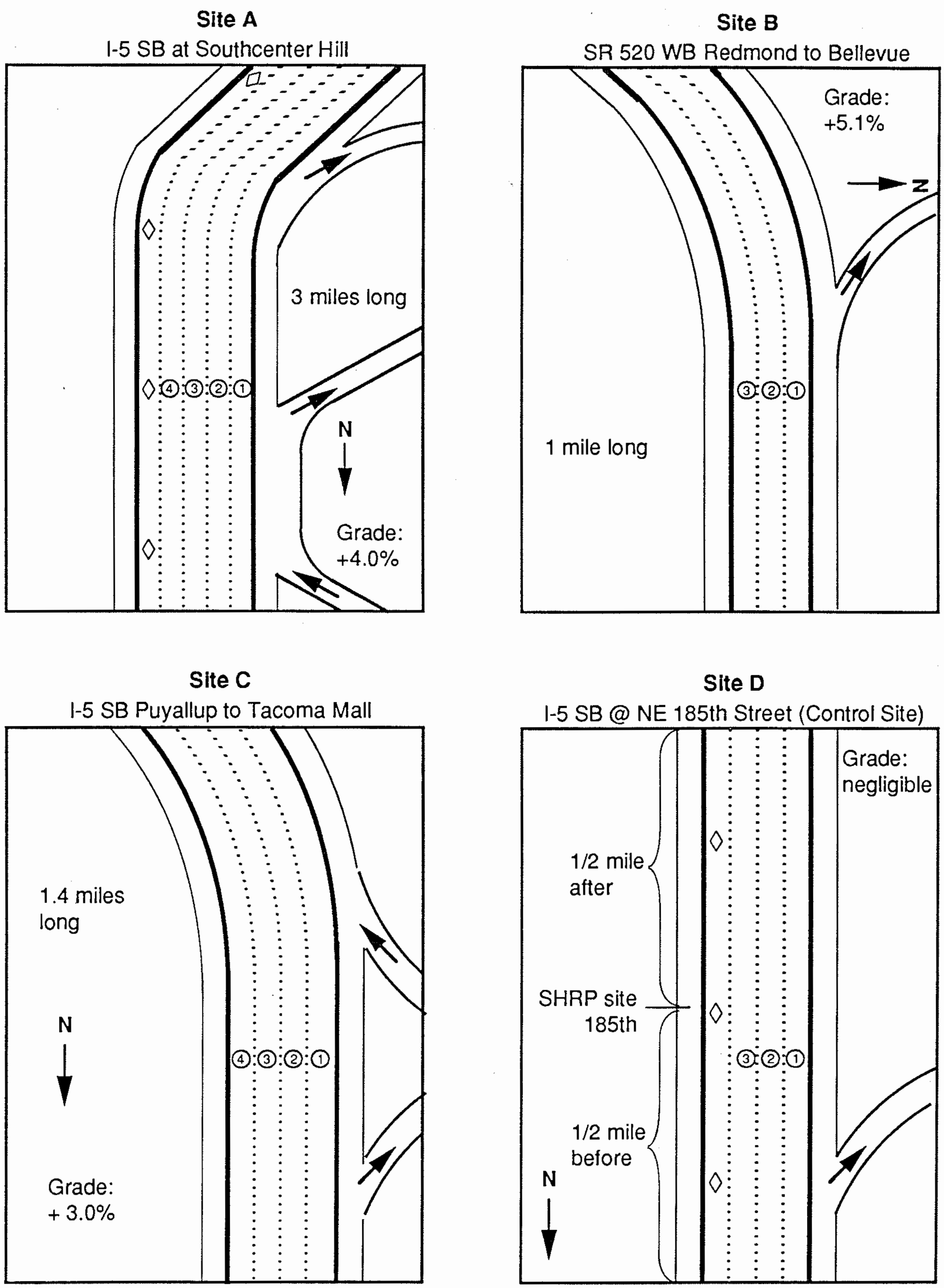


Figure 4. Plan and Profile Views of the Study Sites

Table 1. Facility Characteristics at the Study Sites (1993)

Data Collection Phases	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
No. of Exits	2	1	1	1
No. of Entrances	1	0	1	0
Posted Speed	55 mph	55 mph	55 mph	55 mph
No. of Signs	4	3	2	None

will be referred to as such throughout the rest of this report. Pictures of the signs erected or in place at each site are shown in Figure 5.

Site A: I-5 Southbound at Southcenter Hill

The researchers performed an in-depth analysis at the I-5 Southcenter Hill site. This analysis would indicate whether the operation and safety of the roadway was impacted after the truck lane restriction had been implemented. Extensive "before" and "after" data were collected so changes could be detected. Outside factors that could affect changes in the safety and operation of the facility were also taken into account.

Site B: SR 520 Westbound from Redmond to Bellevue

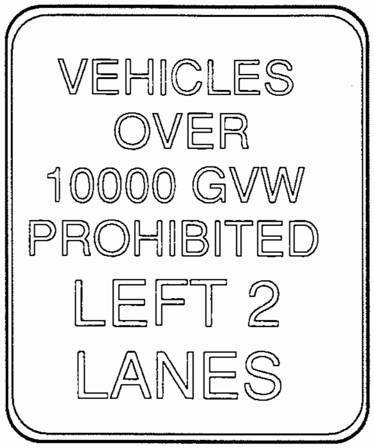
The SR 520/ Redmond to Bellevue site was selected to enable the researchers to detect differences between this three-lane facility and the larger Interstate 5 sites. The researchers hypothesized that truck lane restrictions would have a greater impact on smaller facilities. Comparing the operational and safety characteristics of both sites would indicate whether this hypothesis was accurate.

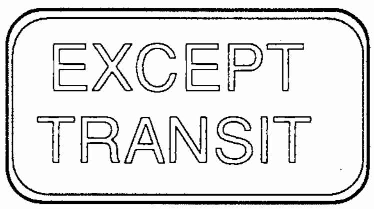
Site C: I-5 Southbound from the Puyallup River Bridge to the Tacoma Mall

By examining a site similar to the Southcenter Hill site, the applicability of the results obtained from the Southcenter Hill to other areas of the state, as well as to other area of the nation, could be examined. The facilities are very similar: they are both multi-lane facilities, with uphill grades in urban areas with high traffic volumes. The researchers anticipated that similar operational and safety characteristics would exist at these two sites.

Site D (Control Site): I-5 Southbound at 185th Street

The purpose of including this control site was to enable the researchers to compare the traffic composition and typical volume levels of this site to those of other study sites. If the percentage of trucks in the traffic stream was consistent throughout the Puget Sound region, it would be reasonable to apply the results of this study to other areas in the region. However, if the percentage of trucks or the volume levels were





Site A: I-5 SB @ South Center Hill

Site B: SR 520 WB, Redmond to Bellevue

and

Site C: I-5 SB, Puyallup River Bridge to Tacoma Mall

Figure 5. Lane Restriction Signing

inconsistent, then it might not be realistic to apply these results to other areas. (The examination of the control site was not intended to check the operation and safety of the roadway with and without a truck restriction. Because no grade exists at the control site, it would have been difficult to make any kind of operational comparisons.)

REPORT CONTENTS

The following information is contained in this report:

- a discussion of the experiences of other areas across the United States that have implemented truck restrictions,
- a summary of factors to consider when selecting, implementing, and measuring the effectiveness of truck restrictions,
- a description of the data collection methods and research approach used in the Puget Sound region,
- a discussion of the results of the Puget Sound experience, including an in-depth analysis at the Southcenter Hill site, a site comparison analysis of all of the study sites, and the survey results, and
- recommendations for future truck restriction implementation in the Puget Sound region based on these findings.

REVIEW OF EXPERIENCES ACROSS THE U.S.

When truck restriction strategies throughout the U.S. are reviewed, it is important to consider

- literature that addresses truck restriction strategies,
- site-specific studies that have examined the effects of truck restriction strategies, and
- common practices of implementing and operating truck restriction strategies.

The types of restrictions prevalent throughout the United States and addressed in the literature include 1) lane restrictions (including exclusive truck lanes), 2) route restrictions, 3) time-of-day restrictions, and 4) speed restrictions. (These restriction types were defined earlier in this report.)

LITERATURE

Current literature provides a wide range of information on the topic of truck restriction strategies. Not only are a number of different strategies utilized throughout the U.S. to restrict truck travel (see Table 2), but a variety of ways to analyze the effectiveness of these strategies is also available. However, the literature lacks a single, comprehensive report that examines and discusses the effects these truck restriction strategies have on traffic flow, safety, the life of the roadway infrastructure, and the economy of a region. Most studies examine only one aspect of the overall effect, such as safety or pavement deterioration. The following section gives an overview of the literature available on the various restriction types.

Lane Restrictions

When a truck lane restriction is in effect, trucks can be either required or requested to use certain lanes or not to use certain lanes. On larger facilities it may be more convenient to specify lanes that trucks are not permitted to use than to specify lanes

Table 2. Truck Restriction Strategies in the U.S.

Location	Restriction Type			
	Lane	Route	Time	Speed
Alabama		X		X
Arizona	X	X	X	
Arkansas	X	X		
California	X	X	X	X
Colorado	X	X	X	X
Connecticut	X			
Florida	X	X		
Georgia	X	X		
Idaho	X			
Illinois		X	X	X
Indiana	X	X	X	X
Iowa			X	
Kansas		X	X	
Kentucky	X			
Louisiana	X	X	X	
Maryland	X	X	X	
Massachusetts	X	X		
Michigan		X		X
Minnesota		X	X	
Mississippi		X		
Missouri	X	X		X
Nevada	X		X	
New Jersey	X	X	X	
New York	X	X		
North Carolina	X	X		
Ohio		X		X
Oklahoma	X	X	X	
Oregon	X		X	X
Pennsylvania	X	X	X	
Rhode Island		X	X	
South Carolina		X		
Texas	X			X
Utah			X	
Virginia	X	X		X
Washington		X	X	X
West Virginia		X		
Wisconsin	X			

that they are permitted to use. There are several variations in truck lane restriction strategies.

Approximately half of the states in the U.S. currently employ some type of truck lane restrictions. However, very few of these states have closely examined these lane restrictions or recorded their effect on traffic flow, safety, infrastructure maintenance, or the economy. Some of the more complete studies that have been conducted to examine the impacts of truck lane restrictions include the following:

- "Operational Effects of Three Truck Lane Restrictions," by Fred R. Hanscom,
- "An Evaluation of the I-95 Truck Restriction in Broward County," by the Florida Department of Transportation,
- "Truck Lane Redistribution Test on an Interstate Highway," by the Nevada Department of Transportation,
- "An Operational Evaluation of the Interstate 20 Truck Restriction in Texas," by the Texas Transportation Institute,
- "An Operational Evaluation of Truck Restrictions on Six-Lane Rural Interstates in Texas, by the Texas Transportation Institute, and
- "Capital Beltway Truck/Tractor Trailer Restriction Study," by the Virginia Department of Highways and Transportation.

The site-specific studies listed here will be discussed in more detail later in this report.

In addition to these state-specific studies, a number of papers have been written that examine national trends with respect to truck lane restrictions. These studies include

- "Impacts and Effectiveness of Truck Lane Restrictions" by the Maryland Department of Transportation,
- "The Effect of Truck Traffic Control Strategies on Traffic Flow and Safety on Multilane Highways," by the University of Virginia, and
- "Urban Freeway Gridlock Study: Summary Report," by Cambridge Systematics, Inc.

The third study was prepared for the California Department of Transportation but contains information useful on a national level regarding truck lane restrictions.

Studies conducted on a national level provide information similar to the site-specific studies regarding implementation considerations and analysis techniques for evaluating the effectiveness of the truck restriction strategy. The evaluation is usually focused on the operation of the facility or safety aspects, but other impacts, such as economics and pavement wear, are also considered.

A study conducted by Garber and Gadiraju, using simulation techniques, indicated that no improvement to the level of safety would result with the implementation of truck control strategies. (2) In fact, on highways with high traffic volumes and a high percentage of trucks in the traffic stream, the implementation of truck control strategies would create the potential for accident rates to increase. The truck control strategies investigated in this report included speed restriction or differential speed limits, and lane restrictions.

The study conducted by the Maryland Department of Transportation was especially good, as it attempted to identify, on a state-by-state basis, the types and locations of truck restriction strategies.

In addition to studies that examine the effects of conventional lane restrictions, two Texas-based studies examine the impacts resulting from exclusive truck lanes:

- "The Feasibility of Exclusive Truck Lanes for the Houston-Beaumont Corridor," cooperatively produced by the Texas Transportation Institute and the Texas Department of Highways and Public Transportation, and
- "Truck Utilization of the I-45N Contraflow Lane in Houston—A Feasibility Study," by the Texas Transportation Institute.

The results of these studies will also be discussed in more detail later in this report in a section that addresses the site-specific studies.

Route Restrictions

Whereas truck lane restrictions are implemented to improve the interaction of trucks with mixed traffic by limiting the lanes of travel available for trucks, route restrictions serve to remove trucks altogether from mixed traffic in certain areas.

Unfortunately, little effort has been made to quantify or even address the effectiveness of route restrictions as a truck restriction strategy, as no literature was found on this subject.

Time-of-Day Restrictions

Time-of-day restrictions prevent commercial vehicle drivers from driving during those times of the day when traffic congestion is at its highest level (i.e., peak traffic times). Because of trucks' large size and limited visibility, people presume that trucks pose serious threats as drivers try to maneuver on crowded roadways. If an accident or incident occurs, lengthy delays result, and substantial vehicle-hours and person-hours are wasted.

The "Urban Freeway Gridlock Study: Summary Report," by Cambridge Systematics, Inc. briefly addressed the topic of peak-period freeway bans for trucks and the implications they might have. After examining the Los Angeles, San Francisco, and San Diego metropolitan areas, the researchers estimated that the peak-period ban would force motor carriers to divert to parallel arterials, would shift operations to off-peak times, would increase the use of two-axle trucks, which are outside the scope of the ban, and would possibly shift the location of the terminals and drop points. The study predicted the following conclusions: 1) increased average speeds on the core freeways during peak times, 2) increased levels of safety on the core freeways, and 3) improved air quality. (3) At this time, this peak-period truck ban in the Southern California region is merely speculative.

Speed Restrictions

Speed restrictions for trucks, or differential speed limits, were originally instituted to improve safety on federal highways. The limited maneuvering and braking qualities associated with most truck designs implied that trucks should be required to travel at lower speeds in mixed traffic to help accommodate for the difference in handling capabilities. However, there is now some concern that differential speeds within and between lanes could pose more of a safety problem.

The report "Different Speed Limits for Cars and Trucks: Do They Affect Vehicle Speeds" did not address this safety aspect, but instead considered how the overall speed of the facility is affected. The researchers examined two states with differential speed limits for cars and trucks and two states that had a uniform speed limit, and the results were as follows:

- truck speeds were reduced when there was a differential speed limit, and
- trucks made up a smaller percentage of the high speed traffic in states with differential speed limits. (4)

No attempts are made in this report to study the phenomenon of reduced speeds and accident frequency to severity.

DESCRIPTION OF SITE-SPECIFIC STUDIES

In this section, site-specific studies outlined in our literature review are discussed in more detail. These studies examine and discuss the effects of truck lane restrictions, with the exception of a study conducted in Texas that also examined the feasibility of exclusive truck lanes. The researchers focused on lane restriction strategies for the following reasons: 1) the intent of this paper is to examine the impacts resulting from only truck lane restrictions, and 2) truck lane restrictions studies dominate the literature.

Florida

Florida researchers planned to examine the effects on both the operation and safety of the Interstate 95 facility after the implementation of a lane restriction. The results of these efforts were summarized in the report "An Evaluation of the I-95 Truck Restriction in Broward County," by the Florida Department of Transportation.

Tractor-trailers and single unit trucks were banned from the median lane in this lane restriction implementation. Traffic volumes, vehicle classifications by lane, speed, and accident frequencies were examined to measure the effectiveness of lane restrictions.

A high compliance rate was discovered when the trucks were redistributed in the non-restricted lanes. The only change in the distribution of passenger vehicles was an increase of passenger vehicles in the median lane northbound and a decrease of passenger vehicles in the median lane southbound. (5)

The speed studies were inconclusive. However, the report noted that, compared to the number of speed violations before the lane restriction had been implemented, the number of tractor-trailer drivers that violated the 55 mph speed limit increased during the morning peak-period and decreased during the afternoon peak-period. (5)

Accident frequencies were assessed, but no conclusions were drawn because of the short analysis period of two months.

Nevada

Nevada researchers undertook a study to determine the impact of a voluntary truck lane restriction. They requested that trucks travel in the left-hand lane to ease the pavement deterioration rate in the well traveled right lane. The results of this study were summarized in the report "Truck Lane Redistribution Test on an Interstate Highway," by the Nevada Department of Transportation.

For the purpose of this study, vehicles were classified as follows: 1) cars (including small trucks), 2) buses, 3) single unit trucks, and 4) truck combinations. Test sites were determined by the condition of the pavement. Pavement design considerations included the original pavement conditions, environmental effects, and funding availability for routine maintenance and improvements. No long-term effects on pavement deterioration rates were studied.

After signs requesting trucks to use left lane were placed on the highway, 60 percent of trucks voluntarily traveled in the left-hand lane. This was consistent even eight months later, when a follow-up study was conducted to determine whether the distributions had changed. Distributions of other vehicles (e.g., cars and buses) were the same before and after the placement of the restriction signs. (6)

On the basis of the redistribution of trucks on the facility, Nevada researchers speculated that recommended improvements could be completed three years to five years early if voluntary lane restrictions were implemented on the entire rural interstate system. This would result in an annual savings in pavement construction of $1.1 million (1988 dollars). Recently constructed projects could achieve an extended life of five years to ten years. Furthermore, future construction, reconstruction, and overlays could be reduced by 10 percent to 20 percent. (6)

Although it was beyond the scope of the study, Nevada researchers noted that the redistribution of trucks had no significant impact on traffic accidents. (6)

Texas

Extensive studies have been conducted in Texas to examine the operational effects of lane restrictions on rural interstates. The results of these efforts were summarized in the reports "An Operational Evaluation of the Interstate 20 Truck Restriction in Texas" and "An Operational Evaluation of Truck Restrictions on Six-Lane Rural Interstates in Texas," both by the Texas Transportation Institute.

The Texas researchers' efforts focused on three six-lane, rural interstate highways with differential speed limits of 65 mph for cars and 60 mph for trucks (vehicles with three or more axles). The three highways included I-20, I-10, and I-35. No control sites were included in this study. The traffic was divided into peak and non-peak periods to account for changes in volume, except on Interstate 10, where there was no difference between peak and non-peak volumes. Specific measures of effectiveness for this study included vehicle speeds and vehicle headways or time gaps. This study did not attempt to examine safety impacts or changes in pavement wear.

After the lane restriction had been implemented, the distribution of trucks increased significantly to a 62 percent compliance rate. At the I-20 site, the percentage of trucks only increased in the right lane. For the sites along I-10 and I-35, the percentage of trucks increased in both the middle and right lanes. No change was detected in the distribution of cars. (7, 8) This is consistent with what the Nevada researchers found.

While the redistribution of trucks was significant, it appeared to have no measurable impact on the time gaps between vehicles or the speed of cars or trucks. However, the report noted that the time gaps for trucks following trucks were less than the time gaps for trucks following cars. It also noted that the facility grade significantly affected the speed of trucks. (7, 8)

In addition to the examination of operational changes, a pre-implementation and post-implementation survey were conducted to determine driver opinion of the effectiveness of the lane restrictions, and to determine the most effective signing system for both motorists and truck drivers.

The results of the pre-implementation survey showed that 60 percent of the motorists favored truck lane restrictions. Only 28 percent of the truckers favored the truck restrictions. They thought the restrictions would cause merging and diverging conflicts, impede cars, and create undue congestion. (7, 8)

The second survey, which was administered after the restriction had taken place, showed 48 percent of motorists favored the restriction, 20 percent of the truckers favored the restriction, and a high number of respondents were unsure whether truck lane restrictions were a good idea. (7, 8)

In addition to examining the operational effects of lane restrictions on rural Texas interstates, two studies were conducted that examined the feasibility of exclusive truck lanes. The results of these efforts were summarized in the reports "The Feasibility of Exclusive Truck Lanes for the Houston-Beaumont Corridor," cooperatively produced, by the Texas Transportation Institute and the Texas Department of Highways and Public Transportation, and "Truck Utilization of the I-45N Contraflow Lane in Houston - A Feasibility Study," by the Texas Transportation Institute.

The first study, which examined the use of exclusive truck lanes for the Houston-Beaumont corridor, concluded that widespread implementation of exclusive truck facilities could not be justified at the time. In addition, implementation concerns, such as legally defining who could use the facility, funding requirements, and the need for truck support facilities (truck stops, garages) further hindered consideration of exclusive truck lanes. (9)

The second study, which examined the potential for an exclusive contraflow truck lane in Houston, originated from an unrelated study that examined the feasibility of operating a contraflow lane for buses. An exclusive bus lane could not be justified with a volume of only 40 buses per hour. So the researchers considered other potential users of the lane.

Trucks appeared to be a promising user group because of the following considerations.

(1) Truck drivers are professional drivers and so they are probably more able to adapt to the rigid operational controls in a contraflow lane.

(2) Trucks and buses have similar acceleration and braking characteristics.

(3) Trucks would be highly visible in a contraflow lane, especially if the combined volume of trucks and buses would keep oncoming contraflow vehicles in sight of opposing traffic at all times.

(4) The displacement of large trucks from the traffic stream might result in operational and safety improvements in the conventional lanes.

Data were collected using a tape recorder and time-lapse photography to determine whether the volume and distribution of trucks throughout the day would be adequate to support their using the contraflow lane. The researchers found that the actual percentage of trucks in the traffic stream was very small.

The research also interviewed trucking firm employees regarding whether they would be in favor of trucks using the contraflow lane. The interviews revealed that none of the firms would be able to effectively utilize the contraflow lanes without additional entry and exit points to and from the lane. The researchers also discovered that much of the truck traffic was at night and not during the peak periods. (10)

The fact that trucks constituted a small percentage of the traffic stream, combined with the lack of utilization predicted by the trucking industry, implied that exclusive truck lanes would not be feasible for the I-45N corridor. This result corroborated the results of the first study. (10)

Virginia

To improve safety levels, the Virginia Department of Highways and Transportation implemented a lane restriction that banned trucks and tractor trailers from the median (farthest left) lane. The report, "Capital Beltway Truck/Tractor Trailer Restriction Study," by the Virginia Department of Highways and Transportation, summarized the results of this effort.

For analysis purposes, vehicles were classified as 1) tractor trailers (any combination, with a three axle minimum), 2) single unit trucks larger than a panel, and (3) other vehicles. Traffic counts were conducted to determine directional split, lane distribution, and class distribution.

The results showed that the total number of accidents for both trucks and passenger vehicles did decrease slightly. In addition, the number of injury accidents decreased by approximately 20 percent. Tractor trailers had the highest accident rate of all vehicle types. The number of tractor trailer accidents occurring in the median lane was less than the number of accidents occurring outside the median lane after the tractor trailer had, just prior to the accident, been traveling in the median lane. In other words, the weaving action of trucks moving out of the median lane because of the restriction appeared to have resulted in an increase in tractor trailer accidents. (11)

Secondary results of this study were as follows.

- Truck and truck/trailer volumes were lowest in the median lane and highest in the extreme right lanes, prior to the implementation of the lane restriction. (11)
- No changes in speed were detected for any vehicle type. (11)
- No change in capacity was expected to result from the implementation of truck lane restrictions. (11)
- Motorists supported the program because they felt less intimidated by the trucks. (11)

COMMON PRACTICES THROUGHOUT THE U.S.

When considering truck restriction strategies, it is helpful to examine current practice in other areas of the U.S. Common practices regarding implementation or operation of these truck restriction strategies may exist that could save valuable time and resources. This section summarizes some of these practices. This summary includes 1) a description of the current restriction, 2) the motivation behind the restriction's implementation, 3) a description of who had the authority to implement the restriction, and, if studied, 4) the effectiveness of the restriction.

Lane Restrictions

A brief description of the lane restrictions that exist throughout the U.S. are given in Table 3.

Restriction Types. Two main types of truck lane restrictions exist throughout the country. The first restricts trucks from using the left lane (or lanes, depending on the facility size), and the second restricts trucks from traveling in the right lane (or lanes, depending on the facility size).

Lane restrictions are implemented on either a site-specific or statewide basis, depending on the motivation behind the restriction and justification of its use. Most site-specific restrictions exist in areas with grades, where trucks cannot maintain speeds, or where there are unusual safety concerns.

Lane restrictions are implemented on a mandatory or voluntary basis. Instead of implementing a mandatory lane restriction for heavy vehicles, Arkansas officials decided to post signs requesting that all trucks use the extreme left lane. This became statewide practice along all of the interstate highways running through Arkansas. Similarly, the state of Nevada has a voluntary, rather than mandatory, truck lane restriction. In Nevada trucks are also requested to travel in the extreme left lanes. Aside from the two exceptions listed here, mandatory restrictions are the most prevalent type of restriction in the U.S.

Table 3. Lane Restrictions in the United States

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?	How Effective have the Restrictions Been?
ARIZONA			State of Arizona Cities of Phoenix and Tucson by existing legislation	
ARKANSAS	to leftmost lane(s) statewide voluntary all trucks 24 hour operation not enforced facility with 2+ directional lanes	equalize pavement wear	State of Arkansas existing legislation allows local, city or county jurisdictions to implement truck restrictions on state highways	deemed not successful
CALIFORNIA	to rightmost lane(s) statewide trucks with 3+ axles 24 hour operation On facilities with minimum 2+ directional lanes		with approval, local, city or county jurisdictions can implement restrictions on state highways	
COLORADO	to right most lane(s) site specific variable weight limits		CO Dept. of Highways as deemed necessary by engineering studies with approval, local, city or county jurisdictions can implement restrictions on state highways by existing legislation	
CONNECTICUT	to right most lane(s) statewide 24 hour operation commercial trucks and buses facilities with 2 + directional lanes		by statewide law	
FLORIDA	from leftmost lane(s) trucks with 3 + axles site specific 7 am to 7 pm enforced	improve safety improve operation reduce stress and intimidation for motorists		no change in safety no change in operation near perfect compliance rate positive public reaction

Table 3. Lane Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?	How Effective have the Restrictions Been?
GEORGIA	*to rightmost lane(s) if allowed by permit to travel within the I-285 perimeter freeway			speculate less weaving and fewer maneuvers
IDAHO	to leftmost lane(s) site specific all trucks on facilities with minimum 2 + directional lanes	equalize pavement wear		
ILLINOIS	to rightmost lane(s) site specific all trucks on facilities with minimum 3+ directional lanes	improve operation	Illinois Department of Transportation by existing legislation	no change in speed shorter queue lengths high compliance rate
INDIANA	to rightmost lane(s) statewide all trucks on all urban freeways with minimum 2+ directional lanes 24 hour operation		by Statute on a statewide basis by existing legislation	
KENTUCKY	to rightmost lane(s) site specific trucks with 30,000 lbs GVW on facilities with minimum 3+ directional lanes			
LOUISIANA	to rightmost lane(s) Site Specific all trucks not enforced		Louisiana Department of Transportation is empowered by legislation to establish truck restrictions by legal document	
MARYLAND	to rightmost lane(s) on grades site specific all trucks	improve operation improve safety legislation and public pressure	by regulation by existing legislation	

Table 3. Lane Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?	How Effective have the Restrictions Been?
MASSACHUSETTS	to rightmost lane(s) site specific trucks with 10,000+ lbs GVW 24 hour operation		by existing legislation	
MISSOURI	to rightmost lane(s) statewide all trucks on all urban freeways with minimum 3+ directional lanes		by existing legislation	
NEVADA	to leftmost lane(s) site specific all trucks voluntary	equalize pavement wear	existing legislation allows local, city or county jurisdictions to implement truck restrictions on state highways	improvements postponed 3-5 years; design life extended by 5-10 years; overlays reduced 10-20% if implemented statewide no change in safety 60% compliance rate
NEW JERSEY	to rightmost lane(s) statewide on all urban freeways with minimum 3+ directional lanes 10,000+ lbs GVW		based on requests by local officials and subsequent DOT engineering studies with approval, local, city or county jurisdictions can implement truck restrictions on state highways	
NEW YORK	to rightmost lane(s) (to left if no shoulders on right) site specific all trucks or 10,000+ GVW depending on location			
NORTH CAROLINA	to leftmost lane(s)			
OKLAHOMA	statewide		by existing legislation	
OREGON	to rightmost lane(s) statewide on all urban freeways with minimum 2+ directional lanes trucks with 8,000+ lbs GVW		legislation allows local, city or county jurisdictions to implement truck restrictions on state highways	

Table 3. Lane Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?	How Effective have the Restrictions Been?
PENNSYLVANIA	to rightmost lane(s) ongrades			
TEXAS	to rightmost lane(s) not enforced	improve operation trucks in left lane were exceeding speed limit by > 10 mph on the average		no change in time gaps no change in speed 62% compliance rate 60% motorists in favor 28% truck drivers in favor
VIRGINIA	to rightmost lane(s) site specific on limited access facilities with minimum 2+ directional lanes	improve safety public showed interest in Maryland's truck restriction concerned with operational disparity between Maryland and Virginia	Virginia Highway and Transportation Commission under statute	no change in speed truck and vehicle accidents decreased slightly positive motorist support
WISCONSIN	to leftmost lane(s) site specific rural facility	equalize pavement wear		low compliance rate speed decreased in left lane no change in queue length

There are some variations in the truck types specified under the restrictions. In some cases, no specification is made, and the restriction applies to all trucks. In other cases, truck specifications are measured by weight, which usually includes vehicles with a 10,000-lb minimum gross vehicle weight. In other cases, truck specifications are measured by the number of axles in the truck configuration, which usually includes trucks with a minimum of three axles. In Connecticut, in addition to trucks, buses are restricted from using the extreme left lanes on any divided, limited-access highway that has two or more lanes in each direction.

Most lane restrictions operate 24 hours a day to ease enforcement efforts and motorist confusion. Florida is an exception in that the site-specific restriction prohibits trucks with three or more axles from using the left lane between 7 am and 7 pm.

Most restrictions apply to facilities with a minimum of two lanes in each direction. However, a number of states limit the use of truck lane restrictions to larger facilities that have at least three lanes in each direction.

In the majority of the states, no attempts are made to enforce the restrictions, usually because of the lack of personnel and the perception of restriction enforcement as a low priority issue. Again, Florida is the exception in that its restrictions are strictly enforced.

