Operational Evaluation of Truck Restrictions on I-20 in Texas

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With the increased expansion of highways to six lanes, questions have arisen as to the proper operational strategy of those facilities. One strategy gaining support is to restrict large vehicles from one or more lanes. The effects of such restrictions, however, had not been extensively studied. The operational effects of a truck restriction on I-20 near Fort Worth, Texas, were analyzed. Vehicle distributions according to classification, vehicle speeds, and time gaps between vehicles were examined to evaluate the operational effectiveness of this left-lane truck restriction. No analysis or evaluation of accident rates or pavement wear was undertaken. Although the directional distribution of trucks changed significantly because of the restriction, no effects were found that could be attributed to the truck restriction in the directional distribution of cars, speeds of either cars or trucks, or time gaps between vehicles.

Recent emphasis of transportation engineering has shifted from the design of new facilities toward maintaining, enlarging, and improving the operation of existing ones. Computer traffic-monitoring systems, changeable message signs, and high-occupancy-vehicle lanes have all been used to improve the operational characteristics of a facility. Another area in which such changes are taking place is in the operational strategy of multilane highways, in which restrictions of trucks, essentially all large vehicles and vehicles pulling trailers, are being examined as tools to increase operational performance. Some engineers and highway users suggest that large trucks are impeding the free flow abilities of smaller vehicles. In the purest sense, because the average speed of trucks was less than the average speed of cars, trucks must be impeding cars, at least to some degree. It has been suggested that trucks should be restricted, leaving one or more lanes clear for non-truck traffic. Conversely, it has been suggested that increasing the concentration of truck traffic would induce increased pavement damage and otherwise restrict the movement of other vehicles. Restricted access of entering vehicles may decrease safety, whereas increased pavement wear may demand higher design standards for the roadway, at least for the outside lanes. The validity of these suggestions has not been fully evaluated by previous research. This lack of relevant research, therefore, indicates need for a well-designed, controlled experiment to study the effects of truck restrictions.

OBJECTIVES

The limitations of most research on this subject center on the lack of a proper study design in which the conditions both before and after a lane restriction are thoroughly examined. It is the primary objective of this study to perform such an experiment. Specifically, this study is concerned with the highway operations aspect of truck restrictions. Although the focus of the following paragraphs is on the left-lane truck restriction at Interstate 20, restrictions were implemented and studied at two other sites in Texas as part of a larger study sponsored by the Texas State Department of Highways and Public Transportation (*1*). All results and conclusions presented were supported by these other studies, except as noted.

BACKGROUND

FHWA surveyed the 50 states, the District of Columbia, and Puerto Rico in June 1986 to study the extent to which lane restrictions had been used (*2*). All 52 surveys were returned, 28 of which reported using no restrictions. The other states reported using restrictions, usually temporarily, for one or more of the following reasons:

1. To improve highway operations,
2. To reduce accidents,
3. To provide for more even pavement wear, and
4. To ensure better operation and safety through construction zones.

A similar study was performed by Sirisoponsilp and Schonfeld (*3*) in February 1988. This study also surveyed the 50 states, the District of Columbia, and Puerto Rico, but only 31 of those surveyed responded. Fourteen states reported having experience with truck restrictions, whereas 17 states reported no experience. Of the 14 states having truck restriction experience, 5 implemented statewide restrictions and 4 were currently studying their effectiveness.

Other studies (*4,5*) have analyzed the effects of truck restrictions on highway operations. However, because of a lack of before-and-after comparisons and an inadequacy of control, the results of these studies are questionable. Therefore, reliable conclusions cannot be drawn without the results first being replicated. Perhaps the most comprehensive research on this subject was performed by Hanscom (*6*) in 1989. A before-and-after study design with a control site was used to evaluate the effectiveness of three different truck restrictions. Hanscom reported voluntary compliance by a higher percentage of trucks at all three sites. To determine the impedance of cars by trucks, the average platoon lengths behind trucks during the before and after periods were computed. The average platoon length change between the before and

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after periods for the test and control sites was then compared, and significant differences between the two were found. The report also found that there were no adverse speed effects resulting from the restrictions. Although the study design was very good, the lack of an appropriate control site makes conclusions based on comparisons between the test and control sites less meaningful. The control sites existed upstream of the test sites and were reported to differ both in composition of traffic and in total volume. The platoon length discussed previously was highly dependent on volume, and, because the volume of the test and control sites varied by as much as 30 percent, that measurement was questionable for determining impedance. Because volumes were determined by 5-min counts and manual methods were used to measure speeds and determine following distances, further doubt is cast on the validity of the results. The need for replication of these results, therefore, is evident.

