Abridgment

Effects of Truck Strategies on Traffic Flow and Safety on Multilane Highways

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Recent legislation has encouraged the increased operation of trucks (defined here as vehicles having six or more wheels in contact with the road and a gross vehicle weight greater than 10,000 lb) on Interstate and primary highways. This has affected safety and the quality of traffic flow on multilane highways. Imposing certain restrictions on truck operations on these highways has been identified as a way to reduce this effect. However, the overall impact of these restrictions on safety and traffic flow has not been fully studied. For example, restricting trucks to specific lanes or lowering their speed limit could have varied effects on traffic. The primary objective of the research described in this paper was to provide information on the nature and extent of the effects of such truck control strategies on traffic flows, speeds, headways, and accident patterns. Simulation was used to study these effects on multilane highways. The results did not indicate any safety benefits from the imposition of these strategies but suggested that the potential for an increase in accident rates would be created, particularly if the strategies were imposed on highways with high volumes and a high percentage of trucks.

Numerous factors have been cited as criteria for judging the operating efficiency of the highway transportation system. The most important parameters named, however, are the speed of travel, congestion, delay, and safety (*1*). The increased operation of trucks with larger dimensions and different handling properties on the nation's highways may affect the interaction between these vehicles and other vehicle types, which may in turn affect the operating criteria. For example, maneuvers such as passing, merging, and lane changing can be impeded by the presence of large trucks, resulting in serious degradation of flow quality.

Therefore, the concept of imposing certain restrictions on truck operations on multilane highways has been identified as a way to reduce the interaction between trucks and other vehicles and compensate for the different operational characteristics of trucks. The two most common restraints are (a) limiting truck traffic to specific lanes of the highway, and (b) imposing a lower speed limit for trucks. Little is known about the effects of these strategies on accident rates and the speed-flow characteristics on different traffic lanes. This study therefore investigated the effects of these truck strategies (when used alone or in combination) on traffic performance and accident patterns.

PURPOSE AND SCOPE

The scope of this study was limited to Virginia highways, but sites were selected to reflect different percentages of trucks in the traffic stream. The specific strategies investigated are presented in Table 1.

The objectives of the study were

- To determine the speed-flow relationships for different traffic lanes at different locations,
- To investigate the relationship between congestion (*V/C* ratio) and accident rates on multilane highways,
- To determine the effect of each strategy on speed and flow distributions on different lanes at different locations, and
- To investigate the effects of lane-use restrictions on accident rates and time headways of vehicles on different lanes.

DATA COLLECTION

Selection of Study Sites

Test sites for the simulation were chosen from sections of Interstate and arterial highways that carry a significant portion of truck traffic. A list of candidate sites was first identified to cover a wide range of truck percentages (from about 5 to 40 percent), and a final set of nine locations was then selected for simulation. The criteria used were (a) ease of collecting traffic data, (b) truck percentages within the range being considered, and (c) availability of accident data. The data on traffic composition were obtained from annual average daily traffic statistics compiled by the Virginia Department of Transportation (VDOT).

Traffic Data

Traffic data collected at the test sites included individual vehicle spot speeds and volume counts. The Streeter Amet recorder was used to collect the data, which were further analyzed by TRAFCOMP computer software to obtain statistics such as speed distributions and volume counts by hour. The data on speed and volume distributions were obtained during 24 continuous hours of monitoring on weekdays.

Accident Data

Data on accident characteristics were obtained from computerized files prepared by VDOT and the Virginia Department of Motor Vehicles (VDMV) for 1985 through 1987. Each study site was identified by its route number, the city or county in which it is located, and its section number. A summary of the accident data is presented in Table 2.

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TABLE 1 STRATEGIES USED IN SIMULATION

Strategy	Differential Speed Limit	Truck Right Lane Restriction
1	55/65	Yes
2	55/65	No
3	60/65	Yes
4	60/65	No
5	50/60	Yes
6	50/60	No
7	55/55	Yes
8*	55/55	No
9	65/65	Yes
10#	65/65	No

\# Base strategy for Rural Interstate highways.

* Base strategy for Urban Interstate and Primary highways.

TABLE 2 SUMMARY OF TRAFFIC AND ACCIDENT DATA AT STUDY SITES

SITE	ROUTE	AADT	LANE NO.	MEAN SPEED	NUMBER OF ACCCIDENTS* FATAL	INJURY	PDO	TOTAL
1	95	68728	1	54.09	2	8	17	27
			2	64.71				
			3	73.15				
2	195	75342	1	59.67	0	6	10	16
			2	60.19				
			3	61.88				
3	95	90205	1	55.15	0	50	62	112
			2	61.25				
			3	62.90				
4	581	75657	1	60.81	1	45	74	120
			2	63.06				
			3	66.49				
5	95	149273	1	64.73	0	24	70	94
			2	65.38				
			3	65.67				
			4	66.14				
6	360	10348	1	52.03	0	9	14	23
			2	55.18				
7	29	22110	1	55.56	2	64	91	157
			2	56.58				
8	58	9050	1	55.34	2	38	50	90
			2	58.24				
9	81	23257	1	64.75	0	18	30	48
			2	66.49				
FOR ALL NINE SITES					7	262	418	687

* Total Number of Accidents at Study Sites (1985 thru 1987).