Motivation for Implementation. Three main goals motivate the implementation of truck lane restrictions:

- to improve the operation and efficiency of the facility,
- to improve the safety of the facility, and
- to extend the life of the pavement.

To experience improved operation or safety on the facility, trucks are most often restricted from traveling in the extreme left lanes; these faster traveling lanes are reserved for automobiles.

To equalize pavement wear and extend the life of the pavement, trucks are usually restricted from using the right-hand lanes. Most trucks travel in the slower moving right-hand lanes and, therefore, the pavement in these lanes is subjected to higher load weights. This reduces the design life of the facility. More specific motivational factors are discussed below.

- In Maryland, tractor trailer accidents increased from 194 in 1982 to 349 in 1983. (12) Public pressure motivated the implementation of the lane restriction.
- In Virginia, the fear of operational disparity for trucks traveling between Maryland and Virginia and a desire to reduce truck related accident problems (a disproportionate number of trucks is involved in accidents—truck traffic only makes up 3.7 percent of the total traffic and yet is involved in 16.6 percent of all accidents) initiated the implementation of a lane restriction. (11)
- In Texas, the motivation to implement a lane restriction arose after trucks received high speed violations in the extreme left lane and from the sense that trucks might be impeding the free-flow of cars in slower moving lanes.
- In Florida, legislation and public pressure initiated the implementation of a lane restriction to determine whether automobile drivers would experience a significant reduction in levels of intimidation and stress.

Authority for Implementation. In many cases, the state highway authorities, under existing legislation, are able to implement truck lane restrictions. In some cases, new legislation is required.

Effectiveness of the Restriction. In nearly every state in which a formal and comprehensive study was conducted (Florida, Nevada, Texas, and Virginia), negligible change in operation or safety was observed after the implementation of the lane restriction. However, the restriction did receive positive public reaction and high compliance from truck drivers. Also, because of the redistribution of trucks across the facility, the potential effect on pavement deterioration rates seemed very positive.

Route Restrictions

A brief description of the route restrictions in place throughout the U.S. is found in Table 4.

Restriction Types. Two classes of trucks are usually subject to truck route restrictions: 1) trucks carrying hazardous or explosive loads, and 2) oversize/overweight

Table 4. Route Restrictions in the United States

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?
ALABAMA	hazardous/explosive loads banned from tunnels in Mobile		City of Mobile by city ordinance existing legislation allows local, city or county authorities to implement truck regulations on State highways
ARIZONA			State of Arizona and Cities of Phoenix and Tucson
ARKANSAS	trucks banned from facilities that cannot support local truck traffic	preservation of infrastructure	Arkansas Highway Department District Engineer
CALIFORNIA	trucks carrying hazardous materials or explosives are rerouted through low population areas	endangerment to persons	California Highway Patrol local, city or county authorities can implement truck restrictions with approval on State highways laws following federal regulations and guidelines
COLORADO			State of Colorado based on engineering studies local, city or county authorities can implement truck restrictions with approval on State highways
FLORIDA	restricted from routes due to load carrying capacities of roads and bridges restricted from routes due to height and width limitations of certain structures	preservation of infrastructure infrastructure limitations	
GEORGIA	trucks with 6 + wheels are not permitted to enter Atlanta without proof of a scheduled stop		Georgia Department of Transportation existing legislation allows local, city or county authorities to implement truck restrictions on State highways

Table 4. Route Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?
ILLINOIS	oversize/overweight trucks are not permitted to use certain routes	facility/infrastructure limitations	
INDIANA	through truck travel is prohibited in the larger cities designated truck routes do exist		Indiana Department of Highways through orders of the Director
KANSAS	truck travel is limited to designated routes		Kansas Secretary of Transportation provided a satisfactory alternate route is provided existing legislation allows local, city or county authorities to implement truck restrictions on State highways
LOUISIANA	specific routes can be imposed for truck traffic		Louisiana Secretary of Transportation on all State Highways
MARYLAND	hazardous/explosive loads re-routed through low population areas re-routed to avoid residential areas, hilly terrain; toll roads, bridges and tunnels	endangerment to persons facility/infrastructure limitations improve operations	Maryland Highway Administration if satisfactory alternate routes are provided
MASSACHUSETTS	trucks carrying hazardous materials or explosives are rerouted through low population areas	endangerment of persons	Massachusetts Department of Public Works for State highways
MICHIGAN	trucks carrying hazardous materials/explosives are routed to low population areas 'through truck routes' and 'local truck routes' for all trucks exist	endangerment of persons	State of Michigan
MINNESOTA	trucks carrying hazardous materials or explosives are rerouted through low population areas trucks with 9,000+ GVW are restricted from certain routes	endangerment of persons	

Table 4. Route Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?
MISSISSIPPI	trucks carrying hazardous materials or explosives are rerouted through low population areas	endangerment of persons	
MISSOURI	trucks are required to re-route due to weight limitations imposed on certain routes	preserve infrastructure which may be damaged by heavy loads	Missouri State Highway Commission
NEW JERSEY			local, city or county authorities can implement truck restriction with approval on State highways based on requests from local officials and subsequent investigation by DOT staff
NEW YORK	all trucks restricted from metropolitan New York City area	improve operation improve safety	
NORTH CAROLINA	designated truck routes do exist	avoid residential areas avoid CBD route bulk food carriers to and from major containment centers	North Carolina Department of Transportation
OHIO	truck or 'through truck' routes do exist	incorporated communities initiated	
OKLAHOMA	truck routes can be established		State of Oklahoma existing legislation allows local, city or county authorities to implement truck restrictions on State highways
PENNSYLVANIA	trucks carrying hazardous materials or explosives are rerouted through low population areas and banned from tunnels heavy trucks are not allowed on certain facilities	to avoid urban areas facility/infrastructure limitations infrastructure preservation endangerment of persons on certain facilities	existing legislation allows local, city or county authorities to implement truck restrictions on State highways

Table 4. Route Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?
RHODE ISLAND			existing legislation allows local, city or county authorities to implement truck restrictions on State highways
SOUTH CAROLINA	vehicle class and size limitations may force re-routing of trucks	preserve infrastructure which may be damaged by heavy loads to avoid urban areas	South Carolina Department of Transportation
VIRGINIA	designated exclusive truck routes do exist		
WASHINGTON	oversize/overweight trucks restricted from certain roads during winter months	to preserve infrastructure which may be damaged by heavy loads	
WEST VIRGINIA	trucks carrying hazardous materials or explosives are rerouted through low population areas	endangerment of persons	

trucks. The route restrictions are usually implemented to avoid high population areas, hilly terrain, toll roads, bridges, and tunnels.

Motivation for Implementation. The two main motivational factors for the implementation of truck route restrictions are that 1) trucks carrying hazardous or explosive materials must be removed from high density or high population areas where, if an accident occurred, lives would be endangered, and 2) facility or infrastructure limitations dictate that large trucks may not be able to travel safely along certain routes because of low overpasses or tunnels with limited clearance. Trucks that have excessive weight may also be prohibited from traveling on certain routes where the infrastructure, including bridges, cannot support the load without being damaged.

Authority for Implementation. In most cases, existing legislation gives highway agencies restriction implementation authority. The state of California is an exception; there, route restrictions can be implemented by both the California Highway Patrol and the transportation agencies.

Effectiveness of the Restriction. No information is available on the effectiveness of route restrictions as a truck restriction strategy.

Time-of-Day Restrictions

A summary of the time-of-day restrictions in place in the U.S. is found in Table 5.

Restriction Types. States employ two main types of time-of-day restrictions for trucks: 1) restricting trucks from traveling during peak or daylight hours and 2) restricting trucks from traveling during the hours of darkness. Time-of-day restrictions apply mainly to oversize/overweight trucks.

Motivation for Implementation. The two main motivational factors for the implementation of time-of-day restrictions are safety and improvement of the facility's operation. To maintain an adequate level of safety, oversize/overweight trucks are required to travel during daylight hours. To improve the facility's operation, slower moving, oversize/overweight trucks that are sometimes wider than a single lane are

Table 5. Time-of-Day Restrictions in the United States

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?
ARIZONA	oversize/overweight trucks permitted only during daylight hours, Monday through Friday statewide on all urban freeways	improve safety	administrative rule by existing legislation
CALIFORNIA			California Highway Patrol local, city and county can implement truck restrictions with approval on state highways
COLORADO	oversize/overweight trucks permitted only during daylight hours in urban areas statewide on all urban freeways	improve safety	Colorado Department of Highways local, city and county can implement truck restrictions with approval on state highways
ILLINOIS	oversize/overweight trucks prohibited 9:30 am -3:00 pm site specific	improve operation	by existing legislation
INDIANA	oversize/overweight trucks statewide on all urban freeways		State of Indiana by existing legislation
IOWA	oversize/overweight trucks permitted only during daylight hours, Monday through Friday statewide on all urban freeways	improve safety	by existing legislation
KANSAS	oversize/overweight trucks variable hours statewide on all urban freeways		Kansas Secretary of Transportation or local authority existing legislation allows local, city or county to implement truck restrictions on State highways

Table 5. Time-of-Day Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?
LOUISIANA	oversize/overweight trucks variable hours statewide on all urban freeways		Louisiana Secretary of Transportation
MARYLAND	variable weight/size limits variable hours site specific on all urban freeways	noise abatement through residential areas	Maryland Department of Transportation on State highways
MINNESOTA	oversize/overweight trucks permitted only during daylight hours, Monday through Friday statewide on all urban freeways	improve safety	
NEVADA			existing legislation allows local, city or county to implement truck restrictions on State highways
NEW JERSEY			based on requests from local officials and subsequent DOT engineering studies
OKLAHOMA	variable weights variable hours on all urban freeways		
OREGON	oversize/overweight trucks prohibited peak periods statewide on all urban freeways	improve operation	
PENNSYLVANIA	in large cities		existing legislation allows local, city or county to implement truck restrictions on State highways

Table 5. Time-of-Day Restrictions in the United States (cont.)

LOCATION	What Type of Restrictions are in Place?	What Motivated the Implementation of the Restrictions?	Who has the Authority to Implement Restrictions?
RHODE ISLAND	variable weight/size limits variable hours site specific - residential areas	noise abatement through residential areas	existing legislation allows local, city or county to implement truck restrictions on State highways
UTAH	oversize/overweight trucks prohibited peak periods site specific	improve operation	
WASHINGTON	oversize/overweight trucks prohibited peak periods through cities (15,000 + pop.), Saturday, Sunday and holidays statewide	improve operation	

prohibited from traveling on the facility during peak periods. A secondary motivational factor is noise abatement through residential areas.

Authority for Implementation. Implementation authority for initiating time-of-day restrictions often lies with the state highway or transportation agency. California is an exception, as the California Highway Patrol also shares the responsibility for implementing time-of-day restrictions.

Effectiveness of the Restriction. No information was available to determine the effectiveness of time-of-day restrictions in improving either the operation or the safety of the facility.

Speed Restrictions

Twelve states currently impose differential speed limits for cars and trucks (see Table 6). The speed limits vary by either 5 mph or 10 mph, with truck speeds always being lower.

The researchers found no formal studies dealing with the effectiveness of speed restrictions. However, although differential speed limits have been implemented to improve the safety of the road environment, many transportation professionals feel they may, in fact, pose a safety hazard.

Table 6. Speed Restrictions in the United States

LOCATION	POSTED SPEED FOR TRUCKS	POSTED SPEED FOR NON-TRUCKS
ALABAMA	55	65
CALIFORNIA	55	65
COLORADO	55	65
ILLINOIS	55	65
INDIANA	60	65
MICHIGAN	55	65
MISSOURI	60	65
OHIO	55	65
OREGON	55	65
TEXAS	60/55*	65
VIRGINIA	55	65
WASHINGTON	60	65

* Day/Night

FACTORS TO CONSIDER FOR IMPLEMENTATION AND ANALYSIS

In reviewing the literature related to truck restriction strategies, the researchers learned much about implementation practices and analysis techniques for determining restriction effectiveness. A compilation of this information is presented below.

Our discussion in this report is limited to the consideration of truck lane restrictions, though much of the information presented here could be applied to the implementation or analysis of other truck restriction strategies.

IMPLEMENTATION CONSIDERATIONS

In a previous section of this report, a number of implementation related questions were raised regarding facility design, facility characteristics, and the anticipated impacts resulting from the implementation of truck lane restrictions. Each of these questions will now be addressed.

Statewide Versus Site-Specific

When considering whether a truck lane restriction should be implemented on a statewide or site-specific basis, one must consider the expected results of the restriction implementation, as well as enforcement and violation issues. (Reactions from the general public and the trucking industry may also be important considerations.) If the key motivation for implementing a truck lane restriction is to equalize pavement wear, it would be sensible to implement it on a statewide basis, as the problem of unequal wear is usually distributed over large areas throughout the state. However, if the motivation is to improve operation in a mountainous area, it may be wise to implement the restriction only in that area. Statewide restrictions are easier to implement and enforce, but they are sometimes difficult to justify, depending on the implementation motivation.

Number of Lanes Restricted

The number of lanes to be included in the restriction is difficult to determine because it depends on other factors, such as traffic volumes, the percentage of trucks in the traffic stream, and the size of the facility. It is also difficult to determine how many lanes should be restricted because little is known regarding the extent of impacts resulting from the implementation of a truck lane restriction. However, it seems that as more lanes are restricted, the resulting impacts increases. Subsequently, it seems a smaller facility (fewer number of lanes) would encounter greater impacts. For example, the impacts would be much greater if the second lane were restricted on a two-lane facility than if the fifth lane of a five-lane facility were restricted.

Which Lanes Restricted

Trucks are typically restricted from traveling in the far left lane or, on larger facilities, the two far left lanes. Often, however, trucks are restricted from the right lane in urban areas to remove them from merge/diverge maneuvers at interchange ramps or to equalize the pavement wear (or delay major rehabilitation to the infrastructure). However, restricting trucks to a single lane can result in an underutilization of the facility's capacity, as peak-period and peak-hour truck volumes typically take up less than one freeway lane. Also, passenger cars tend to avoid using this lane.

Access/Egress Areas Affected

The spacing of entrances and exits along the facility is especially important when considering restricting trucks to the right lane(s). Trucks impair other drivers' ability to see exit signs, and they also reduce the available gaps for vehicles trying to access or exit the facility. If truck traffic is a very small percentage of the overall traffic flow, the spacing of entrances and exits should not present a problem.

Freeway Orientation (Radial or Circumferential)

Radial facilities, by design, generally have greater entrance/exit activity than circumferentially designed facilities. (1) Thus, if a relatively high volume of trucks is in the traffic stream on a radially designed facility, the practice of restricting trucks to the right lane(s) is not recommended.

Traffic Volume

A higher traffic volume or a higher percentage of trucks in the traffic stream results in greater impacts. (1) As the distance between consecutive vehicles decreases (as during high traffic volumes), the lead vehicle's impact on the following vehicle increases. For example, when vehicles are closely spaced, the following vehicle can only travel as fast as the vehicle it is following, unless the driver of the vehicle changes lanes. However, if vehicles are not closely spaced, the following vehicle can travel at faster speeds.

Continual Operation Versus Peak (or Other) Times

As when considering whether the restriction should be implemented on a statewide or site-specific basis, when considering a peak-hour or 24-hour a day restriction, it is important to note the motivation behind the truck restriction and enforcement issues. Peak-hour or time-of-day restrictions are considered to improve the operation of a high volume facility. While this restriction type may be appealing to many peak-period motorists, it raises the issues of roadways rights of access and the economic impact on overall commerce. Widespread time-of-day or peak-hour restrictions would require either higher costs for both shipping and trucking companies or major changes in labor agreements and changes in shippers' hours of operation.

Safety Problems

While there is little conclusive evidence to determine the impacts of redistributing the truck traffic on the facility, the implementation of a lane restriction could lead to a greater number of lane changes for both trucks moving out of the restricted lane and for vehicles moving away from the trucks. This potential increase in lane change activity could lead to an increase in the number of conflicts between the trucks and other vehicles and, ultimately, to a decrease in the overall safety of the facility.

Accelerated Pavement Wear

Little conclusive evidence exists that quantifies the effects of increasing truck traffic in some lanes and decreasing it in other lanes. It is difficult to determine the effects because there is such a long time span before a noticeable change in pavement deterioration rates can be observed empirically. However, the use of ESAL and pavement deterioration relationships based on weight and repetitions are well known and could be applied for analysis purposes.

OPERATION AND ANALYSIS FACTORS

Whether the aim is to improve the operation of the facility, improve motorists' level of safety, or increase the design life of the infrastructure, many factors should be considered before implementing any type of truck lane restriction. These factors can be placed in the categories of traffic composition, traffic flow characteristics, safety characteristics, enforcement issues, economic impacts, and pavement deterioration. Within each of these categories, very specific measures of effectiveness can be defined to accurately measure the level of the impacts that implementation of a truck lane restriction will have.

But the measures of effectiveness chosen may not be uniform throughout the facility. Variations may occur throughout the facility's basic freeway segments and interchange locations. This issue must be considered during the analysis.

Traffic Composition

The composition of the traffic (i.e., the proportion of trucks and non-trucks) gives researchers insight into 1) the change in lane distribution for trucks and non-trucks after the implementation of the lane restriction, 2) the violation rates associated with each facility, and 3) the similarities among the sites chosen for comparison.

The composition of the truck traffic (i.e., the percentage of various truck types in the truck traffic stream) can also be examined to determine the similarities among study sites and to gain insight in the accident analysis.

Traffic Flow Characteristics

Traffic flow characteristics of the study sites can be examined to determine whether any improvement to the operation of the facility was gained by implementing the lane restriction. Specific traffic flow characteristics that can be examined include volume and flow rates, speeds, headways or time gaps, platoon lengths, and truck impedance time (i.e., the amount of time trucks run in tandem in multiple lanes, blocking vehicles from passing).

A change in the level of service (LOS) of the facility should not be used as a measure of effectiveness because the LOS estimates from the Highway Capacity Manual are insensitive to, and unaffected by, changes in lane distributions of the truck traffic. (1) Instead, these calculations are a function of the total number of trucks in all traffic. Therefore, the LOS measure would show that no change occurred before or after the implementation of the restriction.

In many cases, the peak and non-peak data should be examined to help ensure that the vehicles are more evenly distributed through time. A number of traffic flow characteristics, such as speed, headway or time gaps, and platoon lengths are highly dependent on vehicle spacing.

Volume and Flow Rate. Traffic volumes at different study sites can be used for comparison purposes. By comparing the restricted sites, researchers can be assured that the site(s) selected for in-depth analysis is (are) representative of other facilities in the region. Thus, the results of the in-depth analysis can be applied to other areas in the vicinity.

The change in the traffic stream's flow rate can be used as a measure of effectiveness in an in-depth analysis. A decrease in traffic flow rate indicates that the lane restrictions are detrimental to efficient operation of the facility. Conversely, an increase in the flow rate indicates that truck lane restrictions improve the facility's operation.

Speed. Average spot speeds for the various vehicle types can be obtained either manually with the use of a radar gun or via electronic data gathering equipment.

As part of an in-depth analysis, several types of measures of effectiveness describe vehicle speeds. These measures include 1) the change in average spot speeds of both trucks and non-trucks after the implementation of the restriction, 2) the cumulative distributions of speeds for both trucks and non-trucks, 3) the change in speeds for vehicle couplets (i.e., cars following cars, cars following trucks, trucks following cars, and trucks following trucks), and 4) the speed differentials among the lanes.

The change in average spot speeds for two classifications, trucks and non-trucks, can be indicative of improved operation of the facility after the implementation of the lane restriction. If the spot speeds increase for both trucks and non-trucks, the facility has been improved with the implementation of the truck lane restriction. If the spot speeds of either trucks or non-trucks increase, further investigation is needed to determine whether the change is occurring in a specific lane or over the entire facility. If the speeds of the non-trucks have improved, this improvement needs to be weighed against the resulting truck speeds. It may be that the non-truck speed increased minimally but the truck speed decreased substantially. In this case, the lane restrictions should probably be removed.

When comparing before-and-after changes in speed for different vehicle types (trucks versus cars), the grade needs to be taken into account. Different operational characteristics can lead to the conclusion that trucks travel at a much lower speed when, in fact, they only lag during uphill freeway segments.

The variability of speeds within a lane can be determined by examining the cumulative distribution of speeds by vehicle class. This measure must be examined separately for peak and non-peak periods to ensure that the vehicles are more evenly distributed over time because the vehicle speeds are highly dependent on the facility's volume. Changes in volume levels during peak and non-peak periods result in a wide variation of speed measurements throughout the day.

The arithmetic mean of speeds of cars following cars, cars following trucks, trucks following cars, and trucks following trucks can be examined to determine whether trucks are actually impeding the free flow of traffic. For example, if the average speed for cars following trucks is less than the average speed of cars following cars, it may indicate that trucks are indeed impeding the free flow of traffic. Caution needs to be exercised when interpreting these results, however, because a number of other factors, such as traffic volumes, can also impact vehicle speeds.

The difference in vehicle speed between adjacent lanes can also be examined during an in-depth analysis. The speed differential by lane is the absolute value of the difference in vehicle speeds within each pair of consecutive vehicles. It is then important to compare vehicle speeds by lane to determine which lanes are traveling at a faster speed. A decrease in the speed differential can imply an increase in safety. Different speeds in each of the lanes can pose a safety hazard when vehicles change lanes or merge into traffic.

When examining speeds after the truck restriction has been implemented, one must realize that trucks that have just changed lanes may not have adjusted their speed to meet the new traffic flow speed. Faster traveling trucks may also be disobeying the restriction. Therefore, it is important to determine which trucks are obeying the restriction, the slow trucks or the fast trucks, and to determine the lanes in which they are traveling.

Headway or Time Gaps. To compare the two very broad classifications of vehicles, trucks and non-trucks, it is better to use time gaps (distance from the rear bumper of the lead vehicle to the front bumper of the following vehicle) as a measure of effectiveness, rather than headway (distance from the front bumper of the lead vehicle to the front bumper of the following vehicle) because headway estimates do not incorporate the length of the vehicle into the measurement (see Figure 6). (1) Wide variations in vehicle length can exist, making headway estimations inaccurate.

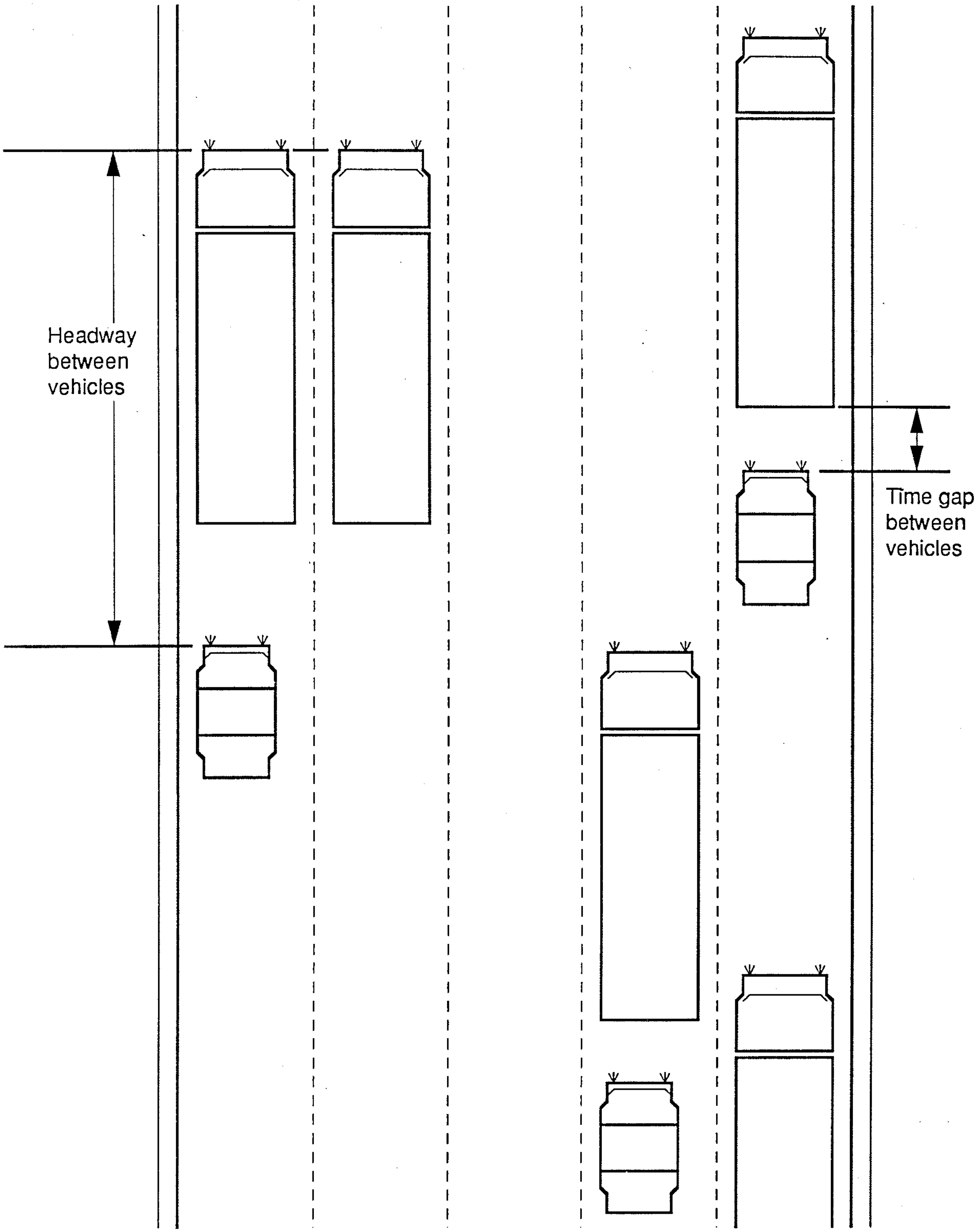


Figure 6. Headway vs. Time Gap Measurements

The measurement for the time gaps between consecutive vehicles should be analyzed separately during both peak and non-peak times to ensure that the vehicles are more evenly distributed through time (the time gap measurements are highly dependent on the volume of the facility). This is critical because as the time gaps become larger, the influence that the leading vehicle has on the following vehicle decreases.

Platoon Length. The average platoon length, even though it is highly dependent on volume, should be examined. The inclusion of this measurement may indicate whether non-trucks are actually being impeded by trucks because they do not have the ability to pass the trucks. In the case of a left-hand lane restriction, non-trucks would be allowed to pass in the left lane without being blocked by a truck. This would result in shorter queues behind trucks in the adjacent lanes.

Truck Impedance Time. Truck impedance time, which can be defined as the number of times per day that trucks occupy the majority of the lanes available for travel by general purpose vehicles, is another important measure. On a typical four-lane facility, truck impedance time may be recorded when trucks occupy lanes one, two, and three; lanes one, two, and four; and lanes one, two, three, and four. It can be assumed that the trucks do not have to be traveling in tandem to be an impedance but may be lagging or preceded by some defined amount of time, t, which takes into account the truck length and the acceptance gap that motorists consider safe for changing lanes (see Figure 7).

Safety Characteristics

When examining the safety characteristics associated with truck traffic, the main concern is to ensure a high level of safety for the vehicle's driver, as well as other motorists who may be impacted when unsafe driving conditions exist. A secondary concern is the high costs associated with truck-related incidents.

The costs associated with truck incidents can be organized into four categories: 1) delay, 2) vehicle operation, 3) accident, and 4) clean-up. (13)

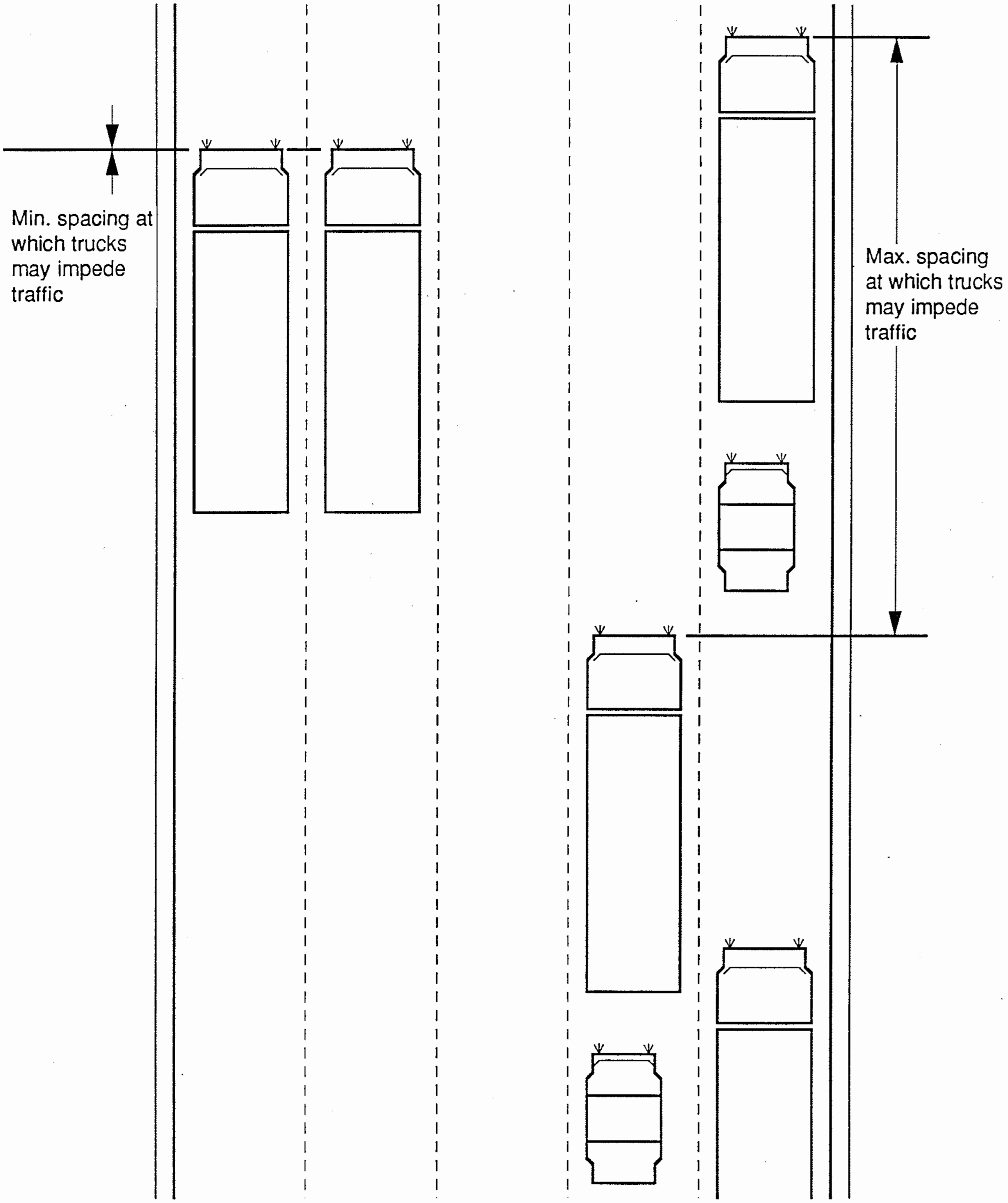


Figure 7. Truck Spacing and Its Effect on Traffic Impedance

Delay refers to the monetary value of time lost in travel to occupants of both personal and commercial vehicles because of the delay imposed by a truck-related incident. The time in excess of the time experienced without the incident is the attributable time delay for trucks. This factors out delay caused by congested flow conditions.