PUBLIC SURVEYS

In order to obtain public comment and aid in the development and analysis of the restriction, public surveys were conducted both before and after implementation of the restriction. Two initial surveys were conducted before the restriction: (a) a trucker survey of large-vehicle operators and (b) a motorist survey of automobile operators. These surveys were structured to determine the opinions of drivers as well as to determine the most effective signing system to convey the intent of the restriction. In addition, three secondary surveys of similar format, two of motorists and one of truckers, were conducted after the restriction. These surveys were intended to poll drivers who had experienced the restriction, and the surveys were structured to determine the opinions of drivers about the effectiveness of the sign as well as the restriction in general.

Initial Surveys

A total of 124 motorist surveys and 140 trucker surveys were completed. These surveys were structured to perform two principal functions: (a) gain an understanding of the opinions of motorists and truckers toward a left-lane restriction of large vehicles and (b) identify which sign best relates the intended message both to motorists and to truckers.

To accomplish the first objective, a question was asked about the respondent's feelings toward the left-lane restriction of trucks. This question revealed that 60 percent of motorists favored the restriction of larger vehicles, whereas only 28 percent of truckers favored such a restriction. Of the truckers not favoring the restriction, 19 percent stated that the restriction would cause merging conflicts, 14 percent stated that the restriction would impede cars, and 13 percent stated that the restriction would cause undue congestion.

In order to accomplish the second objective, three different regulatory signs were introduced. For each sign, questions were asked as to the legality of driving certain types of vehicles in the left lane. The effectiveness of each sign, therefore, was determined by computing the percentages of correct responses to each sign option. The sign that exhibited the highest percentages of correct responses by both types of drivers was deemed the clearest in conveying its meaning. This process ultimately yielded a sign that read No Trucks Trailers in Left Lane.

Secondary Surveys

A total of 345 motorist surveys and 87 trucker surveys were completed. These surveys were designed to perform two principal functions: (a) assess the effectiveness of the sign in being noticed and in conveying its intended meaning and (b) assess the opinions of motorists and truckers toward the restriction and its impact on highway operations.

For the first objective, respondents were first asked if they noticed the sign while driving on the facility. Sixty-eight percent of the motorists answered positively to this question, as did 76 percent of the truckers. Although this result also means that 32 percent of the motorists and 24 percent of the truckers did not see the signs, those missing the signs might have been traveling in the right two lanes. Additionally, the respondents were asked to which types of vehicles they thought the sign applied. This question was similar to those in the initial trucker and motorist surveys, in which the effectiveness of the sign was analyzed by determining the percentages of correct responses to each vehicle type. The average percentage of correct responses was 88 and 73 percent for the motorists and truckers, respectively.

In order to accomplish the second objective, respondents were asked if they thought the restriction improved operations. Forty-five percent of the motorists thought the restriction had improved operations, whereas only 20 percent of the truckers believed that it had. Large percentages of respondents were unsure whether operations had improved (43 percent of motorists and 28 percent of truckers). Approximately half of each group of respondents provided comments. Twenty percent of all motorists surveyed offered that the restriction was a good idea; to the contrary, 28 percent of the truckers suggested that it was a poor idea.

STUDY METHODOLOGY

The three study sites mentioned previously were chosen primarily because they met the requirements of the study. That is, they were chosen because they were six-lane, rural Interstate highways with a speed limit of 65 mph (60-mph truck speed limit). Although a control section would be desirable, no such sections were used because the short lengths of the sites would undoubtedly induce end effects. Although one direction could have been used as the control section, the problems associated with reducing the effects of the intervening variables (volume, directional distribution, truck percentage, peak period, and geometry) would have made before-and-after comparisons weak at best. The site highlighted was located on I-20 between Fort Worth and Weatherford, Texas. The total length of the section was approximately 9 mi, and its 1988 average annual daily traffic (AADT) was 39,000 vehicles. There was an approximate 3 percent upgrade in the eastbound direction and a 3 percent downgrade in the westbound direction. Although flat grade would have been

desirable across both directions, conclusions can still be drawn as long as the effect of the grade is considered in all analyses.