ANALYSIS OF FIELD DATA

Analysis of Traffic Characteristics

The volume and speed data collected at each site were analyzed to identify temporal and locational variations. For highways with two lanes in one direction, traffic volume was higher in the right lane and lower in the left lane. On the average, the right lane carried about 76 percent of the traffic and the left lane about 24 percent. For highways with three lanes in one direction, the right lane carried about 25 percent of the traffic, the center lane about 46 percent, and the leftmost lane about 29 percent. For highways carrying heavy volumes, however, significant differences were not observed among the left lanes. The results of an analysis of variance (ANOVA) suggested that at sites with high volumes, the middle and left lanes were operating with similar traffic characteristics, and the right lane was operating at near capacity. At sites with relatively low volumes, significant differences were observed among the different lanes at a 5 percent significance level.

Development of Traffic Flow Models

The traffic data observed at each site were fitted to the Greenshields traffic flow models (*2*). Separate models were fitted for the individual lanes of each site to observe differences in the traffic stream characteristics among lanes traveling in the same direction. The R^2-values obtained showed that the Greenshields models adequately describe the traffic flow characteristics in each lane. The computed capacity (Q_m) values were then used to determine congestion parameters, as discussed in the next section.

Accident Data Analysis

Accidents in 1985 through 1987 that could be attributed to vehicle and highway interactions were considered in the analysis. Accident involvement rates in terms of 100 million vehicle miles of travel (VMT) were then computed for all vehicles as well as for trucks. These were used to develop models relating accident rates and congestion, as presented in Table 3. These models were used to evaluate the effect of the different truck strategies on highway safety.

Truck Involvement in Accidents

To investigate the effect of each strategy on the accident involvement rate of trucks, it was necessary to develop a simple relationship that would not only describe the truck involvement rate adequately but also contain independent variables that were sensitive to each strategy. It was found that the truck involvement rate (TRINV) was strongly associated with truck volume (TRVOL). Regression analysis was then used to develop the following relationship:

$$TRINV = 8.27 + 0.00278 * TRVOL$$

The effects of implementing truck strategies can result in the redistribution of truck volumes among the lanes, and hence may affect the truck accident patterns in each lane. This model was therefore used to investigate the effect of each strategy on truck-involved accident rates.

SIMULATION OF TRUCK STRATEGIES

The vehicle behavior in each lane at each site was modeled using SIMAN, a simulation software package (*3*). The effects of the different strategies on traffic volumes, speeds, headways, and accident rates at the various study sites were then determined. The basic vehicle movement and operating conditions were modeled before simulating the different restrictions or truck strategies. The vehicles in each lane were represented as entities in a queue. They were generated according to the input volume distributions obtained from the field data, then coded in the experiment frame of SIMAN. As each vehicle was generated, its characteristics (attributes), which included the vehicle type, speed, length, and lane, were assigned.

A highway section approximately 3 mi long was simulated. To simulate vehicle dynamic behavior, a detection mecha-

TABLE 3 ACCIDENTS AS A FUNCTION OF CONGESTION

NO.	ROUTE	CITY/COUNTY	RELATIONSHIP	R^2
1	95	HENRICO	ACCRT = 0.85 + 2.52(V/C)	0.681
2	195	RICHMOND	ACCRT = 1.75 + 8.52(V/C)	0.720
3	95	Pr.WILLIAM	ACCRT = 1.48 + 3.05(V/C)	0.692
4	581	ROANOKE	ACCRT = 1.60 + 2.73(V/C)	0.834
5	95	FAIRFAX	ACCRT = 0.95 + 6.23(V/C)	0.720
6	360	AMELIA	ACCRT = 3.71 + 6.82(V/C)	0.602
7	29	CAMPBELL	ACCRT = 3.37 +11.73(V/C)	0.764
8	58	PITTSYLVANIA	ACCRT = 0.96 + 6.99(V/C)	0.889
9	81	ROCKBRIDGE	ACCRT = 1.16 + 8.08(V/C)	0.627

nism, which scanned the vehicles in each lane every 20 sec, was modeled. The scan shuffled the vehicles into different lanes, subject to prevailing lane-changing and car-following conditions. The vehicle in each lane was processed according to the dynamic conditions modeled for that lane. The model determined if the following car's speed was greater than the lead car and if the time headway was less than 2 sec. If a gap greater than the vehicle length plus a fixed clearance was found in an adjacent lane, the vehicle would move to that lane and its lane code would be changed. (The fixed clearance varied according to the vehicle type.) Trucks were treated differently when truck lane restrictions were being simulated. They were identified by the vehicle type attribute and were restricted to a specific lane (or lanes) using the scan mechanism.