Vehicle operating costs include the vehicle's (including trucks) running costs and fuel consumption costs. These costs may not be substantial when considering the cost to individual vehicles; however, when considering the overall economic impacts, these costs can be quite high.

Accident cost is highly dependent on the accident type. More severe accidents usually result in a greater amount of vehicle or property damage and, therefore, result in higher costs.

Clean-up costs depend on the types of major incidents that occur throughout the year—in some years clean-up costs are very high, while in other years clean-up expenses are minimal. These costs, however, are not a major component of the total economic costs of truck incidents.

Three accident classifications can be established: non-truck/non-truck, non-truck/truck, truck/truck. When determining the effectiveness of truck restriction strategies, the facilities examined are usually limited-access, high-speed roadways with high safety standards. Therefore, the number of accidents involving a single vehicle and a stationary object are minimal. Unrelated accidents, such as drunk driving and engine failure, should not be included when assessing the relationship of changes in safety levels and operational changes (that is, the main concern lies with accidents resulting from operational conflicts, rather than vehicle design or human error).

Accident Rates and Frequencies. The total number of accidents before and after the implementation of the truck restriction strategy can be examined, as well as any observable change in the accident rates for various vehicle types. The formula used to calculate the accident rate for the various vehicle types is given below.

$$\text{accident rate} = \frac{\text{total number of accidents x 100 million}}{\text{ADT x length of section x number of days}}$$

Frequency distributions by day-of-week and time-of-day can be observed to determine consistency among study sites.

Accident rates can be examined for more specific truck types to gain insight into which truck specifications should be included in the restriction. For example, if rigid body trucks have a minimal accident rate before and after the implementation of the restriction, perhaps the restriction specifications should be changed from vehicles with Gross Vehicle Weight (GVW) of 10,000, to include only articulated vehicles.

Research should exercise caution during the analysis to ensure that the number of accidents is not overstated and that outside factors are not ignored. For example, truck accident rates cannot be directly compared to their percentage of the traffic stream because the occurrence rates of multi-vehicle accidents would overstate the accident rates of individual vehicles. (14) For example, if a truck and another vehicle were involved in an accident, the ratio of one truck accident/total trucks on the road would be substantially higher than the ratio of one vehicle accident/total number of vehicles on the road because the proportion of trucks in the traffic stream is usually near 5 percent of the total traffic. This measurement ignores the vehicle-miles traveled and other factors that would tend to reduce the truck accident rate.

Other factors, such as longer consecutive driving hours, more skilled driving requirements, and more nighttime and adverse weather driving, are important. When examining the accident rate (accidents/vehicle mile) by vehicle type, a direct comparison of vehicle-miles traveled should not be used as an indicator without compensating for the other factors as well.

Accident Type. The types of accidents that occur can provide useful insight as to whether the truck lane restrictions actively decrease the facility's level of safety. For example, if the number of accidents involving lane changing maneuvers has increased after the implementation of the restriction, the increase could indicate that unsafe conditions exist when the trucks move out of the restricted lane.

Accident Severity. The degree of severity, number of fatalities, number of injuries, and property damage by lane and vehicle type should be examined to determine whether the accident severity increases when additional trucks are forced to travel in the general purpose lanes. Accident severity may decrease when trucks have to travel at the same speed as the general purpose traffic in the slower moving lanes.

<u>Enforcement Issues</u>

When the implementation of a truck restriction of any type is contemplated, it is important to consider the feasibility of enforcement and the resulting violation rates of the restriction. The violation rate can greatly impact the effectiveness of any restriction. It can also elicit a derogatory public response to the restriction.

Violation Rates. There are two important factors to consider when devising the violation rates. The first is whether the violators are willfully violating or are simply unaware or unclear about to whom the restriction applies. Compliance with a truck restriction that has been recently implemented can be improved with media coverage. Using the media to inform the public that a restriction is in place and to define exactly whom the restrictions apply to may greatly reduce the number of unintentional violations.

Compliance generally decreases over time. (15) If, as motorists drive by, they seldom if ever see the restriction enforced, they become relaxed about violating the restriction, especially if they have disobeyed the restriction previously and did not get stopped. Also, the motoring public may be wary of recently implemented restrictions, assuming that the rate of enforcement will be high initially and then decrease once the restriction has been in operation for a while.

Feasibility of Enforcement. Facility design may greatly inhibit the enforcement of the restricted lane. For example, a facility where trucks are not allowed to use the left lane must have adequate shoulder space on the left-hand side to allow the enforcement officer to pull over large trucks and cite them safely without disrupting the normal flow of traffic. It is not feasible, especially in urban areas with high traffic volumes, to pull over the violators to the right-hand side of the roadway to be cited. Such an action would not only disrupt the efficient operation of the facility but also decrease motorists' level of safety because of the trucks changing lanes.

Merely having police visible at the restriction site, at least in the initial implementation stage, may be adequate. This would predictably deter weaving and speeding, even if physical enforcement is impossible.

In addition to facility design, researchers should consider the personnel available for enforcement and the need to convince enforcement officials of the importance of lane restriction enforcement. Often, enforcement of secondary traffic regulations (those regulations that, if violated, would not cause obvious danger) is considered low priority.

Pavement Deterioration Rate

When considering the impact of truck lane restrictions, researchers should determine not only the short-term effects on pavement wear, such as the increased pavement deterioration rate, but also the long-term effects. One way to decrease the long-term effects on pavement wear is to install alternative heavy duty mix (e.g., Portland Cement Concrete (PCC)) in the pavement's next rehabilitation that is more capable of withstanding repetitive, heavy loads. This action would serve to extend the life of the pavement.

RESEARCH APPROACH

To determine the changes in the facilities' level of operation and level of safety, as well as the applicability of the results of an in-depth analysis to other areas, data were collected at the selected demonstration sites. Data were collected both before and after the truck restrictions had been implemented at the Southcenter Hill site, where the in-depth analysis was done. At the other two sites and the control site, data were only available after the restrictions had been implemented (see Table 7). Data that were collected at each of the sites included traffic counts, speed distributions, and vehicle types by lane, as well as accident and incident data.

IRD DATA COLLECTION SYSTEM

The International Road Dynamics (IRD) Data Collection/Analysis System, a powerful, state-of-the-art traffic measurement system, was used on the southbound I-5 Southcenter Hill site. The roadside computer collects signals from various in-road sensors and interprets them to create a record of the passing vehicles. The vehicle records can be used to study the traffic flow and patterns in a variety of ways. The data collected are stored and can be analyzed either on-site or off-site (see Figure 8).

System Set-Up

The system includes a series of road sensors: an electronic loop followed by two axle sensors, followed by a second electronic loop (see Figure 9). The axle sensors can sense the axle presence but not record weights. Once the upstream loop has been activated by the presence of a vehicle, the axle sensor begins to search for the presence of an axle. The axle sensor stops searching for axles when the presence of a vehicle is no longer detected by the downstream loop.

Axle sensors can also give inexact measurements if the threshold value has been improperly defined. The axle threshold value is the level of the pulse produced by an axle at which an axle is distinguished from background noise in the sensor. Any pulse

Table 7. Data Collection Phases at the Study Sites

Data Collection Phases	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)
Before Period	January 1 - March 11	*	*	*
Sign Erection	March 12	April 4, 1992	April 30, 1990	*
Adjustment Period	March 13 - 31	*	*	*
After Period	April 1 - May 21	June 23, 1992 (7:30 - 8:30 a.m.)	July 1, 1992 (7:15 - 8:15 a.m.)	June 24, 1992 (7:30 - 8:30 a.m.)

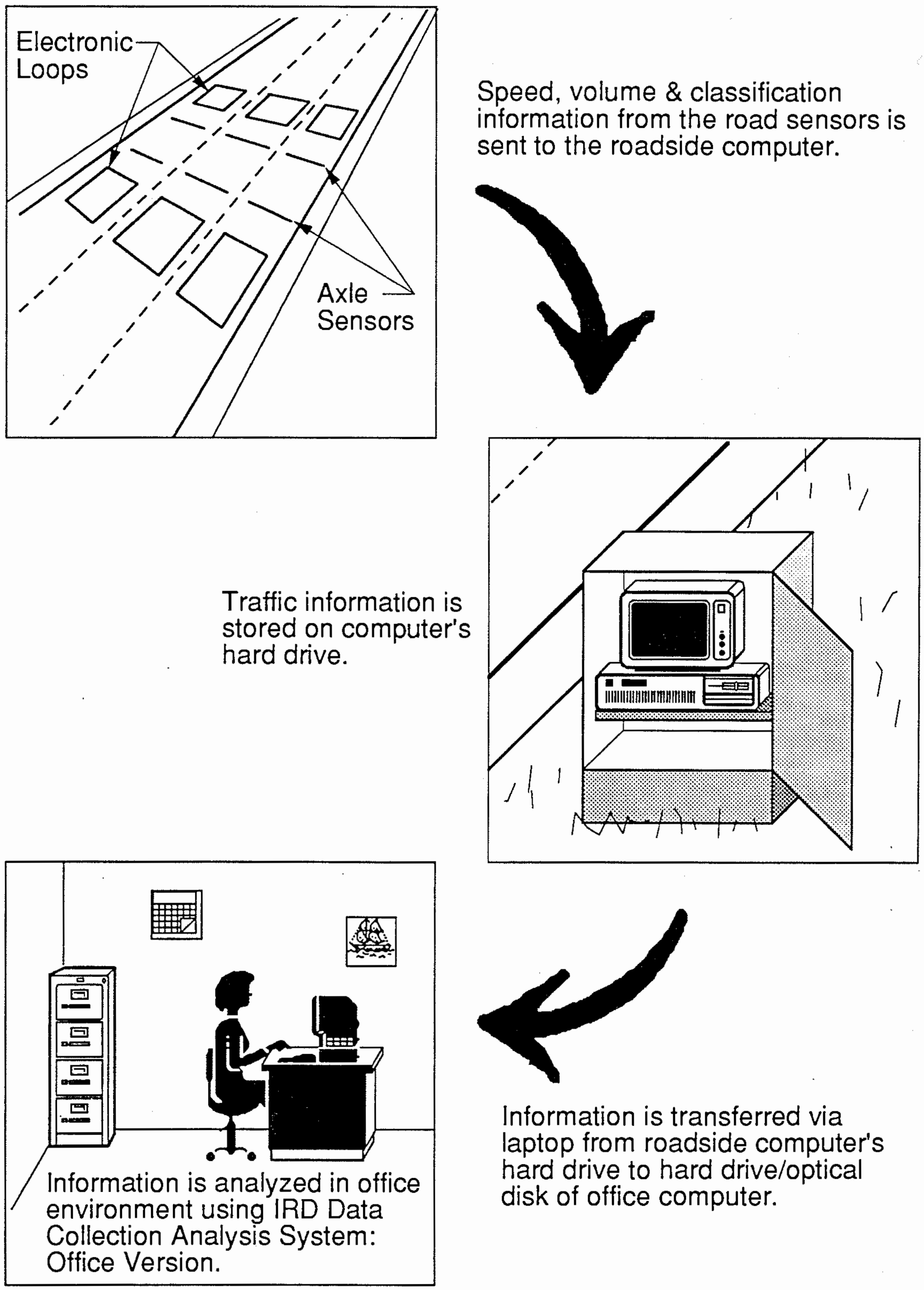


Figure 8. Information Flow for IRD Data Collection System

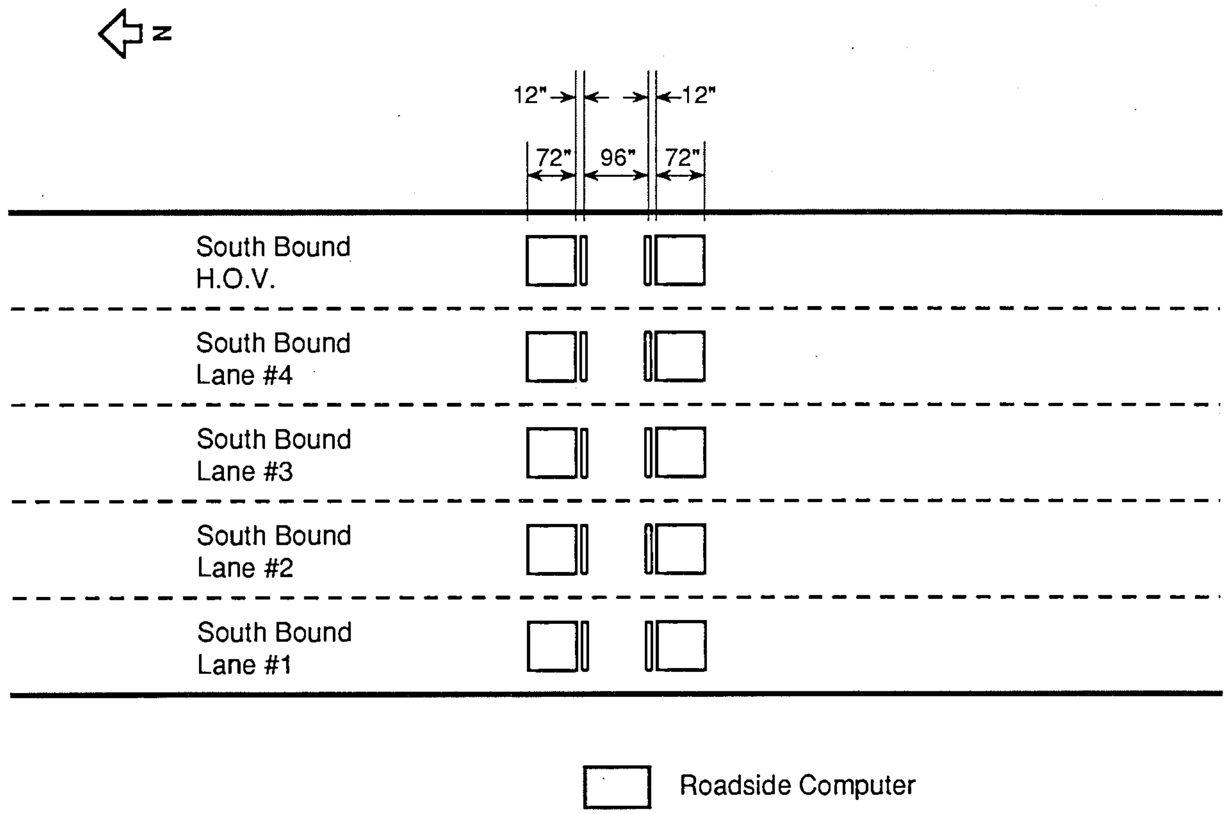


Figure 9. Roadbed System Setup for Automatic Data Collection

larger than this value is considered an axle, anything smaller is not. The threshold value is calibrated in the initial setup of the system.

Speed data are collected using the loops and the following equation:

$$\text{Speed} = \frac{\text{loop separation}}{(t_2 - t_1)}$$

In addition to speed collection, electronic loops are used to obtain the total bumper-to-bumper length of vehicles. The time that the loop remains in an active state is used along with the speed to determine this overall length. If two loops are used, as in this case, the values from the two loops are averaged. Loop measurements can be inexact because loop sensors react to a change in the magnetic field above them. The change in magnetic field varies depending on the metal content of the vehicle and the chassis height. With this variability, there is no exact point along the width of the loop where the loop will turn on or off.

Data Outputs

The types of reports available directly from the IRD system are as follows:

- Class by Hour - counts of vehicles in each class per hour,
- Class by Day - counts of vehicles in each class per day,
- Speed by Class - counts of vehicles in each speed range per day,
- Speed by Hour - counts of vehicles in each speed range per hour,
- Lane Count - counts of vehicles in each class for each lane, and
- Speed Summary - counts and percentages of vehicles above certain speed thresholds, average and median speeds, and speeds in the 85th percentile.

Within the IRD data collection system, a pre-defined, site-specific classification format is contained (see Table 8).

MANUAL TRAFFIC DATA COLLECTION

Data had to be collected manually at three of the sites, Site B: SR 520 from Redmond to Bellevue, Site C: I-5 southbound from the Puyallup River Bridge to the

Table 8. Washington State Vehicle Classifications

Non-Trucks	
1	Motorcycles
2	Passenger Cars
3	Other 2-Axle, 4-Tire Single Unit Vehicles
4	Buses
5	2-Axle, 6-Tire Trucks
Trucks	
6	3-Axle, Single Unit Trucks[1]
7	4+ Axle Single Unit Trucks
8	4 or Less Axle Combination Trucks
9	5-Axle Combination Trucks
10	6+ Axle Combination Trucks
11	5 or Less Axle Multi-Trailer Trucks
12	6-Axle Multi-Trailer Trucks
13	7+ Axle Multi-Trailer Trucks

[1] Articulated buses are included in this class by the IRD system but the bus volumes were subtracted out for purpose of analysis in this study.

Tacoma Mall, and Site D (control site): I-5 southbound at 185th Street, because of limited resources. Data were also collected manually at the I-5 Southcenter Hill location to check the accuracy of the automatic data-collection methods.

Because the data needed for this study had to describe not only the traffic characteristics in absolute numbers, but also the interdependencies between vehicles, the task required a 100 percent sample. For example, the researchers needed to know the speeds of certain vehicle types and how those speeds changed as the vehicle types around them changed. The researchers decided to use videotape to capture all of the necessary information. Only one hour of data was collected at sites B, C, and D. The researchers felt that this number of data was adequate for two reasons: 1) a 100 percent comprehensive sample was being captured and 2) the data collected at these sites were being used for comparative purposes rather than an in-depth analysis.

The percentage of trucks in the traffic stream in comparison to the total volume of traffic and the vehicle breakdown by lane were easily read off the videotape.

Simultaneously, during the videotaping, a select sample of vehicle speeds was gathered with a radar gun. These vehicles and their recorded spot speeds were then used in conjunction with their travel time speeds on the videotape to determine the length of the freeway segment captured on the videotape. Once the length of the roadway had been calculated, vehicle speeds were gathered for the larger sample of vehicles during the hour of data collection. The error that was introduced in combining spot speed measurements with travel time measurements seemed minor in comparison to the other inaccuracies encountered with this method of data collection. However, because the data collected at these sites were used primarily to ensure that Southcenter Hill was not an anomaly in the Puget Sound region, the researchers felt it adequate. The times that each vehicle entered and exited the screen were recorded directly into a computer database. The average speed for vehicle couplets and the speed differential by lane were then calculated.

The time gaps between the various vehicle types were measured in a similar fashion using the roadway lengths from the video and the computer timer. The average platoon length by lane and the truck impedance time were observed directly from the video. This information was compared to the results obtained from the Southcenter Hill site to determine whether any major operational differences were affecting safety.

ACCIDENT REPORT DATABASE

Potential changes in the accident rate, type, or severity resulting from the implementation of truck lane restrictions were detected with the Microcars database maintained by the Washington State Department of Transportation. Information in this database is listed in Table 9.

INTERVIEWS/SURVEYS

To determine whether large trucks in the traffic stream posed a real or just a perceived problem, the researchers compared the safety and operational analysis with the opinions of motorists and truck drivers. They wanted to find whether motorists felt that truck lane restrictions had improved both roadway safety and operation. A survey of the motorists', truck drivers', and the trucking industry representatives' opinions would also indicate the implementability of truck lane restrictions in the region.

Truck Driver Survey

To determine the truckers' opinions of the three sections of truck-lane restricted highways in the Puget Sound region, carefully constructed surveys were administered. The surveys included questions regarding frequency of travel on restricted highway sections, the truckers' experiences with truck-lane restrictions in other portions of the country, their opinions on truck-lane restrictions in the Puget Sound region, and their background characteristics, such as age, gender, and the types of vehicles they operated.

The truck surveys were administered, in person, at two truck-stop locations on two days. The first location was a large, intercity truck stop, located on a section of I-5

Table 9. Information Contained in Accident Report Database

ACCIDENT DATA ELEMENT	SPSSPC NAME
Year	YEAR
Month	MONTH
Day of Month	DAY
Day of Week	WEEKDAY
Hour	HOUR
Minute	MIN
County Number	COUNTY
City Number	CITY
State Route Number	SR
State Route Additional Identifier	ADID (A)
State Route Sequence Number	SEQ
State Route Milepost	MP (No Decimal Point)
Ahead l Back Equation	EQT (A)
WSDOT District Number	DIST
Urban l Rural Location	UR (A)
Functional Class of Road	FC
Administrative Class of Road	ADM
Prefix 1	PREFIX1
Prefix 2	PREFIX2 (A)
Accident Severity	SEVERITY
Number of Injuries	INJURYS
Number of Fatalities	FATALS
Most Severe Injury of Accident	MSVJ
Number of Vehicles in Accident	VEH
Amount of Property Damage $	PDO
Character of Roadway	RDCH
Location of Roadway	LOCATION
Roadway Surface Conditions	SURFACE
Weather Conditions	WEATHER
Light Conditions	LIGHT
Ramp Location	RAMP (A)
Vehicle 1 's Compass Direction	COMP1
Vehicle 1 's Milepost Direction	DIR1 (A)

Table 9. (Cont.)

ACCIDENT DATA ELEMENT	SPSSPC NAME
Vehicle 1's Movement	VMVT1 (A)
Diagram Accident Type	COLDD (A)
Vehicle 2's Compass Direction -	COMP2
Vehicle 2's Milepost Direction	DIR2 (A)
Vehicle 2's Movement	MVT2 (A)
Impact Location	MPLOC (A)
Collision Type	COL
Object Struck	OBJ
Junction Relationship	JUNC
Accident Occurred On or Off Road	ONOFFRD
Proximity of Driver 1 's Residence	RESPROX1
Proximity of Driver 2's Residence	RESPROX2
Proximity of Driver. 3's Residence	RESPROX3
Sobriety of Driver 1	SOB1
Sobriety of Driver 2	SOB2
Driver 1's 1st Contributing Cause	DR1CC1
Driver 1's 2nd Contributing Cause	DRICC2
Driver 2's 1st Contributing Cause	DR2CC1
Driver 2's 2nd Contributing Cause	DR2CC2
Driver 3's 1st Contributing Cause	DR3CC1
Driver 3's 2nd Contributing Cause	DR3CC2
Driver 1 's Vehicle Actions	DR1VAC
Driver 2's Vehicle Actions	DR2VAC
Driver 3's Vehicle Actions	DR3VAC
Investigating Agency	INVEST
(BLANK SPACE)	
Vehicle 1's Type	VT1
Vehicle 2's Type	VT2
Vehicle 3's Type	VT3
State Patrol Accident Report Number	ACCRPT
Most Alcohol Impaired Driver	ALCOHOL
Driver 1's Age	DR1AGE
Driver 2's Age	DR2AGE

Table 9. (Cont.)

ACCIDENT DATA ELEMENT	SPSSPC NAME
Driver 3's Age	DR3AGE
Hazardous Materials Being Transported	HAZMAT
Fuel Spillage Due to Collision	SPILLAGE
Fire Due to Collision	FIRE
Vehicle 1's 1st Miscellaneous Action	V1MISAC1 (A)
Vehicle 1's 2nd Miscellaneous Action	V1MISAC2 (A)
Vehicle 2's 1st Miscellaneous Action	V2MISAC1 (A)
Vehicle 2's 2nd Miscellaneous Action	V2MISAC2 (A)
Vehicle.3's 1st Miscellaneous Action	V3MISAC1 (A)
Vehicle 3's 2nd Miscellaneous Action	V3MISAC2 (A)
Vehicle 1 Additional Information	V1INFO
Vehicle 2 Additional Information	V2INFO
Vehicle 3 Additional Information	V3INFO
Pedestrian 1 Pedalcyclist 1's Injury	PED1INJ
Pedestrian 1 Pedalcyclist 1's Age	PED1AGE
Pedestrian 1 Pedalcyclist 1's Actions	PED1ACTS
Pedestrian 1 Pedalcyclist 2's Injury	PED21NJ
Pedestrian 1 Pedalcyclist 2's Age	PED2AGE
Pedestrian 1 Pedalcyclist 2's Actions	PED2ACTS
Year l Month l Day	DATE
Hour/Minute	TIME
SR Milepost in Whole Numbers	WHOLEMP
SR Sequence Number + Milepost	MPRANGE (SEQ+MP)

A = ALPHANUMERIC VARIABLE

between Seattle and Tacoma. Data were collected there on July 20, 1992, slightly more than four months after the last truck restrictions had been implemented on the I-5 Southcenter Hill. The majority of the truckers interviewed at this truck stop were interstate truckers who came to the Puget Sound region about once a month. The second location was a much smaller facility, commonly frequented by regional and local truckers, also located between Seattle and Tacoma, just off I-5. The survey was administered at this location on August 3, 1992. The researchers obtained 129 completed surveys from the two sites.

Motoring Public Survey

Approximately 400 license plate numbers were obtained at the three sites that had truck lane restrictions in the Puget Sound region. Addresses were then obtained from the Department of Licensing through the Washington State Department of Transportation (some addresses were not available because the vehicles were not registered or were from a rental agency). Before mailing, the surveys were coded with lane of travel and site information. Surveys were then mailed.

The main purpose of the motorist survey was to determine whether motorists had noticed a change in the operation or safety of the roadway after the implementation of the truck restriction, or if they even knew the restrictions were in place.

State Patrol Survey on Enforcement Issues

At the onset of the study, the Washington State Patrol conducted an informal survey. The audience surveyed consisted of troopers of various ages and experience. The survey questions were as follows:

- Are trucks in the inside lane a real or only a perceived problem?
- Will truck restrictions provide improvement to the traffic flow?
- Will truck restrictions further hinder traffic flow or introduce other negative impacts?
- Will concentrating trucks in certain lanes present safety problems?
- Will special enforcement be required?

- Should restrictions be 24 hours a day?
- Do you feel this change would reduce accidents?

Trucking Industry Opinion Poll

The opinions of the trucking industry were solicited through representative organizations at both the state and national levels. Representatives from the Washington State Trucking Association and the American Trucking Association were both informally asked to voice their opinions regarding truck restrictions, in general, and lane restrictions, in particular.

IN-DEPTH ANALYSIS

Because of the automatic data collection system, the researchers were able to collect much more extensive data at the Southcenter Hill site. Thus, they decided to use this site's data to determine the effects truck lane restrictions had on various aspects of traffic flow, as well as a traffic composition representative of the Puget Sound region. The types of data that were collected included traffic volumes, vehicle types, vehicle speeds, and time gaps between vehicles.

The researchers analyzed the "before" and "after" data to determine whether a change had occurred (increase or decrease) and whether this change was statistically significant. A test of significance was conducted using the standard difference of the means approach. The standard difference of the means test required the mean and standard deviation values to be calculated for each measured variable before and after the implementation of the lane restriction. A 95 percent confidence interval was assumed (z-value of 1.96). The following formula was used to calculate the allowable difference between the two means:

$$X_{allowable} = 1.96\sqrt{\left(\frac{s_1}{n_1}\right)^2 + \left(\frac{s_2}{n_2}\right)^2}$$

where:

$X_{allowable}$ = allowable difference between the means,

s_1 = standard deviation of before sample,

n_1 = before sample size,

s_2 = standard deviation of after sample, and

n_2 = after sample size.

The allowable difference between the means was then compared to the actual difference between the means determined from the "before" and "after" measurements. If the actual difference between the means exceeded the allowable difference, the researchers could conclude that the means did differ. Please note while reviewing the before/after tables that statistical significance is highly dependent on sample size. While the difference between the before and after measurements may be comparable, differences in sample size may lead to different significance results.

TRAFFIC COMPOSITION

To determine the applicability of these results to other areas of the Puget Sound region, as well as to other areas of Washington State, or to the nation, it was important to compare the traffic composition at the Southcenter Hill to other areas. This comparison included examining both the percentage of trucks and non-trucks on the roadway, as well as the dominant types of trucks on the roadway.

Percentage of Trucks in Traffic Stream

At the Southcenter Hill site, the researchers found that trucks made up a very small percentage of the total traffic flow (articulated buses were *not* considered trucks in this analysis). During weekdays, truck traffic accounted for just over 3 percent (on average) of the total traffic flow. On weekends, the percentage of trucks in the traffic stream dropped (on average) to just below 2 percent (see Figure 10).

One can assume, on the basis of the literature, that the redistribution of such a small percentage of trucks throughout the facility caused by the lane restriction would have little impact on the roadway operation or motorists' safety. (1)

Truck Lane Distribution

The researchers expected that, once the lane restriction had been implemented, the number of trucks traveling in lane 4 (median lane) would drop to zero (assuming 100 percent compliance), and truck traffic in lane 3 (lane adjacent to restricted lane) would increase substantially. This, however, was not the case.