Data Collection

A system of tapeswitches was designed and implemented to collect all data. Two tapeswitches, placed 15 ft apart to permit the computation of vehicle speeds, were temporarily installed across all traffic lanes. A computer program detected and collected the electronic activations of all tapeswitches, while another computer program reduced the activations into useful operational data. To check the accuracy of the collection and reduction procedure, the highway segment was also videotaped during all data collection periods. To obtain the base conditions of the highway, 10 hr of data were collected during peak and nonpeak periods on August 17 and 18, 1988. One year later, in August 1989, signs were manufactured and installed. These signs were spaced evenly throughout the length of the site, with approximately 1 mi between signs. Two signs were placed back to back on one pole in the median, and a Begin and End message sign was placed atop the first and last signs, respectively. No attempts were made to enforce the restriction. After a 90-day adjustment period, 15 hr of data were collected on November 14, 15, and 16, 1989.

A peak period was defined to account for volume differences within the data. In this manner, speed and headway averages could be compared with some confidence that volume did not control the results. Peak periods were determined by examining 15-min volumes in both directions. The intervals in which the volumes were clearly greater than the average were considered to be in the peak period, with everything else constituting the nonpeak period. Using this analysis, the peak periods were defined as 4:00 to 6:00 p.m. in the westbound direction and 6:30 to 8:30 a.m. in the eastbound direction.

Operational Characteristics and Data Manipulations

Three operational characteristics of traffic flow were examined: (a) vehicle classification, (b) vehicle speed, and (c) time gap between vehicles. The time gap between vehicles is that between the passing of a fixed point by the rear axle of the leading vehicle and the front axle of the following vehicle. This parameter was deemed applicable (more than leading or lagging headway) because it did not incorporate vehicle length and therefore provided a more accurate description of how closely vehicles follow one another.

The vehicle classification system used was designed such that comparisons could be made between groups of vehicles, with each group composed of vehicles assumed to have similar operating characteristics. It is, therefore, important to understand the limitations of the classification system, as some vehicles may exhibit the characteristics of more than one classification. Two classifications were used: (a) vehicles with two axles and (b) those with more than two axles. This system permits assumptions to be made about the nature of the vehicles within them. Vehicles with two axles generally include passenger cars, pick-ups, vans, motorcycles, and some single-unit trucks; vehicles with more than two axles generally include some single-unit trucks, passenger cars and pick-ups pulling trailers, all tractor-trailer combinations, and buses. For simplification, vehicles with two axles are referred to as cars, and vehicles with three or more axles are called trucks.

In order to analyze the distribution of vehicles, the percentage of vehicles in each classification was examined as a percentage of (a) total vehicles in the lane, (b) total vehicles in the direction, and (c) total vehicles in both directions. In addition, the percentage of each classification in a lane as a percentage of the total number of vehicles of the same classification in a direction was examined. This type of analysis relates how each classification of vehicle is distributed across a direction. Changes in the distributions of trucks and cars across each direction were evaluated to determine the impacts of the restriction. A redistribution of trucks was certainly expected, but the magnitude of the change was not known. The redistribution of trucks may effect a corresponding redistribution of cars, and the combination of these changes may have either positive or negative consequences.

In order to analyze vehicle speeds, the arithmetic mean of the speeds of each vehicle classification in each lane was computed and examined. Because the sequence of vehicles was also known, the arithmetic means of the speeds of cars following cars and of cars following trucks were computed and examined (for all lanes). One important point to consider when forcing trucks to switch lanes is that those trucks may not have adjusted their speeds after switching lanes. Furthermore, which trucks were complying with the restriction, the faster or the slower ones? This question is important because those trucks previously in the left lane were exceeding the speed limit on average by as much as 10 mph. If the trucks that switched lanes did not adjust their speeds, an increase in the speed differential in the center or even the right lane might result, thereby increasing the potential for hazard within those lanes. In addition to examining the average speeds of groups of vehicles, the speed differential was computed for each lane. A decrease in the speed differential in a lane would likely increase the safety of the roadway. The absolute value of the difference between the speed of each vehicle and that of the preceding vehicle was calculated. The average speed differentials before and after the restriction were then compared to test for statistical significance. Finally, the cumulative distribution functions of the speed for each classification of vehicle were examined. The cumulative distribution function relates important information about the variability of the speeds within a lane. The manner in which the cumulative distribution functions were examined is explained at the end of this section.