As seen in Figure 11, the distribution of trucks at the Southcenter Hill site did not change significantly after the implementation of the lane restriction. The percentage of trucks traveling in lanes 3 and 4 remained relatively constant, implying a high restriction

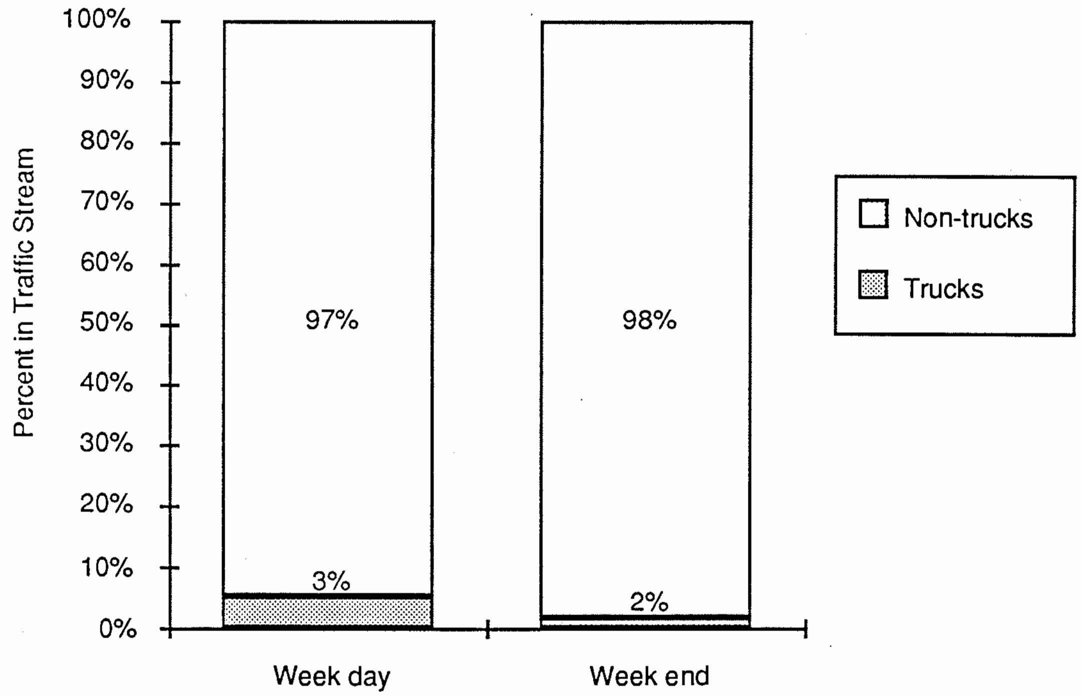


Figure 10. Percentage of Trucks in Traffic Stream

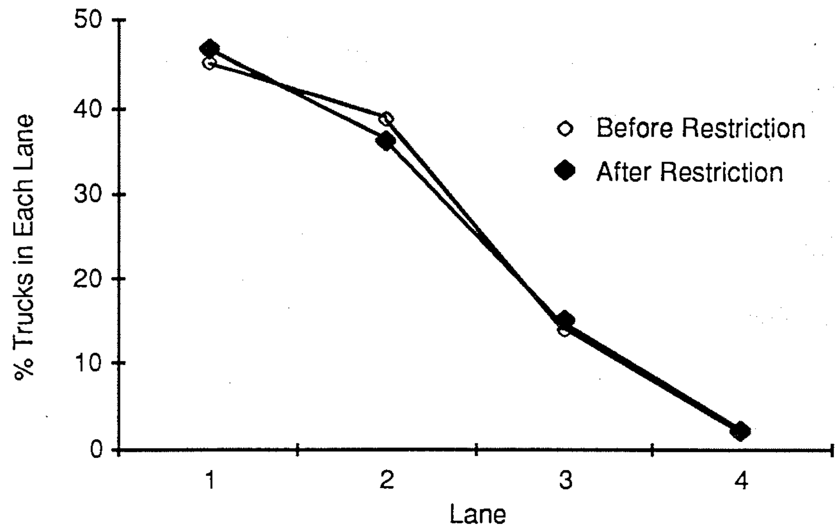


Figure 11. Average Weekday Truck Distribution by Lane

violation rate. Some shifting of truck traffic did occur in Lanes 1 and 2 (extreme right lanes), but this did not appear to be a direct result of the lane restriction.

This lack of truck traffic redistribution throughout the facility has serious implications for this analysis. Any changes noted in the operation or safety of the Southcenter Hill site may not be attributable to the lane restriction because lane distribution conditions remained the same before and after the implementation of the restriction.

Truck Traffic Composition

The researchers needed to determine the most prevalent truck type on the roadway for later use in conducting accident analyses. They looked for trends regarding the truck types most frequently involved in accidents at the Southcenter Hill site.

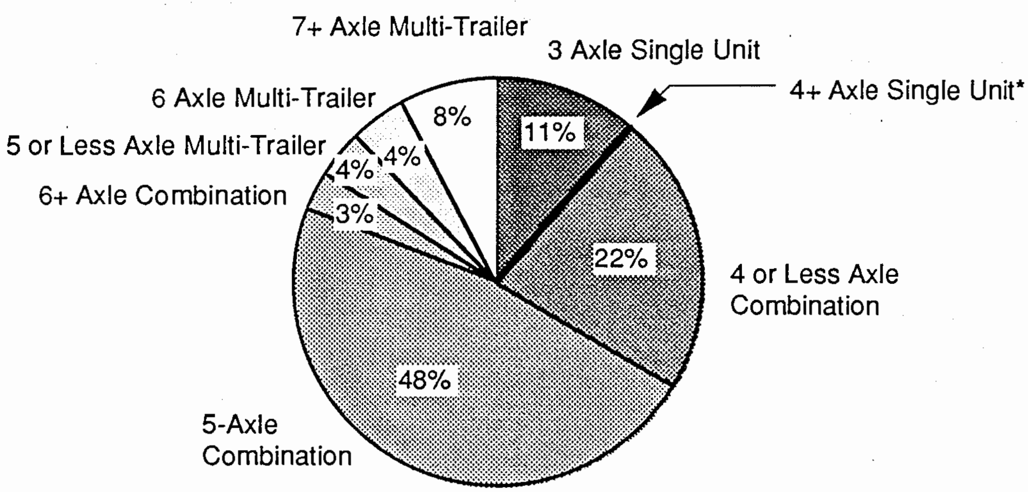
As seen in Figure 12, the largest number of trucks on the Southcenter Hill roadway segment were combination trucks with five axles. The next largest numbers of truck types included combination trucks with four or fewer axles and single-unit trucks with three axles.

TRAFFIC FLOW CHARACTERISTICS

It is important to consider the effects of travel lane restrictions on traffic flow characteristics. For example, is the traffic volume great enough to warrant a lane restriction, or is the volume so great that a lane restriction would introduce a safety hazard? It is also important to examine the impact of the restriction on speed, time gaps, and platoon lengths to determine the level of benefit gained from the restriction. Truck impedance time is an important indication of how frequently trucks block faster moving vehicles.

Volume

Both truck and non-truck traffic volumes are important factors in determining the truck restriction strategy to implement and in predicting the success of the strategy once it has been implemented.



* The percent of 4+ axle single unit trucks was negligible (i.e. ~ 0)

Figure 12. Weekday Truck Traffic Composition

Average Daily Volumes. The purpose of examining the average volumes for both trucks and non-trucks was to determine the degree to which trucks would affect the traffic flow of non-trucks. Traffic volumes were examined by day-of-week to determine when the highest volumes for both trucks and non-trucks occurred.

Unlike the volume levels for non-trucks, the number of trucks on the roadway did not increase significantly during the weekdays in comparison to the weekends (see Figure 13). This relative consistency in truck volumes implies that trucks do not pose a greater problem during the week than on the weekends.

Average Hourly Volume Distributions for Trucks and Non-Trucks. By examining the average hourly volume distributions for both trucks and non-trucks, the researchers could determine whether the times at which the truck volumes were maximized coincided with the maximum non-truck volumes. This would indicate the degree to which trucks were a problem during non-truck peak periods.

Figure 14 shows that trucks do not pose a severe problem during the non-truck peak periods. First, the number of trucks in the traffic stream was very small in comparison to the number of non-trucks. Second, truck volumes were more evenly distributed throughout the day and experience no real peak.

Average Hourly Volume Distribution for Trucks Traveling in Lane 4. Previously, when examining the truck lane distribution, the researchers had discovered that virtually no redistribution of trucks occurred in the restricted lane (lane 4). By examining the hourly volume distribution for trucks in lane 4 both before and after the lane restriction went into effect, researchers could gain insight into the motivation for trucks to continue traveling in lane 4 after it had been restricted.

One motivational factor for continued truck travel in lane 4 clearly stands out. The number of trucks traveling in lane 4 increased substantially during the hours between 2 pm and 8 pm (see Figure 15). This is the peak traffic period for this highway segment.

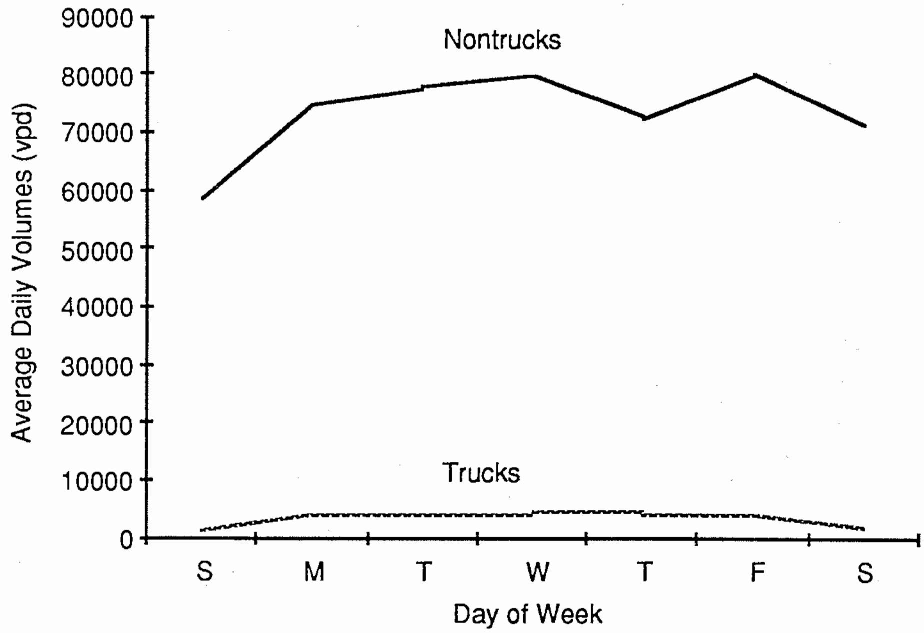


Figure 13. Average Daily Volumes

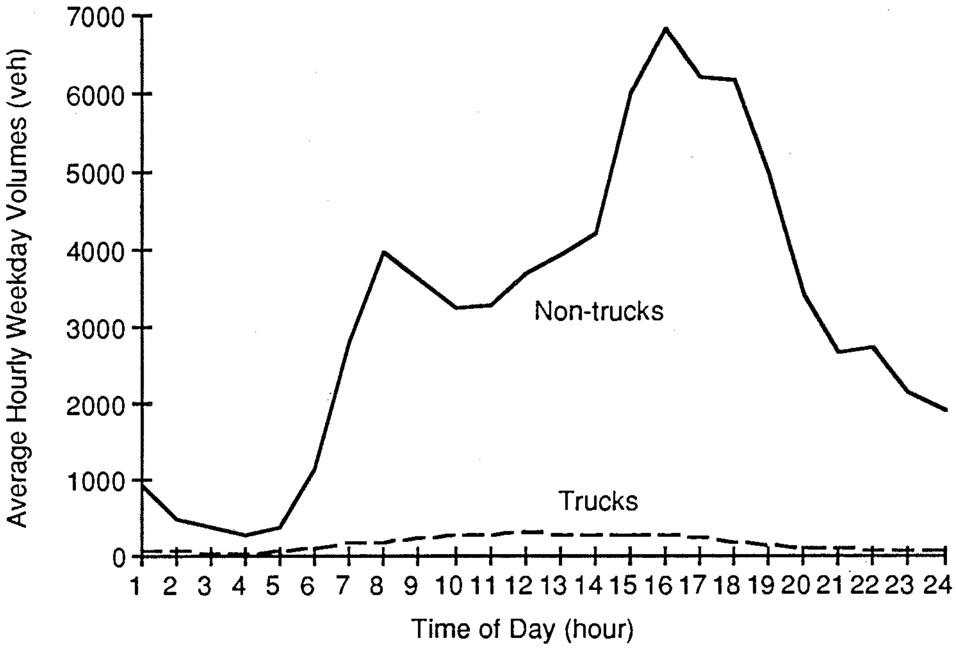


Figure 14. Volume Distributions, throughout the Day, for Facility

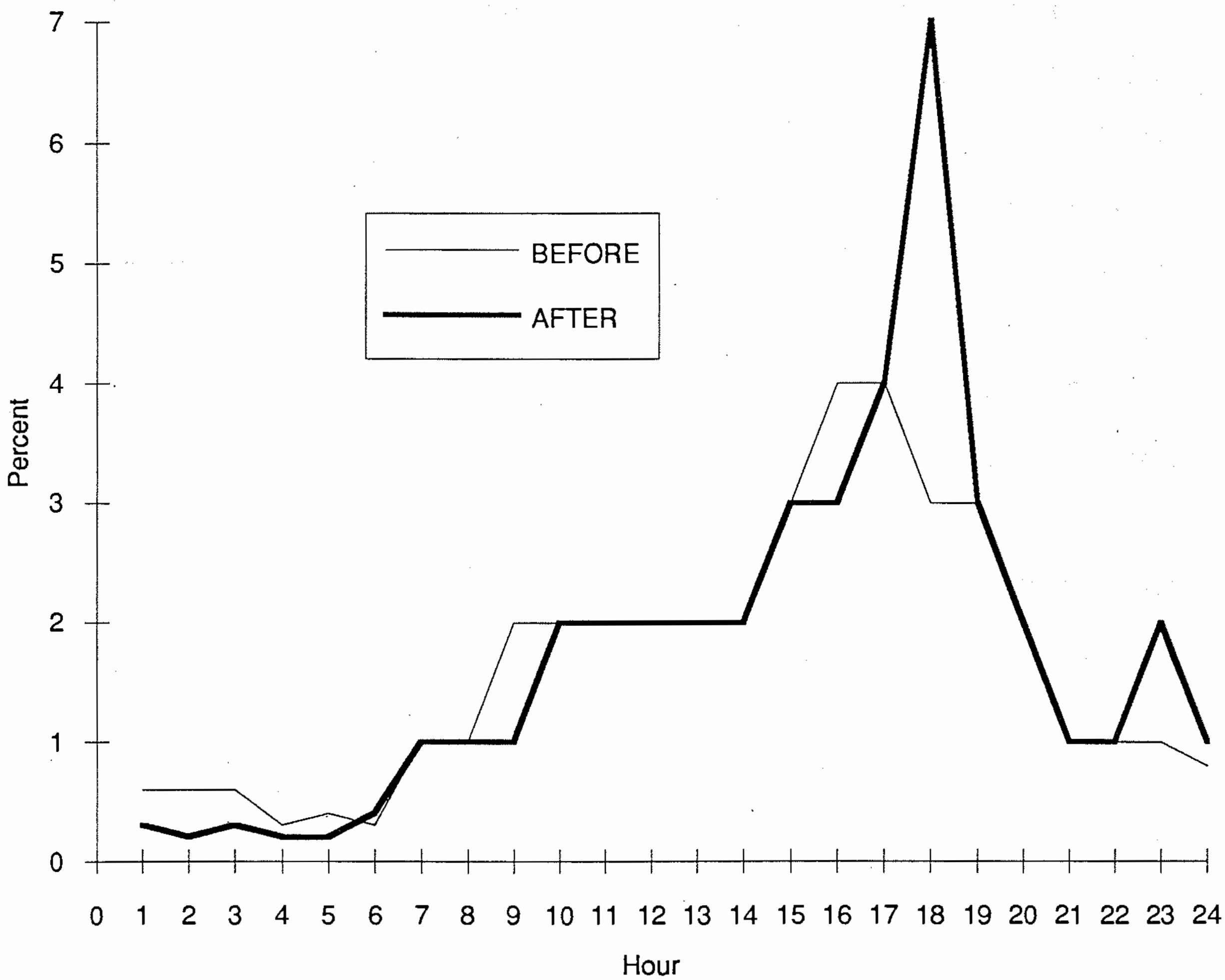


Figure 15. Hourly Distribution of Truck Volumes in Lane 4

Obviously, trucks traveled in the faster moving lane to save time and operating expenses (fuel, vehicle wear and tear).

It should not be assumed, however, that this is the only reason trucks traveled in the restricted lane. The increase in truck traffic volumes in lane 4 occurred both before and after the implementation of the lane restriction, suggesting some consistency in the operation of the facility. It is likely that the truckers were unaware of the restriction.

Change in Average Weekday Traffic Flow Rate. Traffic flow rates at the Southcenter Hill facility, including both trucks and non-trucks, increased significantly (see Table 10). The number of trucks per day increased by approximately 16 percent, and the daily volume for non-trucks increased by nearly 18 percent. This increase in traffic flow could be explained by seasonal changes in traffic patterns or other socioeconomic reasons.

This increase in the number of vehicles occurred in lanes 2, 3, and 4; however, lane 1 showed no significant increase in the number of vehicles–trucks or non-trucks. (Note that while the increase of trucks in lane 4 was statistically significant, because of such a small sample size, the actual increase of one truck is negligible.) The consistency in traffic flow in lane 1 could be a result of the assumption that lane 1 is the "slow lane," and both trucks and non-trucks thus avoid this lane. However, while the *number* of trucks increased in lanes 2, 3, and 4, the *proportion* of trucks in each of these lanes remained relatively constant.

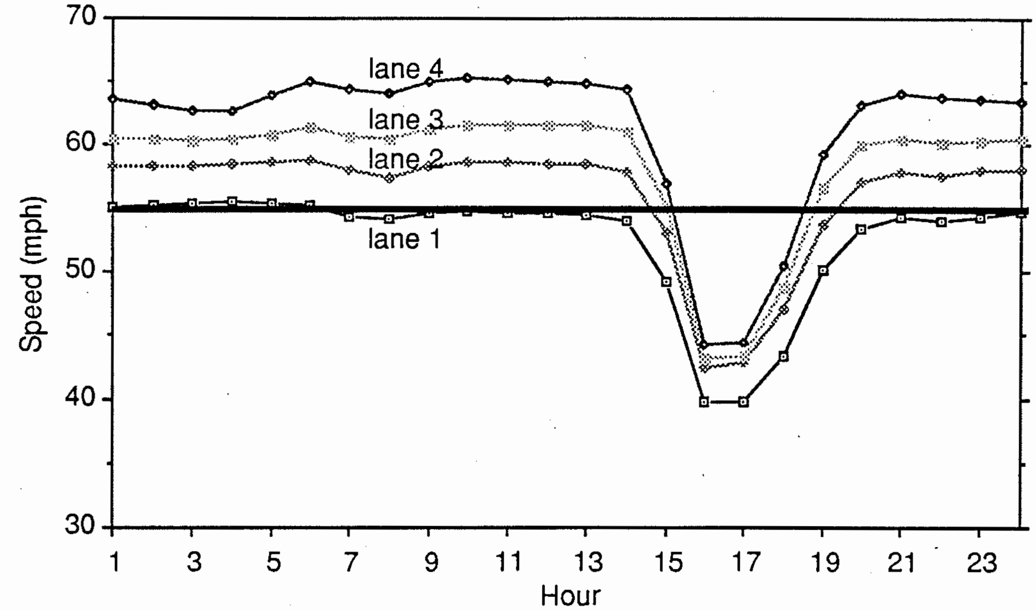
Speed

By examining the speed of the facility, both before and after the implementation of the lane restriction, the researchers would be able to better understand the operational efficiency of the facility and the violation patterns for both trucks and non-trucks.

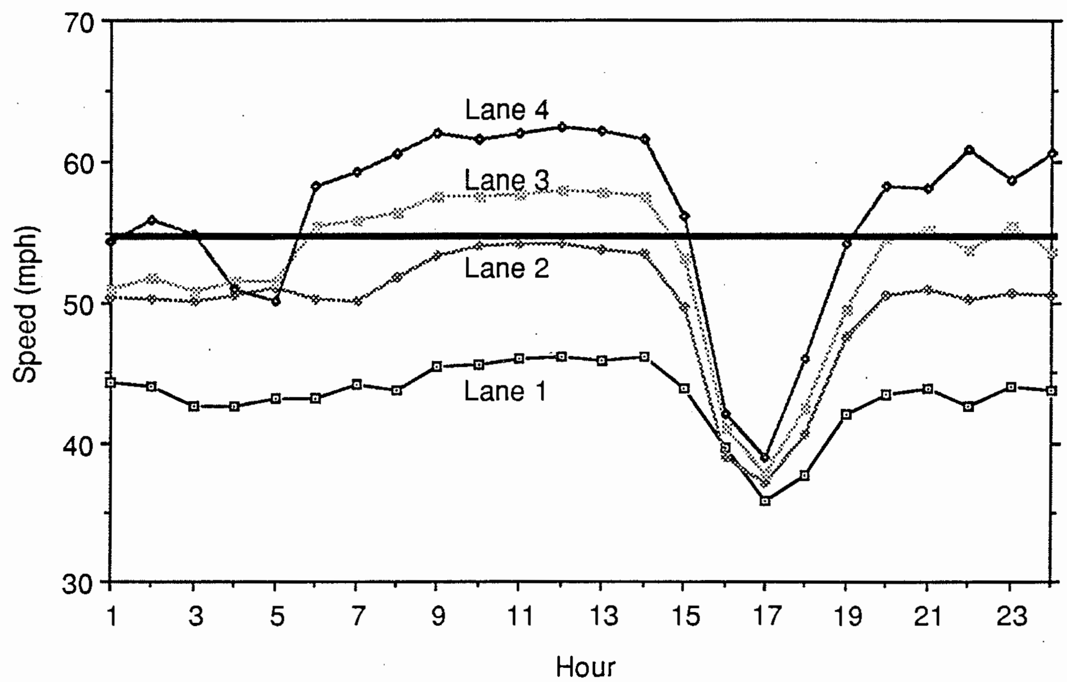
Average Hourly Speed Distributions for Trucks and Non-Trucks. Trucks and non-trucks maintained similar speed patterns (see Figure 16). In each case, average speeds increased progressively from lane 1 to lane 4, with the highest speed in lane 4

Table 10. CHANGE IN AVERAGE WEEKDAY TRAFFIC FLOW RATE

	BEFORE	AFTER	SIGNIFICANT CHANGE
DAILY TRUCK TRAFFIC (vpd)	3643	4227	INCREASE
DAILY NON-TRUCK TRAFFIC (vpd)	66272	77916	INCREASE
TRUCK TRAFFIC (vphpl)			
Lane 1	76	80	NO CHANGE
Lane 2	58	68	INCREASE
Lane 3	17	25	INCREASE
Lane 4	2	3	INCREASE
NON-TRUCK TRAFFIC (vphpl)			
Lane 1	574	612	NO CHANGE
Lane 2	660	876	INCREASE
Lane 3	845	985	INCREASE
Lane 4	697	774	INCREASE



Non-truck Speed before Restriction



Truck Speed before Restriction

Figure 16. Average Weekday Speed by Lane
for Trucks and Non-trucks

(except for truck speeds in lane 4 between 4 am and 6 am, a result that may indicate inaccurate data). This trend was true for both trucks and non-trucks, even though trucks typically had a substantially lower speed than non-trucks in each of the lanes. In each case, a substantial decrease in speed occurred between 3 pm and 6 pm, when the facility reached its highest level of congestion and approached capacity.

This examination of the average speeds by lane for both trucks and non-trucks does not appear to show that the trucks traveling at lower speeds limited the non-trucks' speeds in any way. In each lane, vehicle speeds were substantially higher even when the facility was approaching capacity. However, this situation was observed *before* the implementation of the restriction, so no conclusions can be drawn as to any improvements the restriction may have produced.

Average Speed Distributions within Lanes for Trucks and Non-Trucks. The researchers examined the speed distributions by lane, and in each case, non-trucks had the highest speeds (see Figure 17). In addition, the percentage of both trucks and non-trucks traveling at speeds greater than 55 mph increased across the facility from lane 1 (lowest percent > 55 mph) to lane 4 (highest percent > 55 mph). Similar results were noted after the hourly speed distributions for trucks and non-trucks were examined.

Again, the results summarized in Figure 17 were obtained by observing vehicle speeds *before* the implementation of the lane restriction. Therefore, no conclusions can be drawn regarding any changes in speed characteristics that may have resulted from the restriction.

A wide range of average speeds in each of the single lanes could lead to a potential safety problem. However, Figure 17 does not describe levels of safety. The range of speeds in Figure 17 does not reflect variable vehicle speeds at an instance in time; rather it reflects vehicle speeds dependent on changes in volumes throughout the day. When the facility approached capacity, speeds dropped to nearly zero. However, when the facility experienced free flow conditions, speeds were as high as 80 mph. This

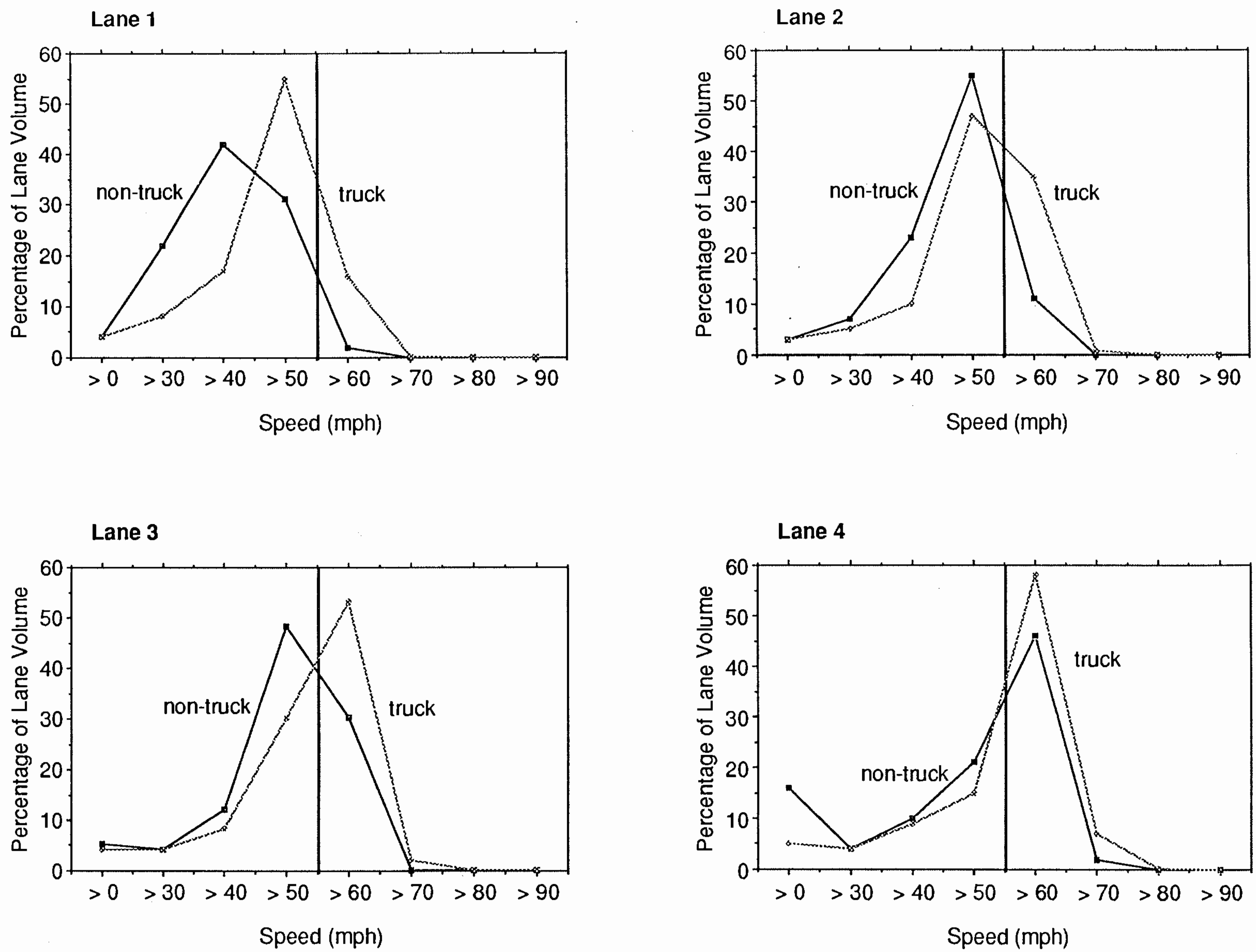


Figure 17. Cumulative Speed Distribution by Lane

does not mean that during similar times of the day, one vehicle traveling at nearly 80 mph and another traveling at only 5 mph would be traveling in the same lane.

Changes in Average Speeds for Trucks and Non-Trucks. A statistically significant increase in average speed for both trucks and non-trucks occurred after the implementation of the truck lane restriction (see Table 11). However, note that this increase for both trucks and non-trucks was less than 4 percent.

To determine whether this increase was attributable to the lane restriction, speed changes were examined lane by lane. In each of the four lanes, the speeds increased significantly for both trucks and non-trucks, except for truck speeds in lane 4, which did not change.

It may be that, because of the road grade and operational limitations, trucks in lane 4 had already been traveling at their peak operational speed before the implementation of the lane restriction. Because of geometric and operational constraints, this peak speed could not increase, regardless of any improvements to facility operation.

Change in Average Speeds for Vehicle Combinations. For each of the vehicle combinations—car following car, car following truck, truck following car, and truck following truck—the average speeds increased significantly after the implementation of the lane restriction (see Table 12). Speeds of these "couplets" were only recorded if the vehicles were within a 1-second time gap (see Figure 18).

Both before and after the implementation of the lane restriction, the speeds for the couplets of cars following cars and trucks following cars were greater than the speeds for cars following trucks and trucks following trucks. The researchers originally predicted that if the average speed for cars following trucks was less than the average speed of cars following cars, trucks might be impeding the free flow of traffic, which appears to be the case. Differences in operational capabilities may explain why the average speeds for the car following car couplet were highest and the average speeds for the truck following truck couplet were lowest.

Table 11. CHANGE IN AVERAGE WEEKDAY VEHICLE SPEED

	BEFORE	AFTER	SIGNIFICANT CHANGE
TRUCK TRAFFIC (mph)	47.0	48.5	INCREASE
NON-TRUCK TRAFFIC (mph)	54.9	55.6	INCREASE
TRUCK TRAFFIC (mph)			
Lane 1	43.5	44.5	INCREASE
Lane 2	49.8	50.8	INCREASE
Lane 3	52.7	53.9	INCREASE
Lane 4	55.1	55.3	NO CHANGE
NON-TRUCK TRAFFIC (mph)			
Lane 1	50.2	51.3	INCREASE
Lane 2	54.2	55.0	INCREASE
Lane 3	56.5	57.0	INCREASE
Lane 4	57.5	58.1	INCREASE

Table 12. CHANGE IN AVERAGE WEEKDAY SPEED OF VEHICLE COUPLETS

	BEFORE	AFTER	SIGNIFICANT CHANGE
Car Following Car (mph)	54.7	55.4	INCREASE
Car Following Truck (mph)	47.0	49.1	INCREASE
Truck Following Car (mph)	53.9	55.4	INCREASE
Truck Following Truck (mph)	44.5	46.7	INCREASE

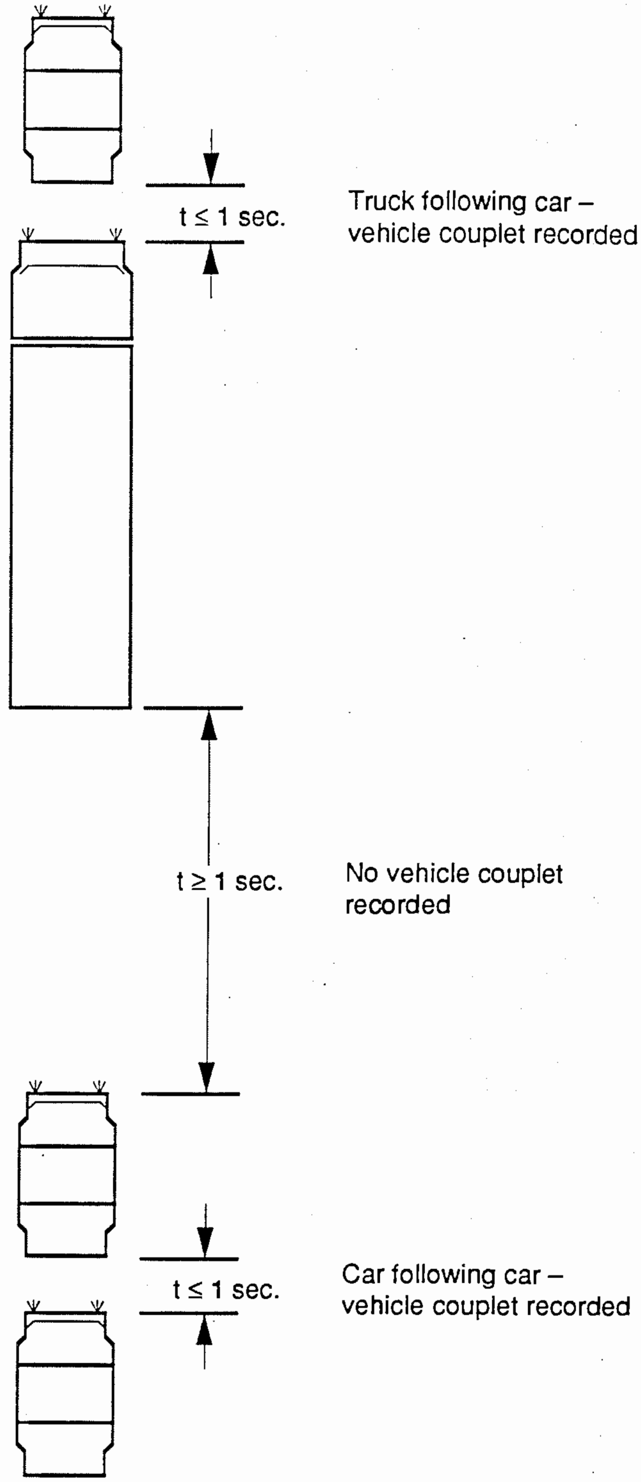


Figure 18. Recording Vehicle Couplets

These results are consistent with the overall increase in vehicle speeds noted previously.

Change in Average Speed Differentials for Adjacent Lanes. Between lanes 1 and 2, and between lanes 3 and 4, the speed differential remained constant (the speed in each lane increased proportionately) before and after the implementation of the lane restriction. However, the speed differential between lanes 2 and 3 decreased significantly (see Table 13) after the restriction had been implemented. A decrease in speed differential usually implies an increase in the facility's level of safety.

If a substantial redistribution of trucks had occurred after the implementation of the lane restrictions, this decrease in speed differential between lanes 2 and 3 could have been easily explained: the average speed in lane 3 would have predictably decreased because of an increase in the truck traffic in that lane (trucks previously traveling in lane 4 would now be in lane 3). However, this explanation does not fit because no measurable redistribution of trucks occurred in lanes 3 and 4.

Changes in Average Speed Violation Rates. Violation rates were determined by measuring hourly distributions per lane for both trucks and non-trucks. Though the posted speed at the Southcenter Hill site is 55 mph, the vehicle speed used was 60 mph (5 mph were added to allow for enforcement and instrument inaccuracies in collecting the speed data).

As expected, an overall increase in speed was accompanied by an increase in speed violation rates for both trucks and non-trucks. Figure 19 displays this information by individual lane.

The percentage of both trucks and non-trucks in violation of the speed limit was greater after implementation of the lane restriction. This percentage varied throughout the day as the traffic volumes varied. As expected, the percentage of trucks and non-trucks violating the speed limit dropped to nearly zero as the facility approached capacity.

Table 13. Change in Average Weekday Speed Differential

	BEFORE	AFTER	SIGNIFICANT CHANGE
Between Lanes 1 & 2 (mph)	4.45	4.05	NO CHANGE
Between Lanes 2 & 3 (mph)	2.85	2.46	DECREASE
Between Lanes 3 & 4 (mph)	3.00	3.19	NO CHANGE

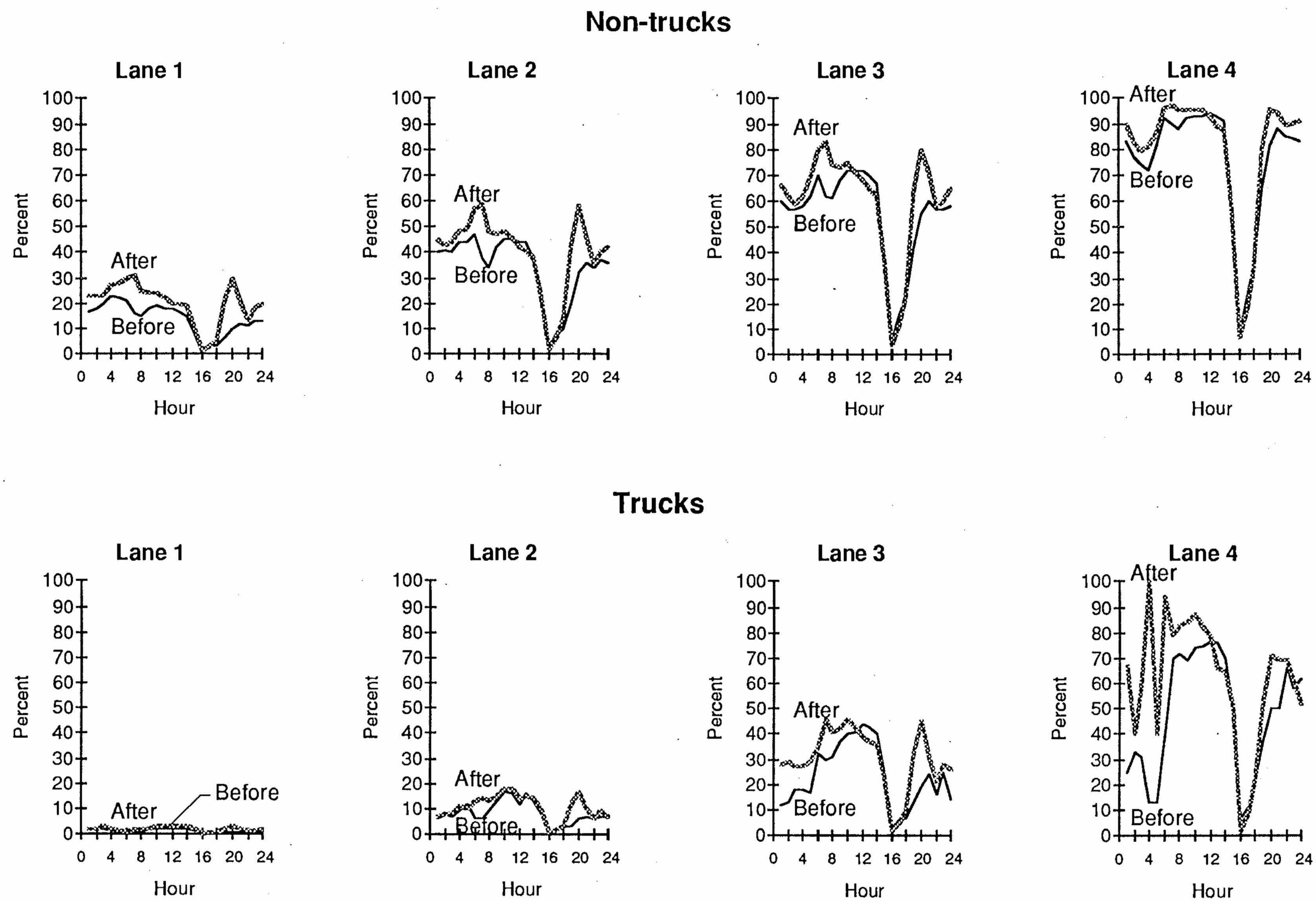


Figure 19. Percentage of Trucks/Non-Trucks Violating Speed (60 mph)

In each case, except for when the facility was near-capacity, the percentage of non-trucks violating the speed limit was greater than the percentage of trucks violating the speed limit. This may be because of the trucks' operational limitations, especially on grades.

There was a definite peak in the number of speed violations immediately following the near-capacity period. This peak in speed violations was much more apparent after the lane restriction had been implemented. The peak occurred in each of the lanes and for both trucks and non-trucks. (It was much less distinguishable in lane 4, where speed violations were already high, and in lane 1 for trucks because truck speed violations were already low.)

This peak in speed violations immediately following a period of severe congestion may not be directly attributable to the lane restriction. It may be a result of the drivers' increased frustration level regarding lost travel time, directly tied to an increase in the overall traffic on the facility.

Time Gaps, Platoon Lengths, and Truck Impedance Time

Several measurements, including the time gaps between vehicle couplets, platoon lengths behind trucks, and truck impedance time (the time that trucks running in tandem occupy multiple lanes of the facility) demonstrate the impact trucks have on the ability of traffic to flow freely.

Change in Average Time Gaps Within Vehicle Couplets. The time gaps between vehicle couplets (that is, car following car, car following truck, truck following car, and truck following truck) decreased significantly in every case except for the truck following truck couplet (see Table 14).

It may be that trucks, which are driven by skilled drivers, were traveling at their minimum allowable spacing (time gap) before the implementation of the lane restriction. Changes in facility operation do not alter this spacing distance; however, factors, such as braking capabilities and driver visibility do affect the spacing between trucks.

Table 14. CHANGE IN AVERAGE WEEKDAY TIME-GAPS FOR VEHICLE COUPLETS

	BEFORE	AFTER	SIGNIFICANT CHANGE
Car Following Car (sec)	0.84	0.80	DECREASE
Car Following Truck (sec)	0.46	0.43	DECREASE
Truck Following Car (sec)	0.83	0.80	DECREASE
Truck Following Truck (sec)	0.54	0.53	NO CHANGE
Car Following Car (sec)			
Lane 1	0.78	0.78	INCREASED
Lane 2	0.83	0.77	DECREASED
Lane 3	0.85	0.82	DECREASED
Lane 4	0.86	0.82	DECREASED
Car Following Truck (sec)			
Lane 1	0.50	0.48	DECREASED
Lane 2	0.43	0.39	DECREASED
Lane 3	0.45	0.41	DECREASED
Lane 4*	0.52	0.51	NO CHANGE
Truck Following Car (sec)			
Lane 1	0.78	0.79	NO CHANGE
Lane 2	0.83	0.78	DECREASED
Lane 3	0.86	0.82	DECREASED
Lane 4*	0.87	0.83	DECREASED
Truck Following Truck (sec)			
Lane 1	0.64	0.63	NO CHANGE
Lane 2	0.48	0.47	NO CHANGE
Lane 3	0.52	0.43	DECREASED
Lane 4*	0.57	0.51	NO CHANGE

*Trucks present in lane 4 after the truck lane restrictions are in place are in violation

There was no real pattern in the time gaps between vehicle couplets by lane (see Table 14).

- The car following car combination's average weekday time gap significantly decreased in lanes 2, 3, or 4, but increased in lane 1.
- The car following truck combination decreased in each case, except in lane 4. The time gap between trucks following cars decreased in each case, except in lane 1, where there was no significant change.
- Trucks following other trucks showed change, except in lane 3, where the time gap between trucks decreased significantly.

Change in Average Platoon Length. Before the truck lane restriction, the researchers predicted they would discover that trucks traveling in the faster lanes (lanes 3 and 4) were blocking the movement of non-trucks into these lanes. This situation would predictably result in lower speeds for the non-trucks and longer platoons of non-trucks behind the trucks. They predicted that after the implementation of the truck lane restriction, non-trucks would be able to "pass" the slower moving trucks by utilizing lane 4, thus reducing the platoon lengths. Non-trucks were considered part of a platoon if they were within a 1-second time gap of the lead vehicle (see Figure 20). In each case, trucks were the lead vehicles.

After the implementation of the lane restriction, contrary to the researchers' prediction, there was no decrease in platoon lengths (see Table 15). In lanes 1 and 4, the lengths of the platoons did not change. In lanes 2 and 3, the platoon lengths actually increased.

Change in Truck Impedance Time. Truck impedance time is a measure of the number of times per day trucks travel in multiple lanes, either in tandem or within a 1-second gap between the rear bumper of the lead vehicle in one lane and the front bumper of the following vehicle in an adjacent lane (see Figure 21). By examining this measurement, the researchers could determine the number of times multiple lanes on the facility were simultaneously occupied by slower moving trucks and the number of times lane 4 (the fast lane) was one of the lanes that was occupied.

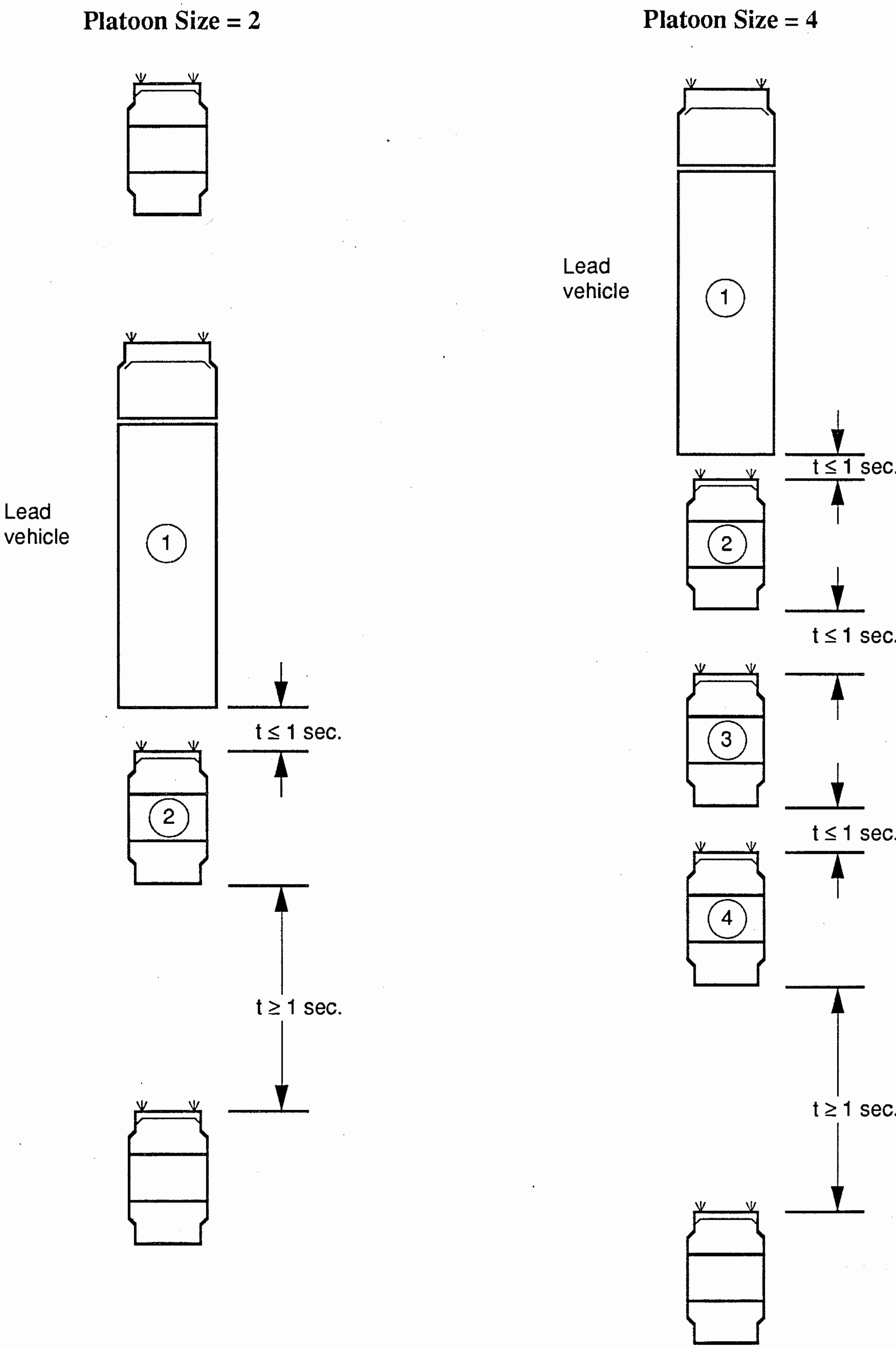


Figure 20. Recording Platoons

Table 15. CHANGE IN AVERAGE WEEKDAY PLATOON LENGTH

PLATOON LENGTH (veh)	BEFORE	AFTER	SIGNIFICANT CHANGE
Lane 1	2.30	2.31	NO CHANGE
Lane 2	2.39	2.49	INCREASE
Lane 3	2.49	2.55	INCREASE
Lane 4	2.72	2.78	NO CHANGE

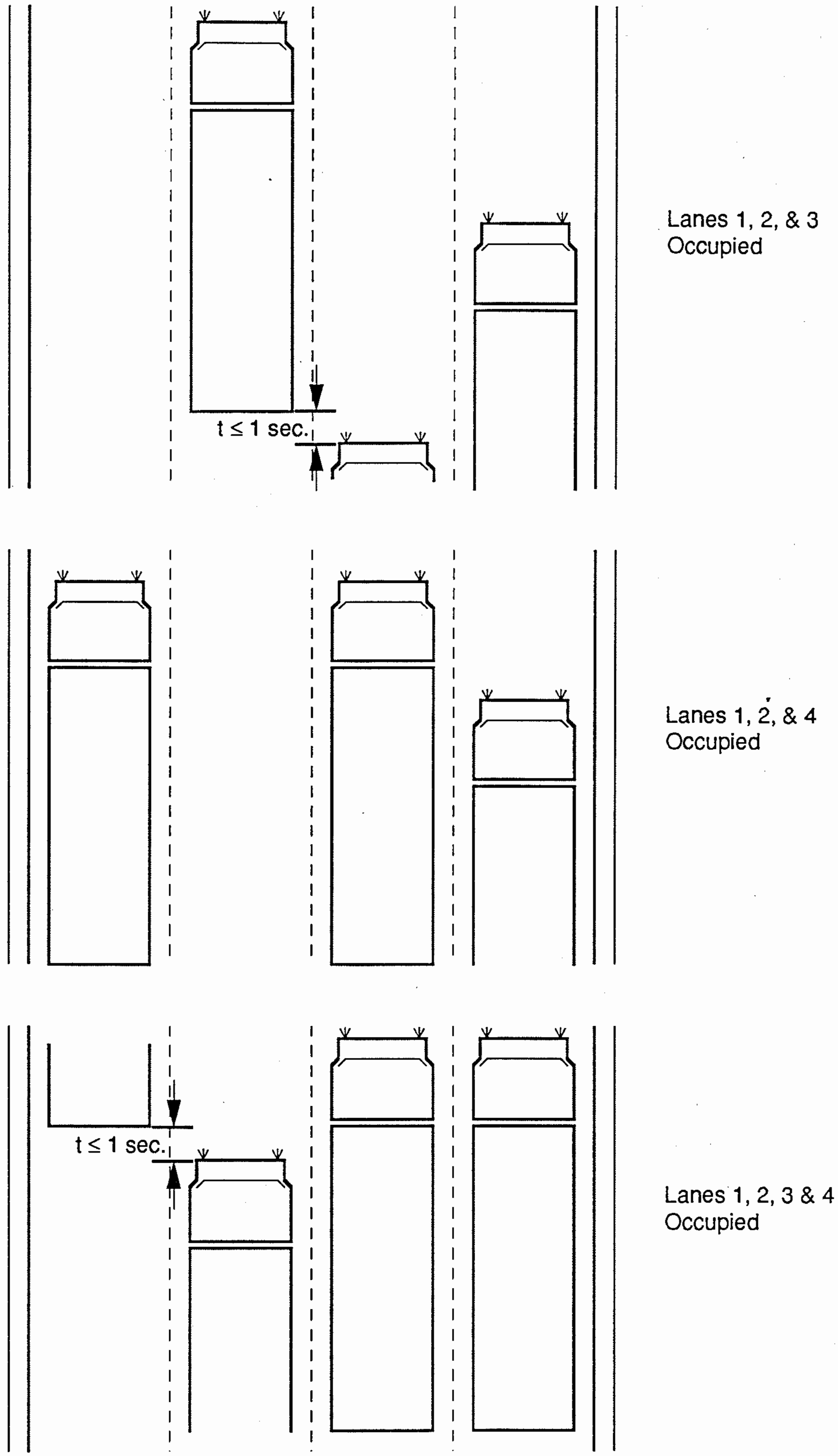


Figure 21. Examples of Truck Impedance

As seen in Table 16, the number of times per day that trucks occupied lanes 1, 2, and 3 significantly increased after the implementation of the lane restriction. If a redistribution of trucks from lane 4 to lane 3 had occurred, this increase could have been easily explained: the trucks previously traveling in lane 4 would have moved over into lane 3, making it more feasible for trucks to travel in tandem in lanes 1, 2, and 3. However, because the lane redistribution did not occur, this was not the case.

There was no change in the number of times per day that trucks occupied either lanes 1, 2, and 4 or lanes 1, 2, 3, and 4. However, the actual times per day that trucks occupied these lanes simultaneously was less than 0.25 for lanes 1, 2, and 4, and zero for lanes 1, 2, 3, and 4. This demonstrates that truck impedance is not a major determinant of improved facility operation.

SAFETY CHARACTERISTICS

When determining the effectiveness of a truck lane restriction, it is important to not only observe the operational impacts that may result but also impacts on the facility's level of safety. The level of safety for a particular facility can be characterized by examining (1) the distribution of accidents across the facility, (2) the types of accidents that are occurring, and (3) the severity of the accidents.

Accident data collected after the implementation of the truck lane restriction were too limited to make a before/after comparison. Instead, the types of accidents that occurred on the facility *before* the truck lane restriction was implemented were characterized on the basis of over ten years of truck-related accident data. The results are discussed below.

Accident Distribution

As seen in Figure 22, the highest number of truck-related accidents occurred in Lane 1 and decreased across the facility. This is realistic because the number of trucks traveling in each of these lanes decreased similarly across the facility.

Had the trucks in Lane 4 redistributed themselves across the facility instead of remaining in Lane 4, a before/after comparison of accident distribution could have been

Table 16. CHANGE IN AVERAGE WEEKDAY TRUCK IMPEDANCE TIME

Lanes Occupied	(times/day) BEFORE	AFTER	Significant Change
1,2, & 3	1.21	3.16	INCREASE
1,2, & 4	0.15	0.22	NO CHANGE
1,2,3, & 4	0	0	NO CHANGE

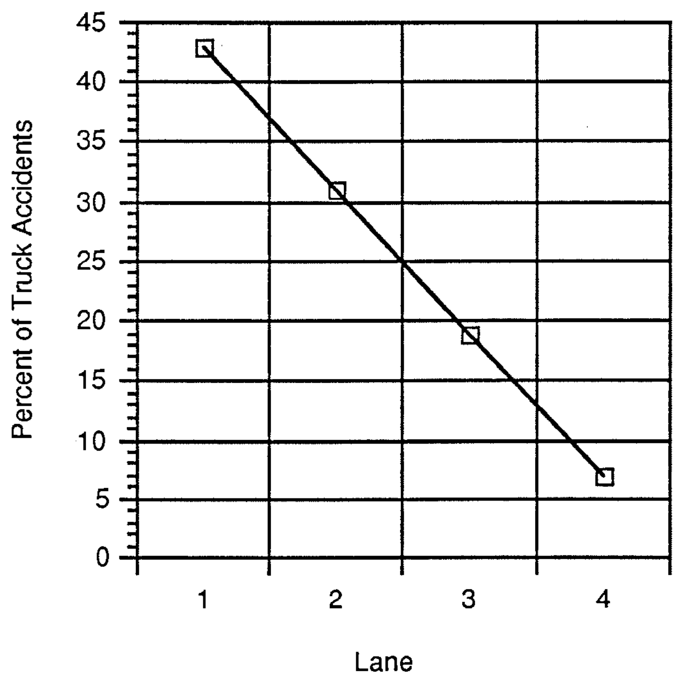


Figure 22. Truck Accident Distribution by Lane

made (with additional data). However, with the lack of truck redistribution, any noted increase in the number of accidents is more likely attributable to an overall growth in truck traffic (and general traffic) and not the lane restriction.

Accident Types

While sufficient data did not exist to complete a before/after analysis, a characterization of the types of accidents that have occurred may provide insight about how the restrictions may affect safety.

First, consider the types of accidents that have occurred by lane. In each lane, the majority of the accidents have resulted from a vehicle (truck or non-truck) moving straight ahead and sideswiping another vehicle (see Figure 23). This was somewhat surprising.

Second, consider the predominant vehicle type (truck or non-truck) that has been initiating the accident. Note in Figure 24 that the majority of accidents that have resulted from (1) merging from an on-ramp, (2) changing lanes to the left, or (3) moving straight were initiated by non-trucks.

The majority of accidents that have resulted from changing lanes to the right were initiated by trucks. This may indicate that a lane restriction that required trucks to move to the right-most lanes would result in more truck-involved accidents.

Accident Severities

Accident severity was examined at three levels: (1) accidents resulting in only property damage, (2) accidents resulting in at least one injury, and (3) accidents resulting in at least one fatality.

Accidents resulting from lane changes to the left appear to be most severe. However, the appearance may be misleading because relatively few accidents were recorded that actually resulted from left-hand lane changes. Similarly, only a single truck-related accident was recorded that resulted from merges from the on-ramp. Note that data from a substantially larger number of recorded accidents have shown that

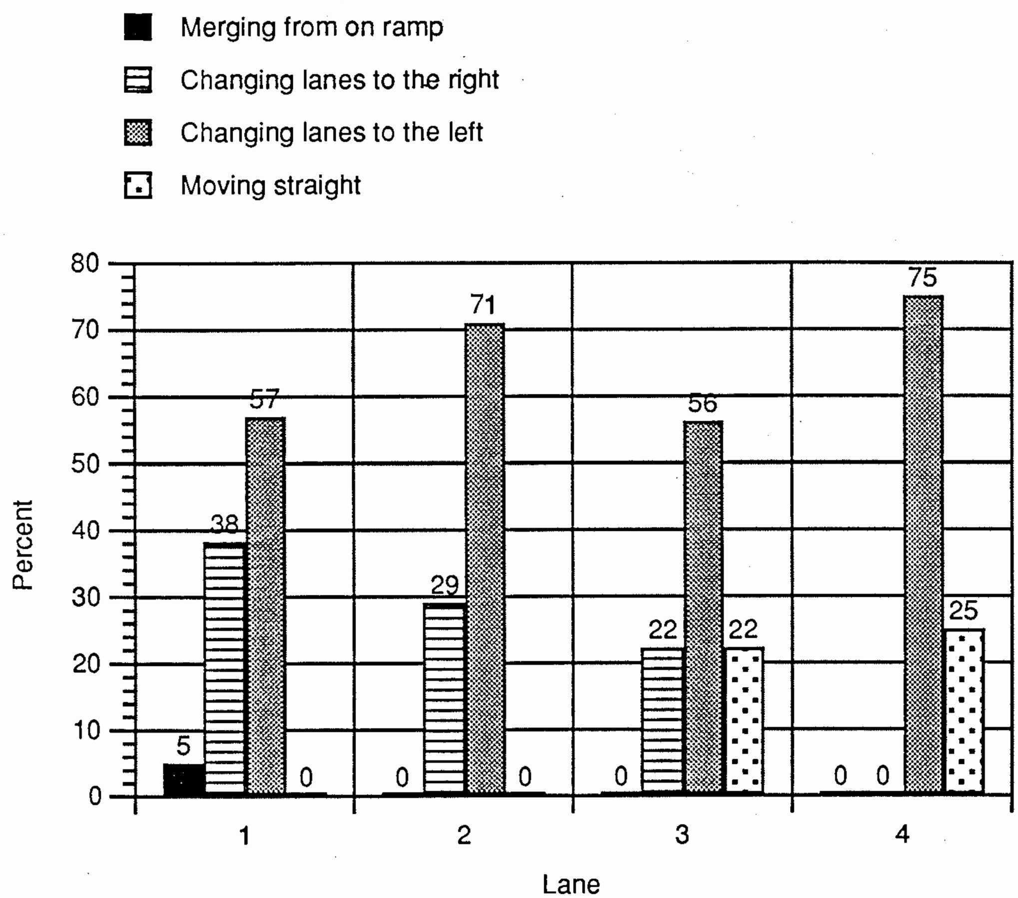


Figure 23. Distribution of Vehicle Movement at Time of Accident by Lane

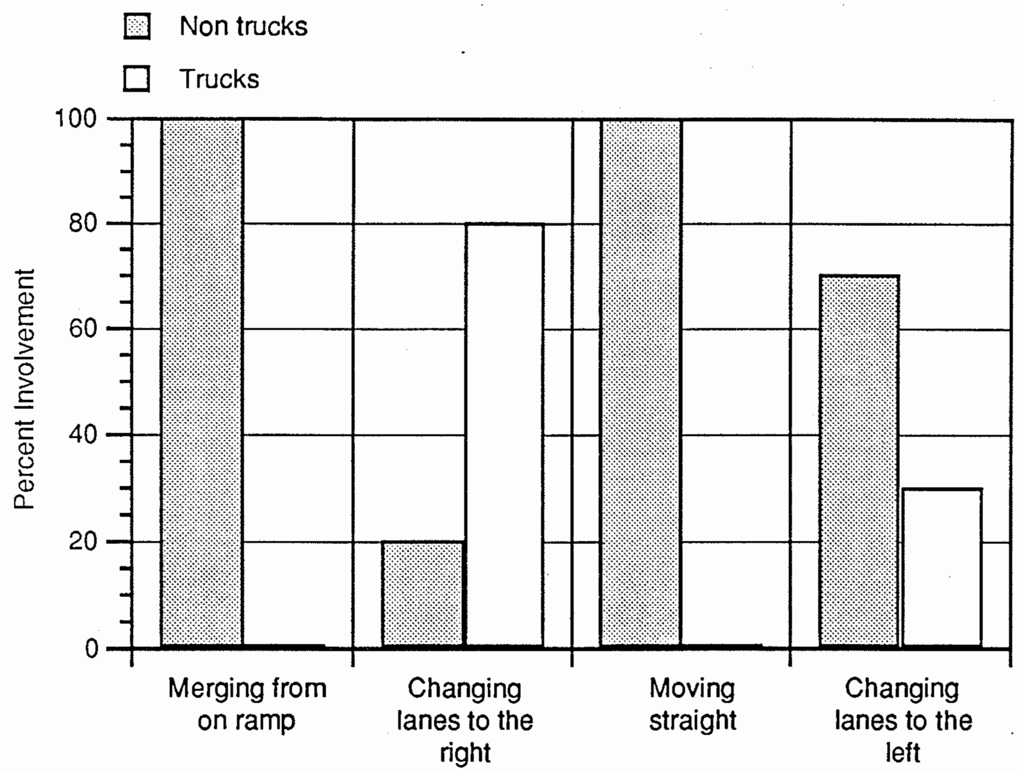


Figure 24. Truck/Non Truck Involvement by Vehicle Movement

accidents resulting from both changing lanes to the right and moving straight usually result in minor injuries (see Figure 25).