In order to analyze the time gaps between vehicles, the arithmetic mean of the time gaps of four groups of vehicles was computed and examined in each lane. These four groups included the four combinations of the leading vehicle's classification and the following vehicle's classification. Although these average time gaps provide a general indication of how closely vehicles are following one another, they are meaningless unless all vehicles are evenly distributed throughout time. The use of peak and nonpeak periods reduces the chance of irregular distributions but does not guarantee a perfectly regular one. Therefore, conclusions based on average time gaps should be made knowing these limitations. The entire distribution of time gaps should be examined to fully differ-

entiate changes between the before and after stages. Examination of the cumulative distribution functions allows comparisons to be made only at the smaller time gaps, in which differences result from interactions among vehicles. This distinction is important because, as the time gaps become larger, the influence the leading vehicle has on the following vehicle is minimal and, instead, depends heavily on traffic volume.

A hypothesis provided by some highway users in the surveys mentioned previously was that, because faster trucks would be forced into the slower traffic stream of the outside lanes, they would bear down on the cars in front of them. To test this hypothesis, vehicle pairs consisting of cars followed by trucks were identified and the time gaps between them examined. The proportion of pairs in each lane in which the time gaps were less than 2.0 sec were then compared before and after the restriction. These tests were repeated using a criterion of 1.5 sec for the time gap.

The cumulative distribution functions both of the time gaps between vehicles and of vehicle speeds were examined for the following four variables: (a) stage (before or after implementation of the truck restriction, (b) period (peak or nonpeak); (c) lane, and (d) group. The group variable included the four combinations of the leading vehicle's classification and the following vehicle's classification. Therefore, the four groups were (a) cars following cars, (b) cars following trucks, (c) trucks following cars, and (d) trucks following trucks. Manipulation of these four variables allowed many different types of comparisons to be made. Four types of comparisons were made by plotting and examining the cumulative distribution functions in the following manners:

1. All four groups on one graph, with stage, lane, and period variable (24 graphs);
2. Both stages on one graph, with lane, period, and group variable (48 graphs);
3. Comparable lanes (left, center, or right lanes of both directions) on one graph, with lane pair (1-4, 2-5, and 3-6), stage, period, and group variable (48 graphs); and
4. Comparable lanes and both stages on one graph, with lane pair, period, and group variable (24 graphs).

Statistical Methods

Different statistical tests were used to test the significance of observed changes in the operational parameters discussed previously. An alpha level of 0.05 was used for all tests. The chi-square statistic was used to test the significance of changes in the directional distribution of vehicles. Contingency tables were constructed to observe changes in the distributions of vehicles across lanes from before to after the restriction. Each direction of traffic was analyzed separately, as was each classification of vehicle. Collapsed two-by-two contingency tables were used to test the changes in the proportions of trucks in the left lane. The use of the chi-square statistic in this case is equivalent to a z-test of differences between two proportions.

Speeds of vehicles according to classification were compared in several ways using analysis of variance techniques. A general linear model was constructed and included main effects for the direction of travel (westbound or eastbound), lane (1, 2, or 3), period (before or after), and vehicle classification (car or truck). The analyses for peak and nonpeak periods were carried out separately. Single degree of freedom contrasts were constructed to test for individual lane differences, when overall F-tests supported their use. Comparisons of interest included differences between the speeds of cars and trucks, differences from before to after the restriction in the speeds of each classification, and the comparison of this latter speed difference between the two classifications. The interaction effect between period and classification addresses the last comparison, that is, whether the change in the speeds of trucks from before to after the restriction was the same as the change in the speeds of cars.

Tests involving the calculated speed differentials were constructed similarly. An overall analysis of variance that included effects for direction, lane, and period was performed for the peak and nonpeak periods individually. F-tests for single degree of freedom contrasts were appropriately designed, on the basis of the results of the overall analysis. Interaction effects involving direction and lane were interpreted to indicate the need for individual comparisons when significant at the 0.25 level.

The change in the proportion of trucks following cars with time gaps less than 2.0 and 1.5 sec was tested from before to after the restriction. The chi-square statistic calculated from a two-by-two contingency table was used to test the significance of the difference in each lane. Again, this test is equivalent to a z-test of differences between two proportions.

RESULTS

Compliance

The rate of compliance was analyzed by comparing the percentages of trucks in the left lane before and after implementation of the restriction and calculating the percentage changes. Table 1 presents the percent reduction of truck traffic in the left lane as a percentage of truck traffic in the direction. This table indicates that the percentages of trucks in the left lane decreased by between 62 and 76 percent. All four of these percentage reductions were found to be statistically significant.