ENFORCEMENT ISSUES

Enforcement can have a great impact on the effectiveness of any truck restriction strategy. If no enforcement efforts are made, the temptation for drivers to violate the restriction becomes great because the threat of being fined is diminished. When considering the effectiveness of lane restrictions, planners must examine the relationship between the proportion of trucks in violation of the restriction and the level of enforcement efforts. They must also consider whether enforcing the restriction is feasible, given limited resources, limited personnel, and geometric constraints.

Restriction Violation Rates

The researchers calculated the restriction violation rate by comparing the proportion of truck traffic in the restricted lane and the total truck traffic. At the Southcenter Hill site, the number of trucks traveling in the restricted lane was 94 trucks/weekday, and the total number of trucks on the whole facility was 4,460 trucks/weekday, which equals a violation rate of only 2.1 percent.

This small violation rate seems to indicate that the lane restriction was successful. However, the proportion of trucks traveling in lane 4 before the restriction was also 2.1 percent. This result implies that the lane restriction had no impact because the same proportion of trucks were utilizing lane 4 before and after the restriction was implemented.

Enforcement efforts could possibly have improved the success of the lane restriction. However, it may be that the small proportion of trucks traveling in lane 4 were simply unaware of the restriction.

Feasibility of Enforcement

The feasibility of enforcing the truck lane restriction at the Southcenter Hill site location is very low. Enforcement officers would have to pull over trucks violating the restriction in the extreme left general purpose lane to the left shoulder, which would

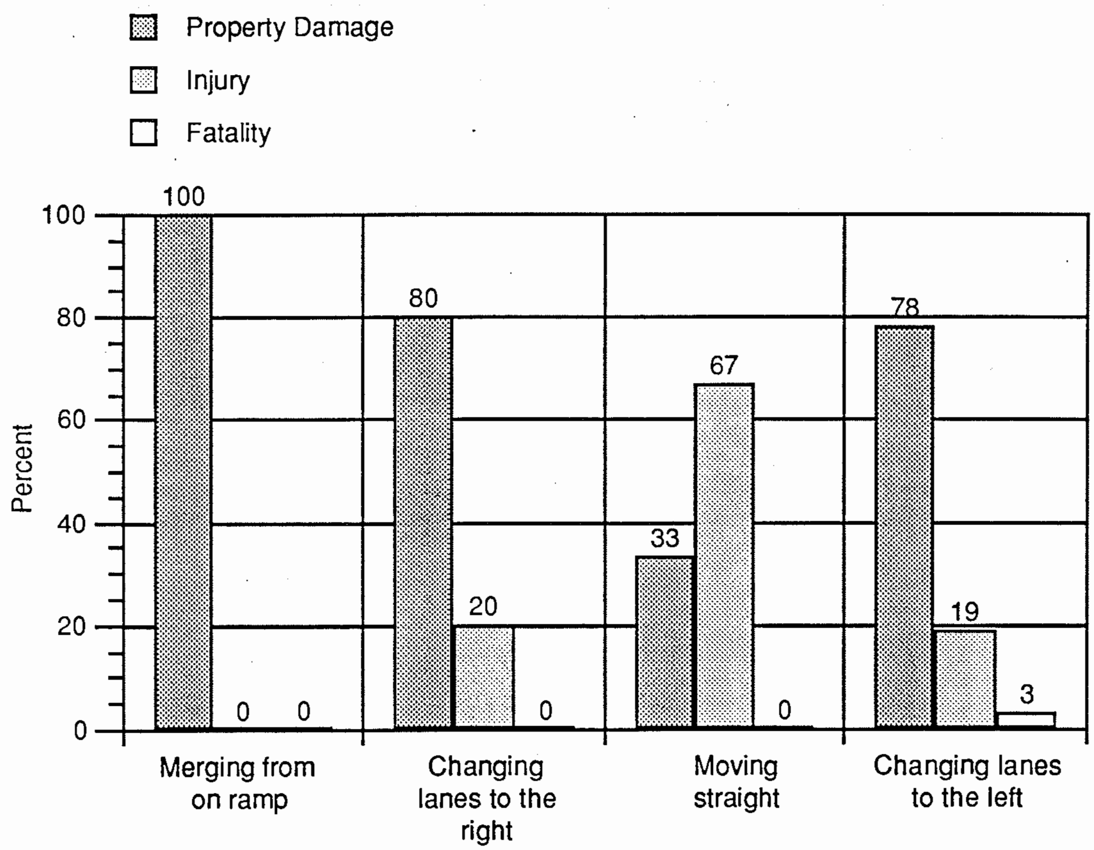


Figure 25. Accident Severity by Vehicle Movement

entail crossing the high occupancy vehicle lane, or pull them over to the right shoulder, which would entail crossing three lanes of traffic. Neither shoulder can safely support a truck. Safety hazards would also be introduced when trucks maneuvered across the roadway. During the peak, non-truck times of the day, enforcement is unrealistic.

ECONOMIC IMPACTS

In quantifying the economic impact lane restrictions may have on the Puget Sound region, planners must consider potential losses of time and money to individual drivers and to the industry as a whole.

At the Southcenter Hill site, before the restriction had been implemented, the difference in average truck speeds (not overall speed differentials) between lane 3 and lane 4 was 3.0 mph. That is, trucks traveling in lane 4 were traveling 3.0 mph faster than trucks traveling in lane 3 (on the average). In other words, if trucks in lane 4 had to move to lane 3, the average speed for these trucks would decrease by 3.0 mph.

Assuming that the restricted roadway segment is approximately 3 miles long, the time needed to travel through the restricted area, both for trucks traveling in lanes 3 and 4 (before the restriction) and for trucks traveling in lane 3 only (after the restriction), can be calculated by multiplying the length of the restricted roadway and the average truck speeds in lanes 3 and 4. The researchers determined that it took 3.26 minutes to pass through the restricted area in lane 4, and 3.45 minutes in lane 3. This is a difference of 0.19 minutes or 11.4 seconds of time lost each time a truck traveled in lane 3 rather than in lane 4.

On the basis of surveys distributed to truck drivers (the results of this survey are discussed in a later section of this report), the researchers found that the average driver traveled I-5 southbound through the Southcenter Hill site approximately 8.56 times per month or 102.72 times per year. If the driver lost 11.4 seconds of driving time each time he/she passed through the restricted area, he/she would lose 19.52 minutes of driving time per year.

Assuming the average annual wage for a Washington driver is $29,287 (16), the monetary loss incurred as a result of the lane restriction can be calculated. An average salary of nearly $30,000 amounts to wages of approximately $14.08 per hour or $0.25 per minute, assuming a 40-hour work week on the average. Monetary losses incurred by the driver as a result of the truck lane restriction would amount to $4.84 per year.

Consider the implications this loss may have for the industry as a whole. The total number of trucks traveling in lane 4 was approximately 25,896 trucks. This number is based on an average weekday truck total of 83 trucks per weekday and an average weekend truck total of 41.5 trucks per weekend day. Multiplying the total number of trucks traveling through the restricted area (25,896 trucks) by the amount of time lost per trip (11.4 seconds) provides the industry's annual driving losses. The lost driving time resulting from the implementation of a truck lane restriction along Southcenter Hill would be 82.0 hours per year (3.42 days per year).

In monetary terms, this time loss would result in $1,155 lost per year (82.0 hours/year × $14.08/hour).

These estimates were made under the following assumptions:

- 100 percent compliance with the restriction,
- no increase in average truck speeds in lane 3 after additional trucks in lane 4 had been added, and
- an average work-week of 40 hours.

In addition, the monetary estimates above do not take into account any penalties a driver might incur because of a delay in delivery times. The researchers felt that an 11.4 second delay per trip was not substantial enough to have any effect on the percentage of late deliveries.

PAVEMENT DETERIORATION RATE

Pavement deterioration rates were examined in an effort to determine the impacts that would result from a redistribution of trucks across a facility. This phenomenon is best described in terms of change in the present serviceability index (PSI). After years of repetitive loads, the pavement reaches a terminal serviceability index (TSI), which indicates that the road needs repair. For this study, a value of 1.5 was assumed for the terminal serviceability index. If no distribution of truck traffic occurred, the facility would reach the TSI at a specific time, assuming normal growth patterns. With a redistribution of trucks across the facility, lane 3 would reach the TSI of 1.5 sooner than under normal growth conditions, and lane 4 would reach the TSI later.

A number of assumptions were made to complete this analysis. The assumptions are as follows.

- 100 percent of the trucks would comply with the lane restriction at the Southcenter Hill study site.
- Pavement deterioration would result solely from ESALs; impacts from weather and freeze/thaw conditions were ignored.
- The present serviceability index would be uniform across the facility.

Also, at the time of this analysis, the pavement was already at the end of its service life according to the stricter standards set by WSDOT (the analysis was conducted assuming a TSI of 1.5, when, in actuality, the pavement life should cease when it reaches a TSI of 2.5 or 3.0).

Using standard values developed specifically for the Puget Sound region's soil and water conditions and based on WSDOT paving practices, curves were developed to show the relationship between present serviceability index and equivalent single axle loads for both lane 3 and lane 4 (see Figure 26 and 27).

An examination of the improved pavement life experienced by lane 4 with the absence of trucks and the reduction in pavement life experienced in lane 3 due to the increase in truck traffic shows some impact in the graphs. However, any impact recognized in the graphs has been derived under unrealistic conditions, such as the absence of weather impacts and 100 percent lane restriction compliance.

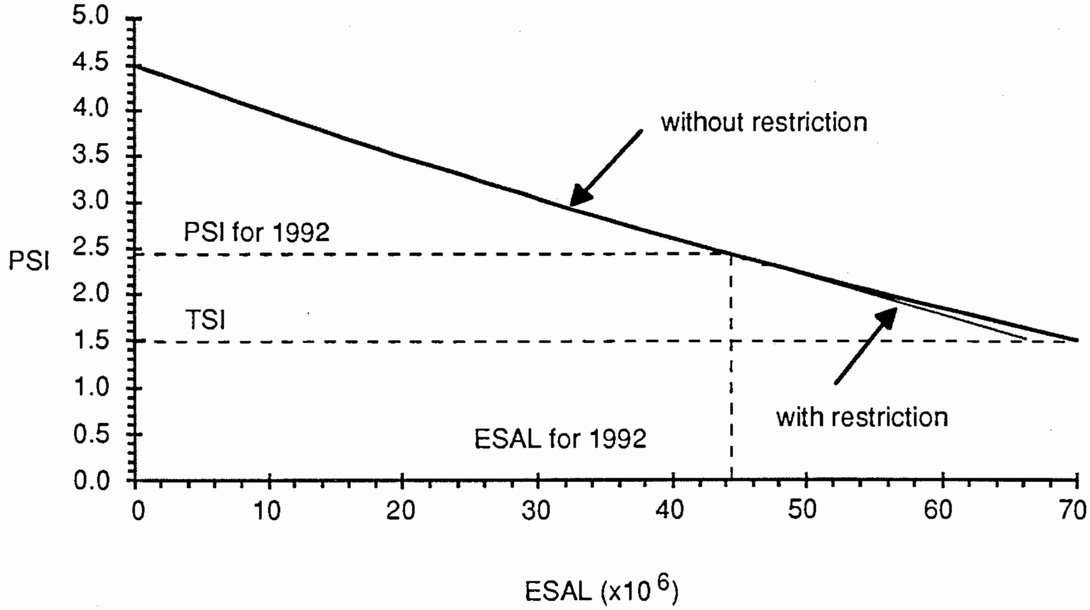


Figure 26. Pavement Deterioration Curve for Lane 3

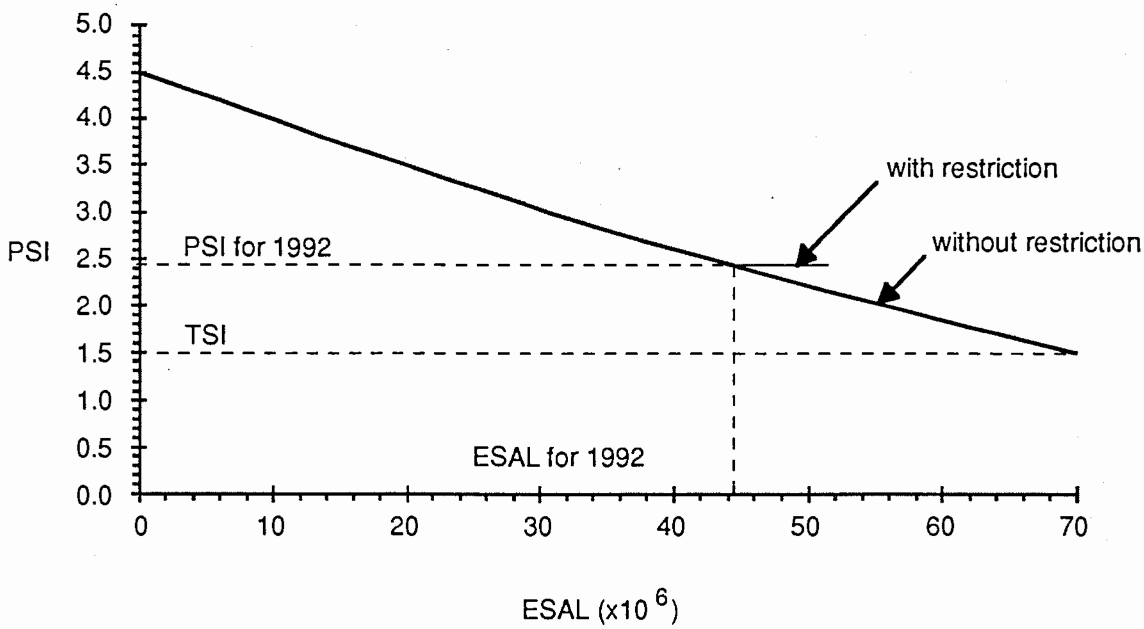


Figure 27. Pavement Deterioration Curve for Lane 4

SITE COMPARISON ANALYSIS

The purpose of the site comparison analysis was to ensure that the measurements taken for the in-depth analysis were reasonable, and to determine the feasibility of applying the results of the in-depth analysis to other areas in the Puget Sound region.

TRAFFIC COMPOSITION

Because the effectiveness of any type of truck restriction strategy depends on a number of factors, two of which are the proportion of trucks on the roadway and their proximity to the facility's access and egress areas, it is important to consider both the percentage of trucks in the traffic stream at each of the sites, and the distribution of trucks across the facility at each of the sites. If either of these factors differ greatly from site to site, the truck restriction strategy implemented at one site (in this case, lane restrictions) may not meet with the same success at the other sites.

Percentage of Trucks in Traffic Stream

The percentage of trucks in the traffic stream appeared to be relatively constant between the three study sites and the control site (see Figure 28). Both the Southcenter Hill site (Site A) and the Tacoma site (Site C) had slightly higher percentages of trucks than the other sites.

This seems reasonable when one considers the location of the sites. The Southcenter Hill site is much closer to Seattle's Central Business District (CBD) and industrial area than either the SR 520 site or the control site at 185th Street. The Tacoma site has a similar proximity to the Tacoma's Central Business District and industrial area.

Truck Lane Distribution

There was some variation in the distribution of trucks across the facility at each of the sites. This may have been due largely to the differing facility sizes and characteristics (see Figure 29).

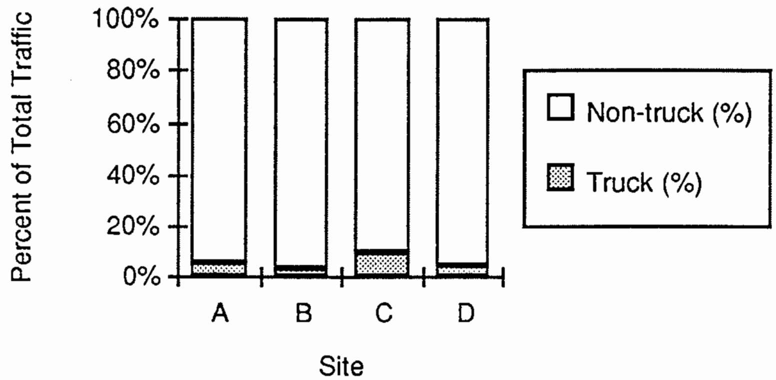


Figure 28. Percentage of Trucks in Traffic Stream

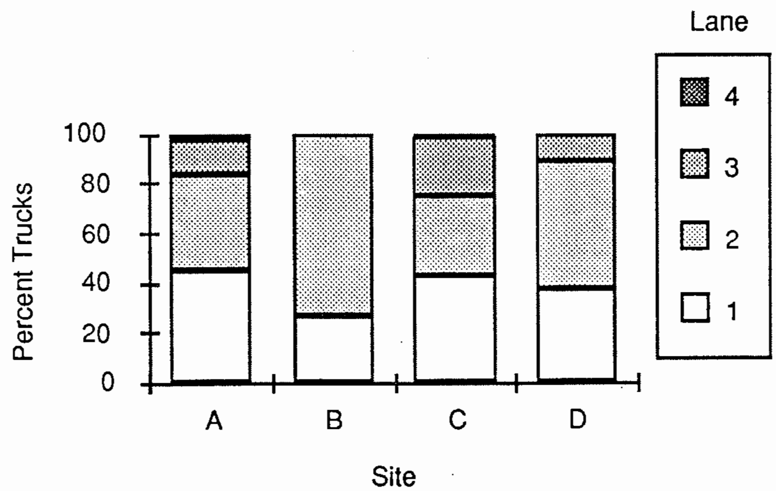


Figure 29. Truck Distribution by Lane (%)

This speculation seems reasonable because the truck lane distributions at the Southcenter Hill site and the Tacoma site were similar. At both sites, the majority of trucks traveled in lanes 1 and 2. These two sites have several common facility characteristics. Both sites

- are along a major trucking corridor,
- are on a major interstate facility,
- are multilane with 4+ directional lanes,
- are close to ports and CBDs, implying that much of the truck traffic has recently entered the facility, and
- have similar geometric designs with comparable uphill grades.

Similarly, most of the truck traffic was in the first two lanes of the control site. This finding was somewhat surprising because there is no grade at the control site. With a better ability to maintain their speed, trucks could potentially travel in the faster moving lanes (lanes 3 and 4).

Along SR 520, which is a smaller facility, most truck traffic was in lane 2. The researchers expected most of the truck traffic to be in lane 1 (the extreme right, slower moving lane) because there is a grade at this site, and trucks lose much of their ability to maintain speed. The large proportion of trucks in lane 2 may be explained by the fact that, approaching the study site, an additional lane merges into lane 1. Trucks may have been traveling in lane 2 to avoid conflicts with the merging traffic.

TRAFFIC FLOW CHARACTERISTICS

Differing traffic flow characteristics, such as average daily volumes, average vehicle speeds, time gaps, platoon lengths, and truck impedance time, can have a great impact on the effectiveness of any truck restriction strategy. A comparison of these characteristics at each of the four study sites is given below.

Volume

Volumes were observed during the morning peak commute for Sites B, C, and D and compared to average volume data collected automatically for the morning peak at Site A. Variation existed in both truck and non-truck volumes at the four sites (see Figure 30). These variations can be attributed to the locations of the study sites, the sizes of the facilities, and the locations of the facilities with respect to major origin or destination points. At each facility, low truck volumes were noted in the left-most lanes (even at the control site, where no restriction exists).

Speed

To ensure that the speed conditions of the study sites were comparable, the researchers examined the average weekday speeds for trucks and non-trucks, the average speeds for vehicle couplets, and the average speed differentials of the various facilities' lanes.

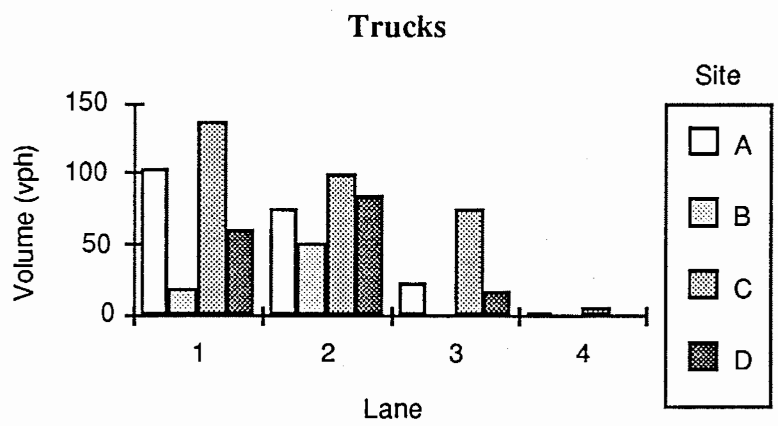
Average Weekday Speed for Trucks. The average trucks' speeds through the three restricted sites and the control site were surprisingly similar (see Figure 31). At the Tacoma site, trucks traveled at much greater speed in lane 4 than when traveling in the same lane at the Southcenter Hill site.

A number of factors could help explain this difference in speed:

- the degree of grade at the site,
- the length of grade,
- the location of on-ramps (a truck that had just entered the facility might not have attained its maximum speed even if traveling in lane 4), and
- whether the truck is traveling loaded or empty.

The researchers also noted that truck speeds observed at the control site, where no grade exists, were comparable to truck speeds observed at the three study sites, where grades do exist.

Average Weekday Speed for Non-Trucks. There was no significant difference in the average weekday speeds of non-trucks from site to site, as expected (non-trucks do



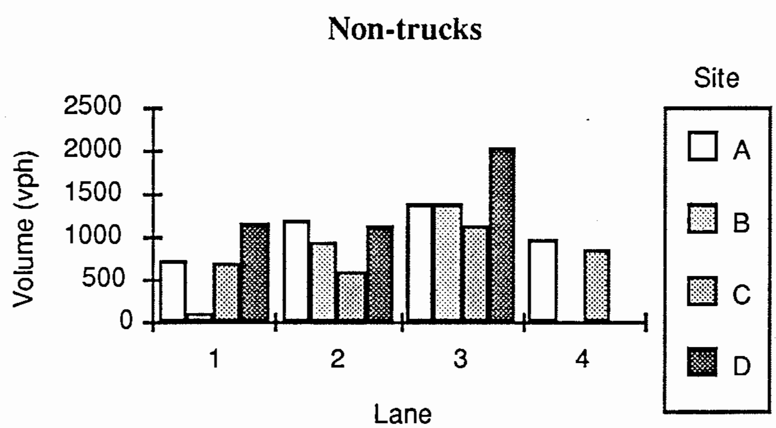


Figure 30. Morning Peak Hour Traffic Volumes

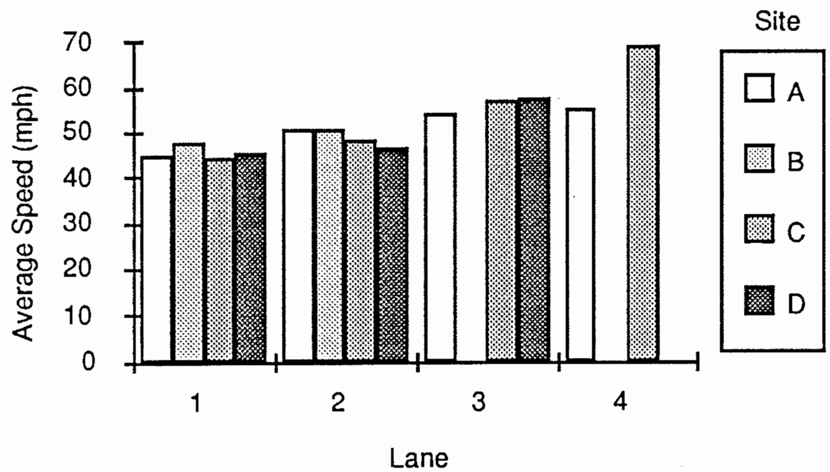


Figure 31. Average Speed for Trucks (mph)

not have the same operational limitations on grades as trucks) (see Figure 32). Non-trucks traveled along SR 520 at much higher speeds in all lanes than at the other three sites. This may directly result from the facility's lower volumes and less severe congestion periods.

Average Weekday Speed for Vehicle Couplets. There was no significant difference in the average speeds for vehicle couplets among the four study sites (see Figure 33). No single site had consistently high speeds for any of the vehicle couplets, nor did any pattern emerge (e.g., the cars following cars couplet was not consistently higher at all of the sites). This result implies that the pattern observed in the in-depth analysis of the Southcenter Hill site cannot be assumed for other areas in the region.

Average Weekday Speed Differentials Between lanes. As seen in Figure 34, there were substantial variations in the average vehicle speeds among lanes. At each site, except Site B: SR 520 westbound, Redmond to Bellevue, vehicle speeds increased from lane 1 to lane 4.

At site B, vehicle speeds in lane 1 were greater than vehicle speeds in lane 2 (resulting in a negative speed differential). The researchers found that a greater proportion of trucks were traveling in lane 2 than in lane 1 at this site. This may explain the lower average vehicle speeds in lane 2.

Substantial increases in speed occurred between lanes 2 and 3 for Sites B and D (SR 520 and the control site), both in excess of 10 miles per hour. This surprisingly large increase in speed between adjacent lanes could be a result of the fact that, at Site B the number of trucks decreased from 51 to zero between lanes 2 and 3, and at Site D the number of trucks decreased from 84 to 17 between lanes 2 and 3. The substantial decrease in trucks (with lower average speeds) could explain the increase in overall average vehicle speeds between lanes 2 and 3.

Site C (Tacoma), where the speed differential between lanes 2 and 3 was not as great, further substantiates this theory. At the Tacoma site, the number of trucks in

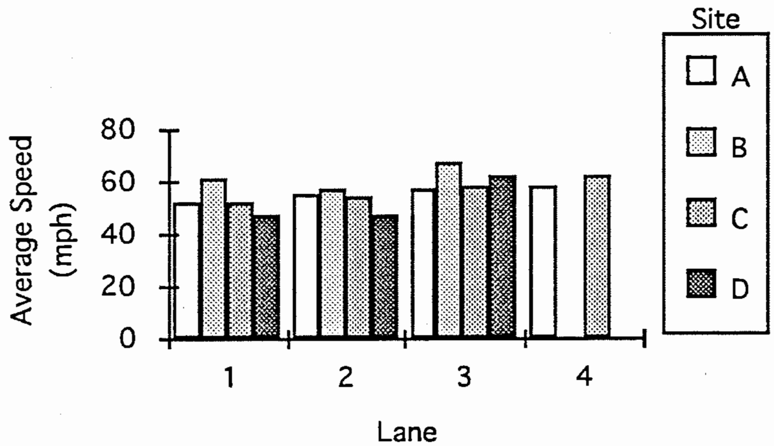


Figure 32. Average Speed for Non-trucks (mph)

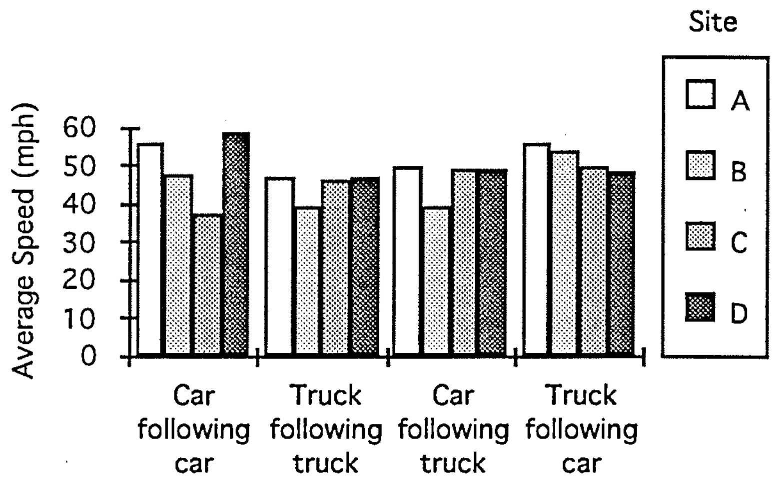


Figure 33. Average Speed for Vehicle Couplets (mph)

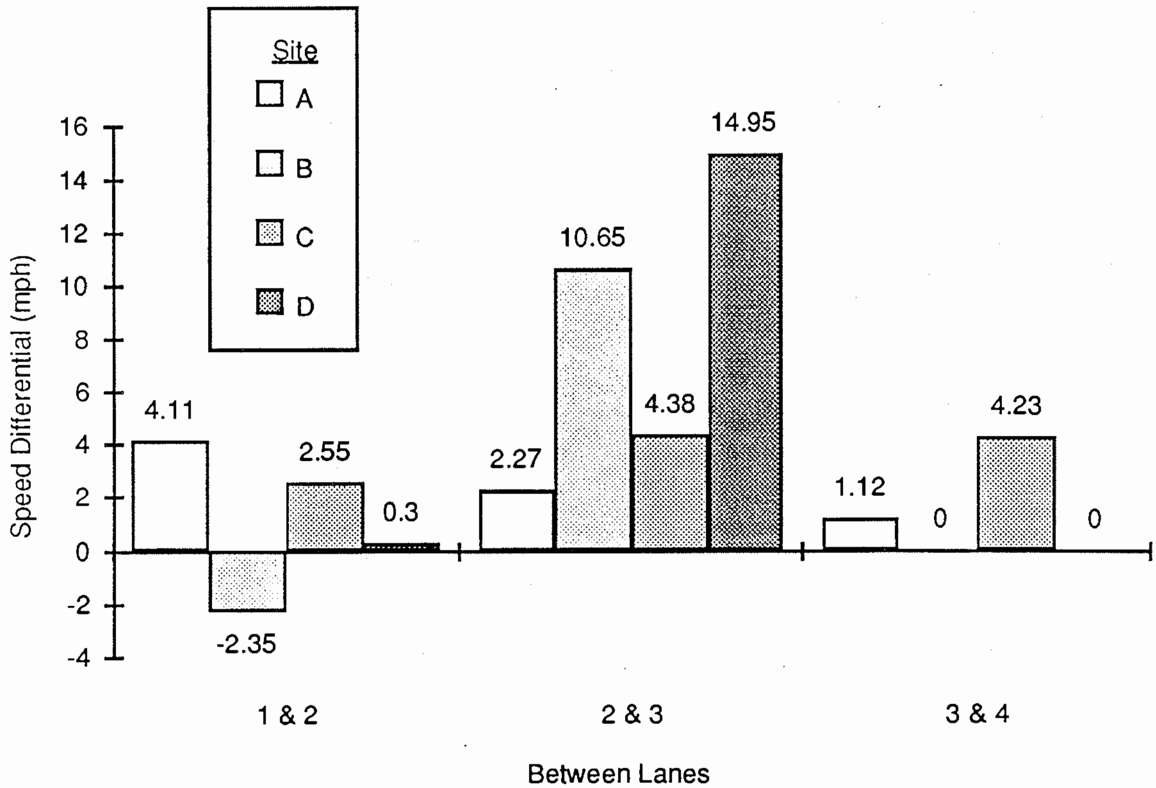


Figure 34. Speed Differentials between Adjacent Lanes

lanes 2 and 3 decreased from 99 in lane 2 to 74 in lane 3. This change in truck lane volumes was not as significant as it was at Sites B and D, hence, the speed differential was not as significant.