Table 2 presents the left-lane truck percentages before and after the restriction. As can be seen in this table, the percentage of trucks in the left lane, as a percentage of truck traffic, was 11.7 percent or less before the restriction. In addition, because of the small ratio of trucks to cars, the overall percentage of trucks in the left lane (as a percentage of total traffic) before the restriction was 1.3 percent or less. After the restriction, the percentage of trucks in the left lane as a percentage of truck traffic was 4.4 percent or less, and the percentage of trucks in the left lane as a percentage of total traffic was 0.4 percent or less. These results exhibit the near nonexistence of trucks in the left lanes at the study site after the restriction.

TABLE 1 PERCENT REDUCTION OF TRUCK TRAFFIC IN LEFT LANES

Westbound		Eastbound	
Peak	Non-Peak	Peak	Non-Peak
64%	76%	62%	64%

TABLE 2 LEFT-LANE TRUCK PERCENTAGES BEFORE AND AFTER IMPLEMENTATION OF TRUCK RESTRICTION

	Westbound		Eastbound	
	% of Total	% of Trucks	% of Total	% of Trucks
	Before			
Peak Period	0.7	8.9	1.3	11.7
Non-Peak Period	0.8	5.3	1.1	7.9
	After			
Peak Period	0.2	3.2	0.3	4.4
Non-Peak Period	0.2	1.3	0.4	2.9

Vehicle Distributions

From the data, the percentage of trucks as a percentage of total traffic can be easily determined. Before the restriction, the percentage of trucks across all lanes of traffic was 8.4 and 14.2 percent during the peak and nonpeak periods, respectively. After the restriction, the percentage of trucks was 6.6 and 15.0 percent during the peak and nonpeak periods, respectively. The percentage of truck traffic, therefore, remained fairly constant from before to after the restriction. Higher percentages of trucks during the nonpeak periods are also evident.

Table 3 presents the percentages of trucks and cars before and after the restriction, as well as the percentage changes. The distribution of trucks changed significantly across both directions and during both periods. In addition, these distributions changed in a peculiar way. As expected, the percentage of trucks decreased in the left lane by between 62 and 76 percent. Unexpectedly, however, the percentage of trucks decreased in the middle lane as well (between 6 and 23 percent), with the percentage of trucks increasing only in the right lane (between 17 and 60 percent). This same pattern of change appeared in both the westbound and eastbound directions and during both the peak and nonpeak periods. Although the percentage of trucks in the right lane increased by as much as 60 percent (eastbound peak period), that increase was generally less than 25 percent. These results suggest that the trucks that moved from the left lane to the center lane caused a subsequent movement of trucks from the center lane to the right lane. Although not likely, it is possible that the trucks moved from the left lane to the right lane. Whatever the case, the concentration of trucks in the right lane was more pronounced than expected, whereas the concentration of trucks in the middle lane was actually less than expected. This result was not substantiated at the other two sites (*1*). At those sites, truck traffic generally increased in both the middle and right lanes.

In both directions, the distribution of cars did not change significantly during the peak period but did change significantly during the nonpeak period. The sample sizes during the nonpeak periods of both directions were so large, however, that any variation between the before and after periods would be found statistically significant. The actual differences were so small in all lanes (usually less than 2 percentage points) that they were of no practical importance. Therefore, there was no change of practical significance in the distribution of cars across both directions and during both periods. Table 3 shows that all of the changes are 7 percent or less in magnitude and exhibit no consistent pattern in their direction of change.

TABLE 3 CHANGES IN DISTRIBUTION OF TRUCKS AND CARS

Lane	Trucks		Cars	
	Percentage (Before - After)	Change	Percentage (Before - After)	Change
	Peak Period			
Westbound				
Left	8.9 - 3.2	DOWN 5.7%	31.1 - 32.8	UP 1.7%
Center	41.9 - 39.1	DOWN 2.8%	42.8 - 41.5	DOWN 1.3%
Right	49.2 - 57.7	UP 8.5%	26.1 - 25.7	DOWN 0.4%
Eastbound				
Left	11.7 - 4.4	DOWN 7.3%	35.2 - 37.3	UP 2.1%
Center	55.5 - 43.0	DOWN 12.5%	41.6 - 40.6	DOWN 1.0%
Right	32.8 - 52.6	UP 19.8%	23.2 - 22.1	DOWN 1.1%
	Non-Peak Period			
Westbound				
Left	5.4 - 1.3	DOWN 4.1%	20.7 - 19.3	DOWN 1.4%
Center	40.6 - 31.1	DOWN 9.5%	47.9 - 50.3	UP 2.4%
Right	54.1 - 67.7	UP 13.6%	31.3 - 30.4	DOWN 0.9%
Eastbound				
Left	8.0 - 2.9	DOWN 5.1%	29.1 - 27.4	DOWN 1.7%
Center	51.1 - 48.0	DOWN 3.1%	46.6 - 48.1	UP 1.5%
Right	41.0 - 49.1	UP 8.1%	24.3 - 24.5	UP 0.2%