Time Gaps, Platoon Lengths, and Truck Impedance Time

To determine the impact of trucks on facility operation, one must consider the time gaps between vehicles, the length of platoons that form behind trucks, and the amount of time trucks occupy multiple lanes of the facility simultaneously (truck impedance time). This impact cannot be measured at a single location. Instead, researchers must study several locations to show that similar impacts resulting from trucks in the traffic stream occur, regardless of the location.

Average Weekday Time Gaps. The time gaps measured at the sites that required manual data collection (Sites B, C, and D) were fairly consistent, although no prevalent pattern was observed (see Figure 35). For example, the time gaps measured at Site B indicated that cars following cars and trucks following trucks had the smallest time gaps. Hence, cars following trucks and trucks following cars had larger time gaps. At Sites C and D, researchers observed that cars following cars and trucks following cars had the smallest time gaps, while trucks following trucks and cars following trucks had the largest time gaps.

The pattern was different for the Southcenter Hill site. At this site, researchers observed that the time gaps for cars following cars and trucks following cars were largest, while the time gaps for trucks following trucks and cars following trucks were smallest. These results are the opposite of the results noted at Sites C and D.

Because of the disparity in the measurements at these sites, no generalizations can be made regarding the travel characteristics of either cars or trucks. For example, it is not necessarily true that, because of operational limitations, trucks lag, creating larger time gaps for the truck following car combination.

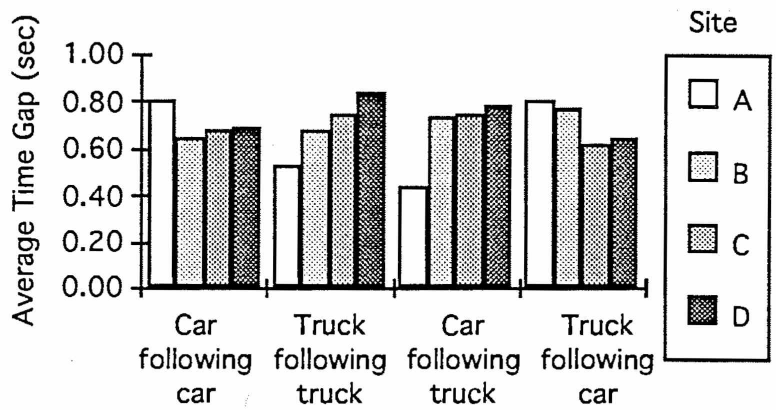


Figure 35. Average Time Gap between Vehicle Couplets (sec)

It is true, however, that time gap patterns were similar at sites C and D. One would not expect this to be the case because there is a grade at Site C, but not at Site D. This similarity may be attributable to site proximity. Site C may experience a high percentage of empty trucks (that are able to maintain high speeds even on uphill grades) because of its proximity to the Port of Tacoma. Trucks at site D are most likely fully loaded because of the absence of a close, major off-load destination and hence, traveling at slower speeds even with no grade.

Data collection methods may have accounted for this variation in time gap measurements between the sites. Because the time gap between vehicles was less than 1 second, it was very difficult to measure from the videotape. Inaccuracies may have occurred.

At the Southcenter Hill site, however, time gaps were calculated from the recorded time that vehicles passed a stationary object (the electronic loops) and the length of the vehicle. While some vehicle lengths may have been measured inaccurately, the measurements were more accurate than ones taken visually from the videotapes, which were highly dependent on human reaction time.

Platoon Lengths. The average platoon length formed behind a truck was similar at each of the three study sites and the control site (see Figure 36). In each case, the average platoon length increased across the facility, with the smallest platoon length in the right-most lane and the longest platoon length in the left-most lane. This is reasonable because faster moving vehicles travel in the left lane. It is often assumed that trucks (especially when fully loaded) cannot maintain adequate speed to keep up with the traffic in these lanes. Thus, vehicles group behind the slower moving trucks until they have an opportunity to pass.

One exception was noted at Site C, where the platoon length increased across lanes 1,2, and 3 then decreased in lane 4. However, this pattern can be explained by the fact that only five trucks traveled in lane 4 during the analysis period.

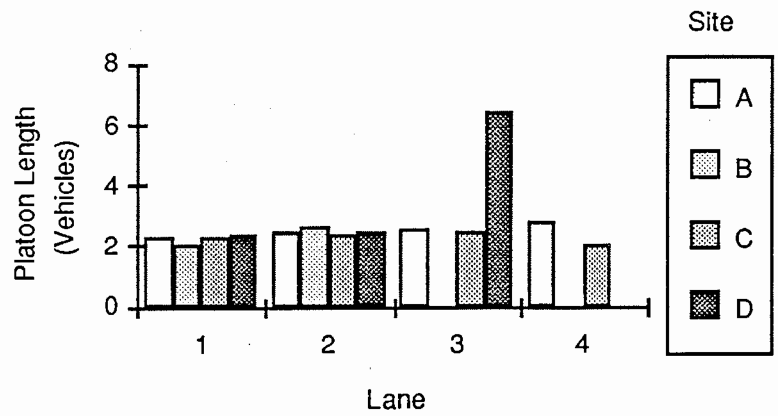


Figure 36. Average Peak Platoon Length by Lane

One surprising outcome was the jump in average platoon length in lane 3 of the control site (Site D). The average platoon length jumped to over six vehicles. This large jump can be explained by examining the traffic volumes in this lane (platoon length is highly dependent on traffic volumes). This lane experienced more than 2,000 vehicles per hour during the morning commute period. Thus, at the time that the platoon counts were taken, the lane was over capacity and nearly at standstill conditions. This problem would cause a substantially higher number of vehicles to be within a 1-second time gap of each other and thus increase the length of the platoon. Other lanes were near capacity but none reached capacity.

Truck Impedance Time. As expected, truck impedance times are greater when the right-most lanes are considered than when the left-most lanes are examined because most trucks travel in the slower moving lanes (see Figure 37). Operationally, truck impedance does not appear to be a concern at any of the sites.

SAFETY CHARACTERISTICS

The sites' accident distributions, types, and severities were compared to determine whether enough similarities existed between the sites to expand the results of this study to other areas. Because of limited accident data, only sites A (Southcenter Hill) and C (Puyallup River Bridge to Tacoma Mall) could be compared, and only for the period before the lane restrictions were implemented. Both facilities are similar in size and proximity to urban centers. The results are discussed below.

Accident Distribution

The distributions of truck related accidents for both sites A and C were similar (see Figure 38). The highest number of accidents occurred in the right-most lanes and decreased moving left across the facility. This result is realistic because the majority of trucks at both facilities traveled in the right-most lanes.

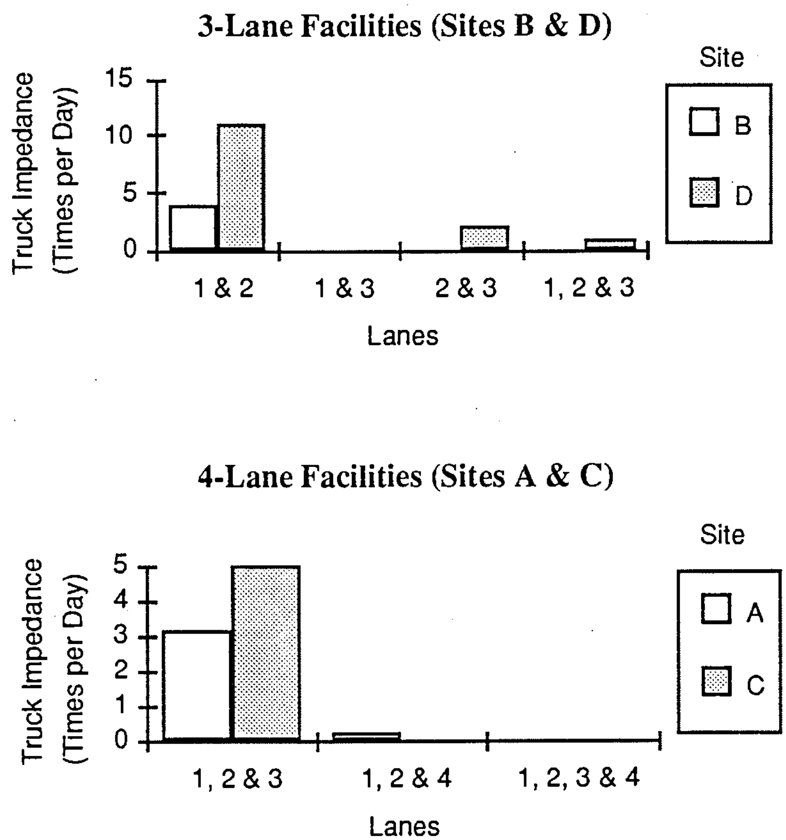


Figure 37. Average Peak Truck Impedance

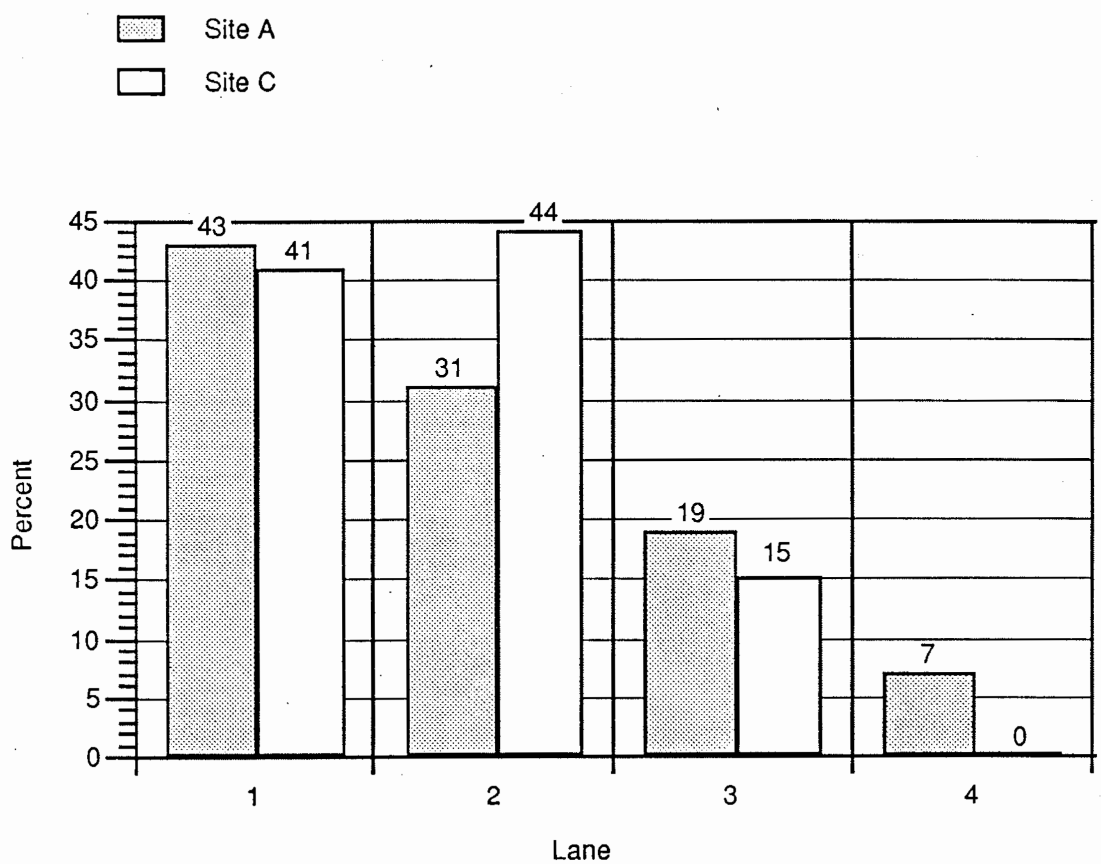


Figure 38. Comparison of Truck-Involved Accident Distributions by Lane

Accident Type

Similarities existed between accident types for the facilities (see Figure 39). Differences of note were that the Southcenter Hill site had a higher percentage of accidents that occurred as a result of lane changes to the right. Also, the Tacoma site had a higher percentage of accidents that resulted from trucks legally stopped in traffic.

Accident Severity

Accidents most often resulted in only property damage at both of the sites being compared (see Figure 40). However, a substantially higher proportion of injury accidents occurred at the Tacoma site. This may have been a result of the slightly higher average speeds noted at the Tacoma site.

ENFORCEMENT ISSUES

Enforcement can have a great effect on the success of any truck restriction strategy.

Violation Rates

The researchers discovered in the in-depth analysis that the violation rate of the lane restriction at Site A: Southcenter Hill was 2.1 percent, based on the proportion of trucks traveling in the restricted lane in comparison to the total number of trucks on the facility.

The violation rate at the Tacoma site was slightly lower at 1.6 percent. This lower rate may be accounted for by considering the restrictions' implementation dates and facility access/egress points. First, the lane restriction in Tacoma had been in effect for several years at the time of this study, while the restriction at Southcenter Hill had only been in effect for a few months. Thus, in support of the theory that a number of the violators may have been unaware of the restrictions, interstate truckers, who do not frequent this area, may have been more aware of the Tacoma restriction because it had been in effect longer. Second, major facility access and egress areas are located within the restricted area in Tacoma. Many of the trucks may have been traveling in the

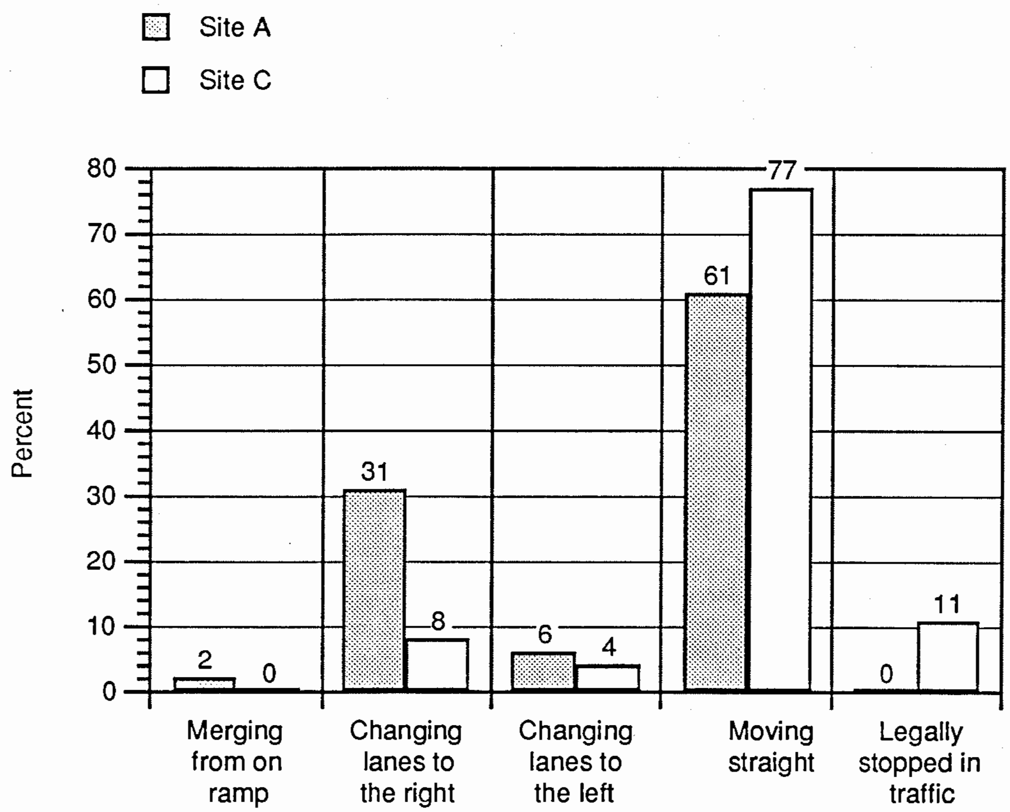


Figure 39. Comparison of Accident Types

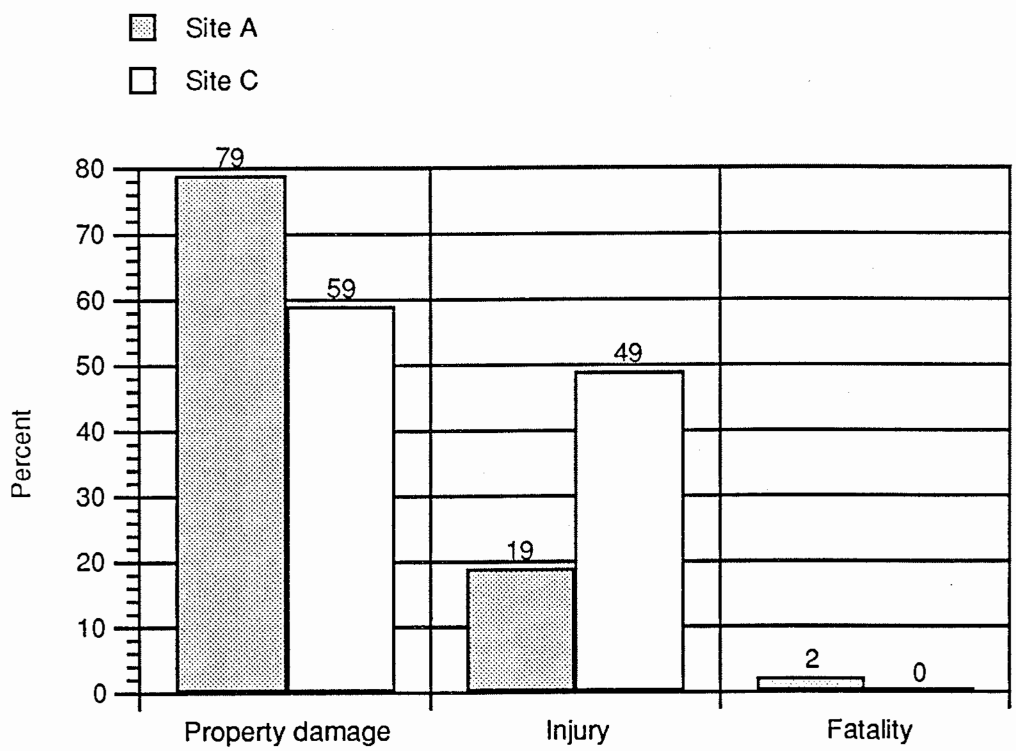


Figure 40. Comparison of Accident Severity

right-most lanes because 1) they had just entered the facility or 2) they were going to exit the facility. Hence, the Tacoma site experienced lower violation rates because fewer trucks were traveling in the left-most lanes.

On the basis of only 1 hour of data (because they had to be collected manually), no violations occurred at the SR 520 site (zero trucks were observed in the restricted lane). The lower violation rate at this site may be directly tied to the lower traffic volumes at this site. The incentive to violate the truck lane restrictions would be greater (resulting in a higher violation rate) if there were a greater volume of traffic.

Feasibility of Enforcement

A number of conditions must exist to make the enforcement of a truck restriction strategy feasible. For a left-hand lane restriction, these include the following:

- facility design must be conducive to enforcement (adequate shoulder space),
- enforcement personnel must be sufficient so other areas of enforcement are not neglected, and
- lane restriction enforcement must be considered a priority by enforcement officials.

Addressing the first of these issues, none of the sites observed provided a facility design conducive to enforcement efforts. Each of the sites has a narrow left-hand shoulder, which is inadequate for safely pulling over a vehicle, especially a large vehicle such as a truck. Also, each of the sites experiences relatively high traffic volumes, which would not allow pulling over the violating vehicle to the right-hand shoulder because of too many lane changing conflicts.

Addressing the other two issues, current economic conditions and other constraints keep personnel levels in enforcement agencies to a minimum. As long as personnel is reduced, the enforcement of secondary traffic regulations cannot become a priority.

SURVEY RESULTS

To determine the acceptance of lane restrictions in the Puget Sound region, the researchers conducted a number of surveys, both formal and informal. The audiences targeted for these surveys included truck drivers, motorists, enforcement officials (Washington State Patrol), and representative trucking associations. The results of these surveys are discussed below.

TRUCK DRIVER SURVEY

To better gain insight into the opinions of truckers with respect to lane restrictions, the researchers examined a summary of the trucker survey results and an estimated favorability model to predict the truckers' acceptance of lane restrictions in the Puget Sound region.

Summary of Survey Results

An examination of the trucker survey results, shown in Table 17, reveals that under "driver characteristics" that the monthly travel on the three sections of highway that have truck restrictions was not particularly high. This reflects the high percentage (80.7 percent) of cross-country operators surveyed (i.e., operators likely to spend less time in the Puget Sound region). This relatively low travel frequency rate may have had some bearing on the compliance questions, as will be discussed below.

Another interesting component of "driver characteristics" was the truckers' reaction to rough pavement. The results indicate that 64.6 percent of truckers sometimes or often changed lanes to avoid traveling on rough pavement. These changes represent a potential safety hazard because lane changes in poor-pavement areas can significantly disrupt the traffic stream and result in truckers using the "faster" lanes. Such lane changes, which from the motorist's perspective may seem unjustified, could be a strong factor in the motorists' perception that trucks frequently travel in the "faster" lanes.

Table 17. Summary Statistics for the Survey of Truckers (averages unless otherwise noted)

Driving Characteristics	
Number of times travel I-5 Southcenter Hill per month	8.56
Number of times travel SR-520 between Redmond and Bellevue per month	2.74
Number of times travel I-5 Puyallup River Bridge to Tacoma per month	5.79
Percent changing lanes to get a better ride: never/sometimes/often	9.82/52.68/37.5
Percent operating: cross country/regional line haul/local line haul	80.7/13.16/6.14
Percent operating: on interstates and freeways/rural areas/urban areas	97.39/1.74/0.87
Percent having suspension type (on tractor/truck drive axle): leaf spring/air/torsion bar/other	23.28/74.14/1.72/0.86
Percent having suspension type (on trailer): walking beam/leaf spring/air	1.74/63.48/34.78
Percent indicating truck rides smoother at: 55-60mph/30mph	10.62/89.38
Percent, when encountering rough pavement: speed up	0.00
Percent, when encountering rough pavement: slow down	50.44
Percent, when encountering rough pavement: maintain speed	21.24
Percent, when encountering rough pavement: change lanes	64.60
Percent feeling they get a smoother ride: loaded/empty	6.25/93.75
Truck Restriction Experience	
Percent encountering truck restrictions in other parts of the state and country	79.46
Percent encountering lane restrictions: seasonal/year-round	22.22/71.11
Percent encountering route restrictions: seasonal/year-round	28.89/66.67
Percent encountering time-of-day restrictions: seasonal/year-round	17.78/61.11
Percent encountering speed restrictions: seasonal/year-round	11.11/70.00
Percent encountering other restrictions: seasonal/year-round	3.33/26.67
Percent seeing Puget Sound truck lane restrictions enforced	32.04
Percent disobeying Puget Sound truck lane restrictions	31.37
Percent seeing others disobey Puget Sound truck lane restrictions	63.46
Percent indicating that it is clear as to which lanes are included in the Puget Sound lane restrictions	68.13
Percent indicating that it is clear as to which vehicles are included in the Puget Sound lane restrictions	66.29
Percent believing lane restrictions improve freeway operations (congestion, maneuverability, etc.)	30.30
Percent believing lane restrictions improve safety	30.61
Percent believing lane restrictions should include buses	66.04

Table 17. (cont.)

Truck Restriction Experience (cont.)	
Percent believing lane restrictions should be expanded to include more freeway sections	21.36
Percent in favor of keeping Puget Sound truck lane restrictions	31.96
Background Information	
Driver's age (years)	40.38
Number of years as a licensed truck driver	15.02
Driver's gender (male/female)	97.37/2.63
Typical operating weight (GVW) in pounds	73,509
Maximum operating weight (GVW) in pounds	78,068
Number of hours per day vehicle is in operation	13.56
Number of accumulated annual vehicle miles	132,568
Percent of typical cargo: perishable/non-perishable/hazardous material/other	34.95/59.22/0.97/4.85
Percent type of truck usually driven: single unit/tractor-semi trailer/tractor-semi and full trailer/other	4.39/59.65/34.21/1.75
Percent of drivers: independent/employed by firm	34.21/65.79

Regarding truck restriction experience, Table 17 shows that nearly 80 percent of the truckers had encountered some form of truck restriction, with year-round lane, speed, and route restrictions the most prevalent types. Regarding the Puget Sound restrictions, over 32 percent of truckers indicated they had seen these restrictions enforced, when, in fact, no such enforcement has ever taken place. It appears that truckers may have thought, incorrectly, that vehicles were being issued citations for violating the lane restriction, or they may have had a distorted perception of enforcement in general. A relatively high 31.37 percent of the truckers indicated that they had disobeyed the lane restrictions. This suggests that a relatively high proportion of cross-country truckers (the dominant trucker type in our sample) violate truck lane restrictions that are not strictly enforced.

Questions regarding the clarity of the restrictions (i.e., signing) indicated that about one-third of the truckers felt the signing was unclear. This response may indicate a signing problem or reflect the truckers' generally negative attitude toward the restrictions.

Roughly 66 percent of the truckers felt that buses should also be restricted. This result suggests that truckers do not appreciate the preferential treatment public mass transportation modes receive.

Another important finding in the "experience" portion of the survey is that only 31.96 percent of the truckers surveyed were in favor of keeping Puget Sound lane restrictions. The researchers expected this response. Some truckers were mostly concerned with perceived safety and public relations (i.e., favored restrictions), but the majority were mostly concerned with operational efficiency (i.e., unrestricted lane changes and presumably higher speeds) and had a generally negative attitude toward any additional regulations (i.e., opposed restrictions).

The truckers' background information (the last portion of Table 17) included an average age of about 40 years, average length of licensing of about 15 years, and a high percentage of males. The gross vehicle weights (GVW), typical and maximum, suggest that many of the truckers in the survey operated vehicles near the 80,000 pound GVW state weight limit. Typical hours of operation per day (13.56) and annual mileages (132,568) were close to national averages. In terms of cargo types, non-perishable goods dominated, but a sizable portion of the truckers transported perishable goods. Finally, about two-thirds of the truckers were employed by firms and the remaining one-third were independent. This figure is also consistent with national data.

Empirical Analysis: Truck Lane Restriction Favorability

From a policy perspective, it is important to understand the factors that determine whether motorists and truckers are in favor of lane restrictions. For example, if motorists are strongly in favor of restrictions (as indicated in Table 18), they can exert political pressure to retain the lanes, regardless of their impact on safety, traffic operations, and pavement deterioration. However, simply looking at the values of Tables 17 and 18 is not sufficient and may be misleading. It is important to go beyond this and to obtain some understanding of the many factors that determine motorists' and truckers' opinions regarding favorability. In this way, a statistically defensible understanding of attitudes toward truck-lane restrictions can be obtained. Such an understanding is achieved by estimating multivariate statistical models of the likelihood that motorists and truckers will favor truck-lane restrictions. A logit model formulation is well-suited to such an analysis and is discussed below.

The researchers estimated separate logit favorability models for truckers and motorists because these two groups had significantly different views regarding the acceptability of truck lane restrictions. This difference was noticeable in the aggregate favorability statistics, shown in Tables 17 and 18 (i.e., 90.85 percent of the motorists favored restrictions, and only 31.96 percent of the truckers favored restrictions), and can be statistically proven by comparing truckers' and motorists' fully estimated logit models. This allows us to statistically reject similarities between truckers and motorists, on truck-lane restriction favorability, with over 99.99 percent confidence (using a χ^2 test).