Vehicle Speeds

Table 4 presents the changes in the speeds of trucks and cars. Changes in the speeds of cars were examined to verify that any changes in the speeds of trucks were classification dependent. Table 4 indicates that the speeds of trucks consistently decreased in the westbound direction and, during the

TABLE 4 CHANGES IN SPEEDS OF TRUCKS AND CARS

Lane	Trucks		Cars	
	Average Speed (Before - After)	Change (mph)	Average Speed (Before - After)	Change (mph)
	Peak Period			
Westbound				
Left	69.7 - 66.1	DOWN 3.6 *	70.8 - 69.5	DOWN 1.3 *
Center	64.4 - 61.9	DOWN 2.5 *	66.4 - 65.4	DOWN 1.0 *
Right	60.7 - 58.4	DOWN 2.3 *	62.9 - 61.9	DOWN 1.0 *
Eastbound				
Left	66.6 - 64.4	DOWN 2.2	70.1 - 70.1	NONE
Center	61.2 - 61.1	DOWN 0.1	67.6 - 68.3	UP 0.7
Right	56.0 - 56.5	UP 0.5	65.0 - 65.4	UP 0.4
	Non-Peak Period			
Westbound				
Left	70.0 - 67.0	DOWN 3.0 *	70.6 - 69.3	DOWN 1.3 *
Center	64.6 - 61.6	DOWN 3.0 *	66.4 - 65.2	DOWN 1.2 *
Right	60.7 - 57.7	DOWN 3.0 *	63.5 - 61.6	DOWN 1.9 *
Eastbound				
Left	64.6 - 68.4	UP 3.8 *	68.8 - 69.8	UP 1.0 *
Center	61.2 - 61.5	UP 0.3	66.0 - 67.0	UP 1.0 *
Right	57.0 - 57.9	UP 0.9 *	62.8 - 64.1	UP 1.3 *

* Denotes statistically significant change

nonpeak period, increased in the eastbound direction. The speeds of cars exhibited the same pattern of change, although the changes were generally smaller in magnitude. The changes were not found to be statistically significant in the eastbound direction during the peak period, when a significant increase in volume occurred. Because these changes were different for direction and period and were consistent for cars and trucks, it cannot reasonably be concluded that the changes were in response to the truck restriction. Therefore, there seems to be no positive or negative impact, as far as speeds are concerned, associated with the redistribution of trucks.

The average speed differential in each lane, as defined previously, was compared from before to after the restriction. Table 5 presents these average speed differentials, as well as the results of the tests for statistical significance of the difference from before to after the restriction. As can be seen in this table, 2 of the 12 tests revealed statistically different speed differentials. These decreases in the speed differential occurred in the eastbound direction during the peak period. (Although the speed differentials generally did not change after the restriction, it is of interest that they consistently increased across a direction from the median to the outside lane both before and after the restriction.)

Testing of the interaction between the average speeds of trucks and cars from before to after the restriction yielded inconsistent results. Table 6 presents the difference between the speeds of cars and trucks (average speed of cars minus average speed of trucks) in each lane before and after the restriction, as well as the results of the tests for statistical significance. Table 6 indicates that the speed difference between cars and trucks generally increased after the restriction. This result is consistent with the finding that truck speeds generally changed from before to after the restriction by a larger amount than car speeds. The increases are most pronounced in the westbound direction, which has a 3 percent downgrade.

TABLE 5 COMPARISON OF AVERAGE SPEED DIFFERENTIALS FROM BEFORE TO AFTER THE RESTRICTION WITH TEST RESULTS

Lane	Speed Differential (Before - After)	Difference Between Before and After	Statistical Significance
Peak Period			
Westbound			
Left	3.3 - 3.1	-0.2	NO
Center	3.7 - 3.6	-0.1	NO
Right	4.8 - 4.7	-0.1	NO
Eastbound			
Left	4.0 - 3.3	-0.7	YES
Center	4.7 - 4.7	0.0	NO
Right	6.8 - 6.3	-0.5	YES
Non-Peak Period			
Westbound			
Left	4.4 - 4.4	0.0	NO
Center	4.3 - 4.4	0.1	NO
Right	5.5 - 5.5	0.0	NO
Eastbound			
Left	4.1 - 4.1	0.0	NO
Center	4.9 - 4.9	0.0	NO
Right	6.5 - 6.5	0.0	NO

TABLE 6 COMPARISON OF DIFFERENCES BETWEEN SPEEDS FROM BEFORE TO AFTER THE RESTRICTION WITH TEST RESULTS

Lane	Difference between Car and Truck Speeds (Before - After)	Difference between Before and After	Statistical Significance
Peak Period			
Westbound			
Left	1.1 - 3.4	2.3	YES
Center	2.0 - 3.5	1.5	YES
Right	2.2 - 3.5	1.3	YES
Eastbound			
Left	3.5 - 5.7	2.2	NO
Center	6.4 - 7.2	0.8	NO
Right	9.0 - 8.9	-0.1	NO
Non-Peak Period			
Westbound			
Left	0.6 - 2.3	1.7	YES
Center	1.8 - 3.6	1.8	YES
Right	2.8 - 3.9	1.1	YES
Eastbound			
Left	4.2 - 1.4	-2.8	YES
Center	4.8 - 5.5	0.7	YES
Right	5.8 - 6.2	0.4	NO

In analyzing the cumulative distribution functions of the vehicle speeds, the methods of comparison discussed previously were used, and the 144 graphs were prepared and examined. When examining the cumulative distribution functions of only one stage (before or after) on one graph, the effect of grade on the speeds of trucks became quite clear. The cumulative distribution functions of trucks in the lanes of the eastbound direction were shifted to the left (lower speed) relative to the cumulative distribution functions of cars. As stated, there is a 3 percent downgrade in the westbound direction and a 3 percent upgrade in the eastbound direction. In Table 4, the average speeds of trucks in comparable lanes, during both periods and during both stages, were also always less in the eastbound direction. This finding suggests that, especially with steeper grades, trucks in the left lane may impede the free flow ability of cars. In trying to discover the differences between the data collected before and after implementation of the restrictions, the graphs were examined in an attempt to detect meaningful differences. However, no consistent differences could be found, even taking all variables into consideration. Therefore, under the current conditions, these results suggest that a redistribution of trucks does not effect any meaningful changes in the speeds of either cars or trucks.

Time Gaps Between Vehicles

In testing whether or not trucks bore down on cars more after the restriction, the chi-square tests discussed previously were performed, with both a 2.0- and a 1.5-sec time gap criterion. Table 7 presents the proportions of gaps less than 1.5 and 2.0 sec before and after the restriction, as well as the results of the tests for statistical significance. On the basis of a 2.0-sec time gap, only 1 of the 12 tests was found to be statistically significant. The tests based on a 1.5-sec time gap produced

TABLE 7 TIME GAP COMPARISON RESULTS

Lane	Proportion of Gaps < 1.5 Seconds	Proportion of Gaps < 2.0 Seconds
Peak Period		
Westbound		
Left	25.0 - 22.2	25.0 - 27.8
Center	17.8 - 19.3	31.4 - 29.2
Right	5.3 - 7.7	12.8 - 12.4
Eastbound		
Left	8.3 - 20.0	8.3 - 20.0
Center	8.3 - 6.3	11.7 - 19.0
Right	0.0 - 6.7	0.0 - 13.5 *
Non-Peak Period		
Westbound		
Left	6.0 - 15.0	10.0 - 20.0
Center	8.5 - 7.5	15.0 - 11.0
Right	2.9 - 2.5	7.2 - 5.7
Eastbound		
Left	5.3 - 8.0	10.6 - 10.0
Center	8.5 - 7.7	13.4 - 11.0
Right	1.8 - 5.4 *	4.2 - 5.4

* Denotes statistically significant change

similar results, with a different single comparison being found significant. Therefore, according to these results, the hypothesis that the restriction would cause trucks to bear down on cars more frequently was not substantiated.

The cumulative distribution functions of the time gaps between vehicles were analyzed to determine the changes, if any, that occurred between the before and after periods, or if meaningful observations could be made by considering only one stage. When analyzing the time gaps from one stage, the only consistent observation was that the time gaps of trucks following trucks were less than those of trucks following cars. Furthermore, the time gaps of trucks following trucks were usually also less than those of cars following cars and of cars following trucks. This observation generally held true during both stages, across all lanes, and during both periods.