Table 18. Summary Statistics for the Survey of Motorists (averages unless otherwise noted)

Driving Characteristics	
Number of times travel I-5 Southcenter Hill per month	14.50
Number of times travel SR-520 between Redmond and Bellevue per month	8.44
Number of times travel I-5 Puyallup River Bridge to Tacoma per month	7.61
Percent changing lanes to avoid following a truck: never/sometimes/often	4.26/24.11/71.63
Percent changing lanes to avoid being followed by a truck: never/sometimes/often	15.44/44.12/40.44
Percent changing lanes to avoid traveling beside a truck: never/sometimes/often	11.85/34.81/53.34
Truck Restriction Experience	
Percent aware of truck lane restrictions on I-5 Southcenter Hill	33.57
Percent aware of truck lane restrictions on SR-520 between Redmond and Bellevue	22.39
Percent aware of truck lane restrictions on I-5 Puyallup River Bridge to Tacoma	25.00
Questions answered only by those indicating awareness of Puget Sound truck lane restrictions	
Percent seeing Puget Sound truck lane restrictions enforced	3.17
Percent seeing truckers disobey Puget Sound truck lane restrictions	77.78
Percent indicating that it is clear as to which lanes are included in the Puget Sound lane restrictions	59.68
Percent indicating that it is clear as to which vehicles are included in the Puget Sound lane restrictions	63.33
Percent believing lane restrictions improve freeway operations (congestion, maneuverability, etc.)	85.53
Percent believing lane restrictions improve safety	81.58
Percent believing lane restrictions should include buses	74.14
Percent believing lane restrictions should be expanded to include more freeway sections	82.54
Percent in favor of keeping Puget Sound truck lane restrictions	90.67
Background Information (answered by all)	
Percent believing lane restrictions improve freeway operations (congestion, maneuverability, etc.)	87.59
Percent believing lane restrictions improve safety	85.42
Percent in favor of keeping truck lane restrictions	90.85
Driver's age (years)	46.59
Number of years as a licensed driver	29.91
Driver's gender (male/female)	67.57/32.43
Type of vehicle usually driven (percent): passenger car/pickup or van/other	83.11/14.19/2.70
Lane vehicle was observed traveling in (percent): lane 1 (leftmost)/lane 2/lane 3/lane 4	34.4/25.7/24.3/ 15.6

In studying truckers' reactions to truck restrictions, the researchers were interested in the factors that determine whether these restrictions are viewed favorably. Factors affecting favorability toward truck-lane restrictions include the following: relevant socioeconomic characteristics, such as gender and age; and driving behavior characteristics, such as the number of times driven per month on the restricted routes, and typical lane-changing behavior in response to rough pavement or proximity to a truck on the highway. In determining whether individuals will support or oppose truck-lane restrictions, it is reasonable to assume that they will support whatever provides them the most satisfaction or economic utility.

Analysts can isolate a number of factors that influence this satisfaction, such as drivers' age, gender, lane-changing behavior, and so on. However, many psychological factors cannot be measured with the data collected. Examples include past negative experiences with trucks or truckers and the manner in which individuals process information and draw conclusions from the information presented to them. These unobservable components introduce a random element into the utility maximizing process that must be considered.

Favorability Model. To incorporate both the observable factors (e.g., age) and the unobservable factors (e.g., psychological factors) into an estimable statistical model of truck-lane restriction favorability, researchers use probabilistic choice theory. (18) To illustrate this approach, let V_y be the observed portion of the utility derived from favoring truck-lane restrictions, and let V_n be the observed portion of the utility derived from opposing truck lane restrictions. Also, let ε_y and ε_n be the corresponding yes/no unobservable, or "random," portion of the utility derived from the choice. With this, the probability that an individual will favor truck restrictions, P_y, is,

$$P_y = P_R[V_y + \varepsilon_y > V_n + \varepsilon_n] \qquad (1)$$

which states that the probability of supporting truck lane restrictions is equal to the probability that the sum of observable and unobservable components of the utility obtained from supporting the restrictions exceed those obtained from opposing them. Note that equation 1 can be rearranged as

$$P_y \quad = \quad P_R[V_y - V_n > \varepsilon_n - \varepsilon_y] \tag{2}$$

This shows that the relative difference in utilities is really the key probability determinant and not its cardinal value.

With the above probability equations, a number of estimable statistical models can be derived by assuming an appropriate distribution of the random components of the utility (i.e., ε's). Arguably, the most suitable form in this context is to assume that the random terms are independent, identically distributed Gumbel variates. This results in the standard logit model, which is specified as (18),

$$P_y \quad = \quad \frac{1}{1 + e^{V_n - V_y}} \tag{3}$$

where P_y, V_y and V_n are as previously defined.

Because the model computes probabilities on the basis of the differences in yes/no utilities (see Equation 2), V_n can be set equal to zero without loss of generality. So Equation 3 becomes

$$P_y \quad = \quad \frac{1}{1 + e^{-V_y}} \tag{4}$$

and the probability of an individual opposing truck lane restrictions is simply $P_n = 1\text{-}P_y$.

Regarding the actual specification of the observable portion of the utility derived by favoring truck-lane restrictions, consider a linear utility function, defined for each individual, of the following form:

$$V_y \quad = \quad \alpha + \beta S + \Theta D \tag{5}$$

where V_y is the observable utility derived from favoring truck-lane restrictions, **S** is a vector of individuals' socioeconomic characteristics, **D** is a vector of individuals' observed driving behavior, α is a constant term, and β and Θ are estimable vectors. With this definition of utility, the favorability models can be easily estimated by using standard maximum likelihood methods (see equations 4 and 5).

Favorability model results. Logit-model estimation results for truckers' favorability toward truck-lane restrictions are presented in Table 19. Note that a positive coefficient increases V_y and increases the probability of favoring restrictions, and a negative coefficient decreases the probability of favoring restrictions.

Regarding specific coefficient estimation results, drivers in the 20-year-old to 40-year-old age group were more strongly opposed to the lane restrictions than drivers of other ages. This opposition may be the result of the economic pressures they experience (e.g., the need to reduce travel times to make more money for their families) or may be simply a reflection of the attitudes of this age group.

The longer period of time the drivers were licensed, the less favorably they viewed restrictions. This suggests that many experienced drivers negatively view truck-lane restrictions, which is a characteristic attitude often associated with highly experienced drivers.

Drivers who indicated they violated Puget Sound lane restrictions were less likely to be in favor of retaining these restrictions than drivers who did not report violating the restrictions. This is an expected finding because violations are a good indicator of disapproval of the law.

Drivers typically carrying non-perishable cargo were less likely to favor restrictions than other drivers. Although this variable did not produce a highly significant coefficient (see t-statistic), it does suggest some differences in opinion based on cargo types. Similarly, truckers indicating that they changed lanes often to avoid rough pavement were less likely to favor restrictions. This lane changing frequency probably reflects a driving style that would be hindered by restrictions, and these truckers would more likely oppose the restrictions.

Table 19. Model of Truckers' Likelihood of Being in Favor of Truck Restrictions

Variable	Esti mated Coefficient	t-statistic
Constant	2.207	2.42
Young/middle-age indicator (1 if trucker is between 20 and 40 years old, 0 otherwise)	-2.59	-3.38
Number of years trucker was a licensed driver	-0.088	-2.67
Restriction violation indicator (1 if driver admits to violating lane restrictions, 0 otherwise)	-1.148	-1.80
Typical cargo indicator (1 if typical cargo is non-perishable, 0 otherwise)	-0.667	-1.20
Lane change indicator (1 if change lanes often to get smoother ride on rough pavement, 0 otherwise)	-0.994	-1.51
Southcenter hill indicator (1 if trucker indicated using I-5 Southcenter hill, 0 otherwise)	2.06	2.36
SR-520 indicator (1 if trucker indicated using SR-520 between Redmond and Bellevue, 0 otherwise)	1.85	1.89
I-5 Tacoma indicator (1 if trucker indicated using Puyallup River bridge to Tacoma Mall, 0 otherwise)	-1.51	-1.58

log likelihood at zero	-65.15
log likelihood at convergence	-42.81
number of observations	94
percent correctly predicted	78.72

Regarding the three truck-lane restriction sites, truckers who traveled on the I-5 Southcenter Hill and SR-520 between Redmond and Bellevue were more likely to favor restrictions. This result may indicate that drivers perceive these highway sections to be high-risk accident areas or that they perceive an impact from slow-moving trucks on the traffic stream. In contrast, truckers who traveled on I-5 in Tacoma were less likely to favor restrictions. This result indicates that drivers do not perceive a great need for restrictions there, perhaps because the relatively high number of lanes available at this site (five lanes in the affected direction of travel) reduces the perception that trucks cause a problem and/or because the presence of frequent merging/diverging at this site necessitates occasional truck-usage of the extreme left lane. Many truckers indicated travel on I-5 in Tacoma and on the Southcenter Hill. The net effect of this is a smaller positive favorability because the positive effect of the Southcenter Hill exceeds the negative effect of I-5 Tacoma.

MOTORING PUBLIC SURVEY

To determine the opinions of motorists with respect to lane restrictions, the following information was examined: 1) a summary of the motorist survey results, 2) an estimated favorability model to predict motorists' acceptance of lane restrictions, and 3) an estimated awareness model to predict the proportion of motorists who are aware that the lane restrictions exist.

Summary of Survey Results

The motorist survey results, presented in Table 18, indicate that motorists reported a higher monthly travel frequency than truckers on the three truck-lane restricted routes. This is an expected finding because motorists travel more regularly in the Puget Sound area than truckers, who often travel cross-country through the Puget Sound area.

A high percentage of motorists indicated that they sometimes or often changed lanes to avoid following, being followed by, or traveling beside a truck. This high percentage suggests that motorists regard trucks as a safety hazard, are intimidated by them, or just want to get around them. The most common maneuver motorists performed was changing lanes to avoid following a truck, with over 70 percent of the motorists indicating that they did this often. Motorists apparently do this to improve visibility and sight distance (which is limited by following a truck) and perhaps to reduce the probability of a truck's wheel-spray impairing their vision on wet roads, or truck wheels flinging rocks that could hit their windshields.

The researchers found that, at most, one-third of the motorists were aware of the specific Puget Sound truck-lane restrictions, in spite of the fact that all of the motorists surveyed were observed traveling on the lane-restricted sections of highway. This result indicates either relatively poor signing or, more likely, a lack of motorist awareness of signs on frequently traveled routes. This "awareness" issue will be explored in a later portion of this paper.

Of the motorists aware of the truck restrictions, very few (3.17 percent) indicated that they had seen these restrictions enforced. This is much more realistic than the trucker-reported enforcement percentage of 32.04 (recall that no enforcement effort is undertaken). The percentage of motorists who reported that they had seen truckers disobey the restrictions was a fairly high 78 percent. This figure, while it seems high initially, could be explained by the fact that the license plate survey was conducted at the beginning of the afternoon peak traffic period. Figure 15 shows that of the hourly distribution of trucks in lane 4 at Southcenter Hill, the highest percentage of truck travel is during the afternoon peak. Thus if the motorists frequently traveled at this time of day, they would have more opportunity to see a truck in violation.

Another striking finding is that a relatively high 74.14 percent of motorists felt that buses, in addition to trucks, should be restricted. This suggests that motorists perceive both buses and trucks as safety hazards or that they both present an operational problem. Finally, over 90 percent of the motorists who were aware of the Puget Sound lane restrictions were in favor of keeping them, in contrast to only about 30 percent of the truckers.

The background information, which was answered by all motorists (even those unaware of the truck-lane restrictions), indicated that the percentage of all respondents in favor of keeping truck-lane restrictions (90.85 percent) was nearly identical to the favorability rating from only motorists who were aware of the Puget Sound lane restrictions.

The statistics of average driver age, nearly 47, and the average number of years licensed, 30, were higher than expected. This also indicates that the survey response rate was higher among older drivers. This higher response rate is likely due to the perception among older drivers that safety-related issues are a priority concern. Similarly, more males than females responded, and this could reflect a truck-safety perception difference between the sexes.

In terms of the vehicle types driven, the vast majority (83.11 percent) were passenger cars, with pickups and vans a distant second (14.19 percent). Finally, the lane position of the motorists at the time their license plates were observed on one of the restricted portions of highway revealed a fairly typical distribution among lanes for a congested, major metropolitan area such as Seattle.

Empirical Analysis: Truck Lane Restriction Favorability

The motorists' favorability toward truck lane restrictions was modeled using the same theories of probability described above to determine truckers' favorability toward with respect to lane restrictions. The results of the motorists' responses are discussed below.

Favorability model results. Logit model estimation results for motorists' favorability toward truck-lane restrictions are presented in Table 20. This table shows that individuals in the 30-year-old to 45-year-old age group had a higher likelihood of favoring restrictions than members of other age groups. This seems to indicate the

Table 20. Model of motorists' likelihood of being in favor of truck restrictions

Variable	Coefficient	t-statistic
Middle-age indicator (1 if motorist is between 30 and 45 years old, 0 otherwise)	0.767	2.69
Number of years motorist was a licensed driver	0.0256	2.29
Pickup truck/van indicator (1 if typical vehicle is a truck or van, 0 otherwise)	-0.535	-0.71
Lane change indicator variable (1 if change lanes often to avoid being followed by a truck, 0 otherwise)	1.58	1.98
Southcenter hill indicator (1 if motorist indicated using I-5 Southcenter hill, 0 otherwise)	1.04	1.97

log likelihood at zero	-98.43
log likelihood at convergence	-39.50
number of observations	142
percent correctly predicted	90.14

safety-oriented nature of this age group, which may be the result of being parents of young children or simply a safety attitude that this group has developed from education and/or media exposure. This age group overlapped the 20-year-old to 40-year-old truckers, who were more likely to oppose restrictions. Occupational concerns may dominate any safety concerns that this age-group of truckers may have.

The longer the drivers had been licensed, the more likely they were to favor restrictions. This result may also be safety-related, as more experienced drivers may have seen more dangerous situations caused by trucks in the "fast" lanes. More experienced drivers may also be more sensitive to the congestion effects of trucks in the "fast" lane. This "years licensed" variable produced an opposite effect in the truckers' model. Again, this seems to be a result of occupational dominance.

The model shows that individuals who drove a pickup truck or van were less likely to favor restrictions than individuals who drove passenger cars or other vehicle types. The coefficient of this variable was not statistically significant (see t-statistic), but because maximum likelihood estimators are statistically consistent (i.e., have smaller variances with larger sample sizes), a large sample size would probably have shown this variable to be significant. It is included in this model because it suggests that larger vehicles operators sympathize with truckers' concerns or that people in larger vehicles may feel less threatened by trucks.

Motorists who stated that they changed lanes often when followed by a truck were more likely to favor restrictions than others. This lane-changing behavior seems to be an indicator of an individual's perception of the danger presented by trucks. Thus, individuals who change lanes often, when followed by trucks, have a truck-related fear, justified or not, that translates into favorability toward restrictions.

Finally, motorists who traveled on the I-5 Southcenter Hill were more likely to favor restrictions. This response reflects the operational problem perceived by motorists on this section of highway. No statistically significant relationship between favorability and travel on the other sections of the restricted highways (SR-520 and I-5 Tacoma) was found.

Empirical Analysis: Truck Lane Restriction Awareness

One of the surprising results of the motorist survey was that, several months after the restrictions had been implemented and signed, less than one-third of the motorists—who were chosen for inclusion in the motorist survey after they were seen traveling on one of the three restricted sections of highway—were aware of the truck-lane restrictions. If the factors that influence whether a motorist is aware of restrictions could be determined, it might be possible to determine ways to make truck restrictions more noticeable (e.g., with better signs).

To study motorist awareness of truck restrictions, the researchers again applied the utility-maximizing logit model approach, with P_a, the probability of being aware, and P_{na}, the probability of being unaware. As was the case with the favorability models, V_{na}, the observable utility from being unaware, was set equal to zero without loss of generality. This gave

$$P_a = \frac{1}{1 + e^{-V_a}} \tag{6}$$

where V_a is the observable portion of utility provided by being aware. (Compare this to Equation 4.)

The logit model estimation results for this model are presented in Table 21. This table shows that gender played a statistically significant role and that male drivers were more likely to be aware of the restrictions than female drivers. This difference may reflect the stereotypical aggressive-driver image of males who become more frustrated when trucks impede their traveling speed and thus, are more aware of attempts to restrict the truck-induced impedance.

The longer motorists had licenses, the lower was the probability that they were aware of the restrictions. Perhaps more experienced drivers have settled into driving

Table 21. Model of Motorists' Likelihood of Being Aware of Truck Restrictions

Variable	Coefficient	t-statistic
Constant	-1.87	-1.97
Gender indicator (1 if motorist is male, 0 otherwise)	0.851	2.06
Number of years motorist was a licensed driver	0.0249	-1.79
Pickup truck/van indicator (1 if typical vehicle is a truck or van, 0 otherwise)	-0.414	-0.76
Southcenter hill indicator (1 if motorist indicated using I-5 Southcenter hill, 0 otherwise)	0.761	1.97
SR-520 indicator (1 if motorist indicated using SR-520 between Redmond and Bellevue, 0 otherwise)	2.63	1.62
I-5 Tacoma indicator (1 if trucker indicated using Puyallup River bridge to Tacoma Mall, 0 otherwise)	-1.55	-1.06

log likelihood at zero	-102.59
log likelihood at convergence	-89.71
number of observations	148
percent correctly predicted	65.54

patterns and expectations that decrease their likelihood of being aware of relatively minor traffic operation changes that do not directly affect their driving behavior.

Motorists who usually drove pickup trucks and vans were also less likely to be aware of the restrictions, although, as was the case with the motorist favorability model, this was not statistically significant. It is included in the model because a larger sample size may have resulted in a significant vehicle-type effect.

Finally, motorists who traveled on the I-5 Southcenter Hill and SR-520 were more likely to be aware of truck restrictions, whereas those who traveled on I-5 Tacoma were less likely to be aware of them. Four explanations for this are possible. First, the position and wording of the signs on the I-5 Southcenter and SR-520 sections of highway may be better than those on the I-5 Tacoma section. Determining this difference would require an extensive human factors study. Second, the I-5 Tacoma lane restrictions, which were implemented long before the other restrictions, may have become so familiar that they go unnoticed on a daily basis. Third, the comparatively high incidence of merging/diverging on the I-5 Tacoma section may distract drivers' attention from regulatory signs. Fourth, perhaps I-5 Southcenter and SR-520 are perceived to be more adversely affected by trucks traveling in the extreme left lane, and this increases awareness. Recall, these two sections have fewer lanes and less merging/diverging than the I-5 Tacoma section, and these features may be directly correlated with the motorists' awareness of the truck-lane restrictions.

STATE PATROL SURVEY ON ENFORCEMENT ISSUES

The information summarized below was collected from an informal survey, not from one that was formally constructed. The survey responses, therefore, may contain a great deal of bias. However, this information does provide some valuable insights into the concerns of law enforcement representatives regarding lane restrictions.

Real Versus Perceived Problem

When asked whether the problem with trucks in the traffic stream was real or just a matter of motorist intimidation, the majority of state patrol respondents felt that a real problem did exist. However, those who felt the problem of trucks in the traffic stream was only perceived and not real cited two reasons. First, trucks seldom traveled in the left lane, therefore, they were unable to intimidate the traffic. Second, the traffic volumes were already so high and the traffic, subsequently, traveled at such low speeds that the truck traffic had no additional negative impacts.

Operational Considerations

State Patrol troopers expressed mixed feelings when asked whether the truck lane restriction should be in effect continuously or only during peak periods. A slight majority of the troopers thought it would be less confusing if the restriction were in effect 24 hours a day. But a large proportion of the troopers felt that peak-period restrictions would be sufficient.

Operational Impacts

The majority of the State Patrol troopers who responded to this survey expected improvement in the operation of the facility. Four reasons were given for this expected operational improvement. First, they felt that trucks in the extreme left lane reduced the average speed in the faster traveling lanes because of operational differences. Second, trucks traveling in the inside lane reduced the potential for cars to use this lane to pass, which resulted in longer queues in the adjacent lanes and, consequently, slower speeds. Third, should a truck become disabled while traveling in the extreme right lane, it would be less disruptive to the flow of traffic and easier for emergency response vehicles to access it. Finally, at the Southcenter Hill site, trucks traveling in the extreme left lane intimidated vehicles trying to enter the adjacent HOV lane.

The troopers who could not foresee improvement in operation cited two reasons for their skepticism. First, high volumes of traffic and the consequent low travel speeds would not improve with a redistribution of the truck traffic. Second, if a high percentage of trucks traveled in the extreme right lanes, they might hinder merging traffic trying to enter or exit the facility, which might result in longer queues at the on-ramps. This research agrees with the troopers' first speculation but disagrees with the second; the volume of trucks is so minimal that no facility access/egress problems would result with a redistribution.

Safety Impacts

The majority of the State Patrol troopers who responded to this survey could foresee no safety problems resulting from the implementation of a truck lane restriction. Some even predicted a reduction in car/truck incidents because aggressive automobile drivers would be able to utilize the extreme left lane and would not be forced to maneuver to pass the trucks. Lane change and speed related accidents could predictably be reduced.

The state troopers who could foresee a problem with safety cited problems at on/off ramps, where cars merge or change lanes to exit. The braking capabilities of trucks might not be able to adjust when slower moving vehicles entered the freeway. The speed differential between the "truck lanes" and the "car lanes" could result in similar problems. Enforcement procedures could produce another safety hazard. Violators traveling in the extreme left lane would have to merge over to the extreme right shoulder to be cited.

Additional Enforcement Efforts

Two general opinions prevailed regarding additional enforcement for a truck lane restriction. First, the regular State Patrol could watch for "failure to obey restriction sign" violations without any additional personnel required. Second, a number of troopers speculated that very few violators would be stopped because they would have to move from the extreme left lane to the extreme right shoulder to be cited. This would negatively impact both the operation and the level of safety of the facility.

INFORMAL TRUCKING INDUSTRY OPINION POLL

Informal interviews with members of the Washington State Trucking Association (WTA) indicated that this organization, on the whole, does not object to truck lane restrictions. In fact, the WTA views them as very favorable and supports their implementation because they can help the trucking industry's public image.

The American Trucking Association (ATA), which represents mostly firms but also some independents, does not oppose truck lane restrictions either. However, this organization does object to peak-period restrictions. Peak-period travel is often unavoidable because shippers set a 9 am to 5 pm load and unload schedule, which means the truckers have to be on the road from 7 am to 9 am and from 5 pm to 7 pm. Despite the shippers' scheduling constraints, truck drivers make an effort to avoid the peak period to improve their public image, and to save on the high operating costs resulting from sitting in traffic (e.g., fuel costs).

The ATA feels, because of differing business operations and constraints, independent truckers are likely to violate restrictions more often than truck drivers employed by firms.

CONCLUSIONS AND RECOMMENDATIONS

A number of conclusions regarding the implementation of truck restriction strategies were drawn on the basis of the in-depth and site comparative analyses of the Puget Sound region and survey techniques. These conclusions are summarized below, and recommendations are made based on this project's results.

CONCLUSIONS

The conclusions are organized by the three analyses that were performed: the in-depth analysis, the site comparison analysis, and the survey results.

In-Depth Analysis

During the in-depth analysis, the researchers examined a number of factors, including traffic composition, traffic flow characteristics, safety characteristics, enforcement issues, economic impacts, and pavement deterioration. One caution should be noted when interpreting the in-depth analysis results. The lane distribution at the Southcenter Hill site did not change significantly during the before-and-after analysis, indicating that a proportion of truck drivers were either willfully violating the lane restriction or unaware that a lane restriction existed. The lack of truck traffic redistribution throughout the facility has serious implications for this analysis. Any changes noted in the operation or safety of the Southcenter Hill site may not be attributable to the lane restriction because lane distribution conditions remained the same before and after the implementation of the restriction.

With respect to traffic composition, the following was noted.

- Trucks make up a very small percentage of the traffic in the Puget Sound region: just over 5 percent on the weekdays and just over 2 percent on the weekends.

With respect to traffic flow characteristics, such as volume, speed, time gaps, platoon lengths, and truck impedance time, the following was noted.

- Unlike the volume levels for non-trucks, the volume level for trucks on the roadway does not increase significantly during the weekdays or during certain times of the day (morning and afternoon peak periods).
- The number of trucks violating the lane restriction is dependent on the level of congestion experienced by the facility. The number of trucks in violation of the restriction increases greatly during the afternoon peak period.
- Trucks and non-trucks experience very similar speed distributions throughout the day, but truck speeds are substantially less, on the average, than non-truck speeds.
- Both trucks and non-trucks experience a slight (but statistically significant) increase in average speed after implementation of the lane restriction, but it is unclear whether this increase is attributable to the lane restriction.
- Speeds of vehicle couplets may indicate that trucks are impeding the free flow capabilities of traffic because the average speeds for cars following cars and trucks following cars are greater than the speeds of cars following trucks and trucks following trucks.
- The only change in speed differential occurred between lanes 2 and 3, where a decrease was noted. However, this decrease does not appear to have resulted from the implementation of the lane restriction.
- The number of trucks and non-trucks violating the speed limit increased substantially between 6 pm and 10 pm after the implementation of the lane restriction. Again, this increase does not appear to have resulted from the implementation of the lane restriction.
- Platoon lengths increased in lanes 2 and 3.

- The number of times per day trucks occupied lanes 1, 2, and 3 increased, but because there was no redistribution of trucks throughout the facility, this increase cannot be attributed to the lane restriction.

The safety analysis resulted in the following observations.

- The proportion of truck related accidents in each lane is similar to the proportion of trucks traveling in each lane (i.e., the majority of truck travel is in the right-most lanes; hence, the highest proportion of truck-related accidents occur in the right-most lanes).
- The majority of accidents resulting from merging from an on-ramp, changing lanes to the left, or moving straight is initiated by non-trucks; the majority of accidents resulting from changing lanes to the right is initiated by trucks.
- The majority of truck-related accidents results only in property damage or minor injuries.

With respect to enforcement issues, the researchers were mainly interested in the violation rates.

- Restriction violation rates were only 2.1 percent. However, the proportion of trucks traveling in lane 4 prior to the restriction was also 2.1 percent, indicating that the restriction had no noticeable impact on the distribution of trucks throughout the facility. Operational characteristics at the study sites may have contributed to this lack of effect.

With respect to economic impact, the analysis revealed only minor impacts that the motor carrier industry would experience as a result of the truck lane restriction.

- Assuming 100 percent restriction compliance, the economic loss incurred by a driver who had previously traveled in lane 4 but who now had to travel in lane 3 would total $4.84 per year (19.52 minutes of lost driving time). For the industry as a whole, economic losses would total $1,155 annually (82.2 hours of lost driving time).

The pavement analysis resulted in the following observation:

- Even assuming extreme conditions (i.e., 100 percent compliance with the restriction and no weather effects on the pavement), a truck lane restriction would have minimal impacts on the life of the pavement at the Southcenter Hill site.

Site Comparison Analysis

A number of the same factors that were examined in the in-depth analysis were also examined as part of the site comparison analysis but with a different purpose. The primary purpose of the site comparison analysis was to determine whether enough consistency existed among the sites to apply the results of the in-depth analysis to other areas in the region. The conclusions are summarized below.

- The proportion of trucks in the traffic stream varies depending on site proximity to major terminals, ports, and CBDs.
- Truck distribution throughout the facilities, truck and non-truck speeds, and restriction violation rates vary depending on (1) site proximity, (2) facility size, (3) volume levels of the sites, (4) degree and length of grade, and (5) location of entrances and exits.
- Variation in time-gap measurements could have resulted from inaccurate data collection methods.

Survey Results

On the basis of the three logit models estimated on favorability and awareness, several important implications regarding truck-lane restrictions can be identified.

- 90.85 percent of motorists favor lane restrictions, while only 31.96 percent of truckers favor lane restrictions.

- The trucker who is least likely to favor lane restrictions admits to violating restrictions, frequently changes lanes to avoid rough pavement, typically carries non-perishable cargo, is between 20 and 40 years old, and has been licensed for many years.
- Truckers were more willing to favor Puget Sound truck-lane restrictions if they traveled on the I-5 Southcenter and SR-520 restricted highway sections. There is some support for restrictions in areas with few lanes and in areas that do not require merging/diverging lane changes. Lane restrictions in areas with high concentrations of merging/diverging traffic may be perceived to adversely affect the safe operation of traffic.
- The motorist who is most likely to favor restrictions frequently changes lanes to avoid being followed by a truck, drives a passenger car, is between 30 and 45 years old, and has been licensed for a long time.
- The motorist most likely to be aware of Puget Sound truck-lane restrictions is male, drives a passenger car, and has been licensed for a relatively short time. Motorists are more likely to be aware of restrictions when benefits are perceived (e.g., the relatively low number of lanes and merging/diverging sections on I-5 Southcenter and SR-520) and when they are not distracted by complex geometrics (e.g., the merging/diverging at the I-5 Tacoma site).

RECOMMENDATIONS

At this time, truck lane restrictions are not recommended for further implementation in the Puget Sound region. This recommendation is based on four factors.

First, little evidence exists nationally to support the notion that truck lane restrictions improve the operation, safety, or pavement deterioration rates of a facility or that they reduce economic impacts to the users. Studies conducted in Florida, Texas, and

Virginia found negligible change in the operation or safety of a facility after the implementation of a truck lane restriction.

Second, the literature indicates that a higher proportion of trucks in the traffic stream results in greater impacts when those trucks are redistributed across the facility. (1) Therefore, because the proportion of trucks in the traffic stream is very small, approximately 5 percent in the Puget Sound sites studied, the researchers suggest that any truck redistribution would result in minimal impact on the operation, safety, and pavement deterioration rates of the facility and on the economic standing of the user. (Remember that the in-depth analysis performed as part of this study was inconclusive because of a lack of truck traffic redistribution.)

Third, too much variability exists among the study sites for widespread implementation of truck lane restrictions. Again, citing from the literature, higher traffic volumes and a higher percentage of trucks in the traffic stream result in greater impacts when the truck traffic is redistributed across the facility. (1) Both of these factors, traffic volume and truck traffic proportion, varied among the sites selected for comparison. Most of this variability lay in differing facility sizes and differing proximities to major trucking origins and destinations (e.g., the ports). This variability implies that the results of a truck lane restrictions test conducted at a single site cannot be extrapolated to other sites. Instead, each site requires analysis based on its own characteristics to determine the potential impacts of a truck lane restriction.

Lastly, while the majority of motorists may favor truck lane restrictions, only a small proportion of trucking industry representatives are in favor of them. Implementation of a truck lane restriction may be viewed by the industry as an infringement of its rights to operate a business.

For the truck lane restrictions already implemented in the Puget Sound region, no additional signing efforts are recommended. The signs that are currently in place meet the state's sign specification and are felt to be adequate. However, development of an informative brochure for distribution to the trucking industry may be beneficial. A brochure that lists the facility segments in Washington that are subject to a truck-related restriction may encourage compliance.

No additional enforcement efforts are recommended to achieve higher restriction compliance. The percentage of trucks that violate the restriction is small; citing the trucks in violation would not be an efficient use of the enforcement resources.

Other types of restrictions, such as time-of-day restrictions, should not be considered for implementation in the Puget Sound region without a comprehensive survey of national experiences. (Little formal literature was found that discussed the success of time-of-day restrictions, route restrictions, and speed restrictions for improving the operation, safety, or pavement deterioration rates of a facility or the economic impacts to the user.)

Further work should instead concentrate on public education efforts. While no conclusive evidence supports the benefit of restrictions, over 90 percent of the motorists surveyed favored truck lane restrictions. Obviously, motorists' perception is that trucks cause a problem on the roadway. However, it is not fair to restrict the trucking industry on the basis of motorists' perception alone. Therefore, further research may be required (1) to determine *why* motorists perceive trucks the way they do and (2) to determine the education efforts that would be most successful in presenting the motoring public with accurate operational and safety-related information.

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