When examining the cumulative distribution functions for gaps of both stages (before and after) on one graph, it was first established that the volume had not changed significantly since the restriction was implemented. If the volume changed coincident with the implementation of the truck restriction, the headways likewise changed because of the interdependence of headway and volume, thereby making headway comparisons between stages meaningless. To determine if the volume changed, the 15-min flow rates examined previously for determining the peak and nonpeak period definitions were again examined. Averages of the 15-min flow rates for each stage, lane, and period were taken but no significant volume changes were found except during the peak period in the eastbound direction. In that direction, volumes increased by between 31 and 58 percent from the before to the after stage. Therefore, conclusions based on observations of the cumulative distribution functions in the lanes of that direction should be made with knowledge of this change in volume.

To discover differences between the data collected before and after implementation of the restrictions, all of the graphs described previously were prepared and examined. Again, just as with vehicle speeds, no consistent differences could be found, even taking all variables into consideration. However, the site is rural and has a low volume-to-capacity ratio. With such large average headways, even during the peak period (usually greater than 5 sec), vehicles were not greatly affected by the vehicle in front of them. Therefore, it was difficult to detect meaningful differences in the time gaps between vehicles under these conditions. Nevertheless, the results suggest that a redistribution of trucks does not effect any discernible changes in the time gaps between vehicles.

CONCLUSIONS

This study, which examined the effects of a left-lane truck restriction on a rural six-lane Interstate in Texas, produced no startling results. Speeds, time gaps, and classifications of vehicles were recorded before and after implementation of the restriction, allowing the examination of several parameters in the investigation of the effects. The restriction succeeded in its purpose, with compliance rates between 62 and 76 percent achieved without enforcement. Few trucks were present in the left lanes of the roadway before the restriction. After the restriction, only 3 percent of all trucks remained in the left lanes. At the reported study site, the percentages of trucks significantly increased in the right lane (only) of each direction. At two other sites in Texas that were examined and reported on elsewhere (*1*), the percentages of trucks significantly increased in both the center and the right lanes. This redistribution of trucks across the three lanes of each direction did not cause any change of practical significance in the distribution of cars.

The examination of speeds resulted in statistically significant changes in the speeds of trucks relative to cars from before to after the restriction; however, the changes could not be attributed to the truck restriction. In the westbound direction only, the average speeds of trucks decreased more than those of cars after the restriction. The presence of a 3 percent downgrade in this direction cannot be ignored in interpreting this result. Furthermore, the possibility that enforcement activity was the cause of the larger shift in truck speeds should be considered, as trucks in the left lane were exceeding the speed limit by as much as 10 mph on average. Comparative shifts in the speeds of vehicles in the eastbound direction (3 percent upgrade) were only sporadically significant and, when significant, were not consistent in their direction of change.

Speed changes from before to after the restriction were also investigated by comparing the speed differentials in each lane. This measure was defined as the absolute value of the difference in the vehicle speeds within each pair of consecutive vehicles. Two significant reductions in average speed differentials were found. These changes occurred during the peak period in the eastbound direction. A coincident increase in volume, which also occurred only during the peak period in the eastbound direction, is the most probable cause of this result.

The final test, which explored the likelihood of trucks bearing down on cars, examined the proportion of instances in which trucks followed cars with small time gaps (1.5 and 2.0 sec). Only 2 of 24 tests were statistically significant, indicating that the greater concentration of trucks in the right lanes did

not result in an increase in this event. This conclusion is based on the inconsistency of the results associated with the two time-gap values and the possibility of spurious results associated with multiple testing.

This study attempted to quantify measures that could be interpreted as indicative of operational performance. A left-lane truck restriction was then implemented and evaluated on the basis of examination of these measures. No definitive results were found that could be attributed to the implementation of the truck restriction. Although the study design was sound, the lack of an appropriate control site limited the interpretation of many of the results. Furthermore, the presence of a horizontal grade and significant volume changes over the course of the study also complicated the interpretation. Finally, on the basis of the characteristics of the reported study site, the application of these results should be limited to low-volume facilities.

Implementation of truck restrictions, such as the lane restrictions studied, theoretically has the potential to improve the capacity and safety of the roadways. The lack of evidence from the current research to support strong conclusions in these areas has two important implications. The first is the requirement that the results reported here be applied only to similar roadways, that is, rural, low-volume facilities with relatively little truck traffic. The second is the need for further research to investigate whether these results can be extended to higher volume roadways or roadways with larger truck percentages.

RECOMMENDATIONS

Because no discernible negative effects on highway operations could be attributed to the truck restriction, the restriction should be left in place. After a 2-year period, the feasibility of performing an accident analysis should be examined. Such a study would investigate whether the restriction caused an increase in accidents. In addition, more research should be performed on the differential design of pavements on six-lane highways.

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