In modeling driver response to posted speed differentials, the change in operating speeds was accomplished by specifying compliance with speed limits. This information was obtained from analyzing the existing speed distributions. Once in each scan the vehicle's distance attribute was updated to reflect distance traveled. The model also determined if the distance was greater than 3 mi, in which case the vehicle was eliminated.

A data collection mechanism triggered at the end of each hour recorded hourly vehicle counts and mean speeds in each lane. Using the output analysis module of SIMAN, the speed distributions were examined and ANOVA tests were performed.

The model logic and the operations simulated at the exit section were verified by comparing the hourly volumes input to the model obtained from the field data with the hourly vehicle counts made by the model. The results indicated that both sets of volumes were approximately equal, suggesting that the logic was acceptable.

SIMULATION RESULTS

Impacts on Traffic Volumes

In analyzing the simulation results regarding the percentage of vehicles that changed lanes (a justifiable parameter for interaction), the imposition of no differential speed limit (DSL) minimized interference among cars and trucks. From less to greater interference, the DSLs, with lane restriction, can be ordered as 65/65, 55/55, 60/65, 55/65, and 50/60. However, results of imposing DSLs with no lane restriction did not produce adequate evidence to ascertain which restrictions are better than no restriction.

The operation of trucks was affected by the imposition of DSLs. Under lane restriction, all trucks are in the right lane; however, under DSLs with no lane restriction, the distribution of trucks among lanes was influenced by the amount of speed differential and number of lanes.

Effects of Truck Strategies on Time Headways

Imposing truck speed and lane restrictions on given volumes may affect vehicle headways. The imposition of speed strategies alone did not cause any significant impact (at 5 percent significance level) on the headways of vehicles in different lanes. However, the restriction of trucks to the right lane resulted in significant decreases in time headways of vehicles in the right lane at some of the study sites (see Table 4).

The results also indicated that the time headways of vehicles in the right lane decreased significantly at sites with high average annual daily traffic (AADT) and a high proportion of trucks. A significant reduction in headways in the right

TABLE 4 EFFECTS OF LANE RESTRICTION ON TIME HEADWAYS ON RIGHT LANE

Site	No. of Lanes	Truck %	AADT	Headways(sec) Before	After	Percent Decrease	Significant Decrease ?
1	3	15.76	68728	6.48	5.47	15.6	Yes
2	3	3.59	75342	9.61	8.67	9.8	No
3	3	13.13	90205	7.54	5.54	26.5	Yes
4	3	8.42	75657	15.90	9.68	39.0	Yes
5	4	11.58	149273	6.64	4.43	33.2	Yes
6	2	21.99	10348	21.91	20.92	4.5	No
7	2	12.17	22110	11.55	10.91	5.5	No
8	2	17.45	9050	34.49	34.18	0.9	No
9	2	32.71	23257	60.88	23.86	60.8	Yes

NOTE : AADT values given are projections for 1989.

lane implies a reduction in the number of acceptable gaps available for drivers wanting to merge from entrance ramps. This creates the "barrier" effect, making it difficult to merge, which results in a hazardous situation at and near each entrance ramp. These results suggest that, for highways with three and four lanes in one direction, the imposition of a right-lane restriction for trucks may create an unsafe condition at entrance ramps when the truck proportion is higher than 3.6 percent and the AADT is greater than 75,000.

Effects on Vehicle Speeds

Figure 1 shows typical results of the speed distributions in the right lane, before and after simulating a 55/65 DSL with lane restriction. Figure 2 shows the speed distributions in the right lane due to the imposition of the 55/65 DSL and lane restriction at three different study sites, carrying 4, 16, and 33 percent truck volumes. Figure 1 shows that the speed distribution tends to be symmetrical with no restriction but skewed with restriction. Figure 2 also shows that the skewness increases with the percentage of trucks in the traffic stream. It is well known that the potential for accidents in a traffic stream increases with increases in skewness of its speed distribution. Therefore, the results suggest that the potential for accidents increases in the right lane with the imposition of the DSL and lane restriction. Also, this effect increases further with increases in truck percentage. The speed distributions in other lanes did not change significantly, although the mean speeds varied slightly.

Effect on Accident Rates

Using the appropriate relationship between the congestion and accident rates mentioned earlier in this paper, the expected

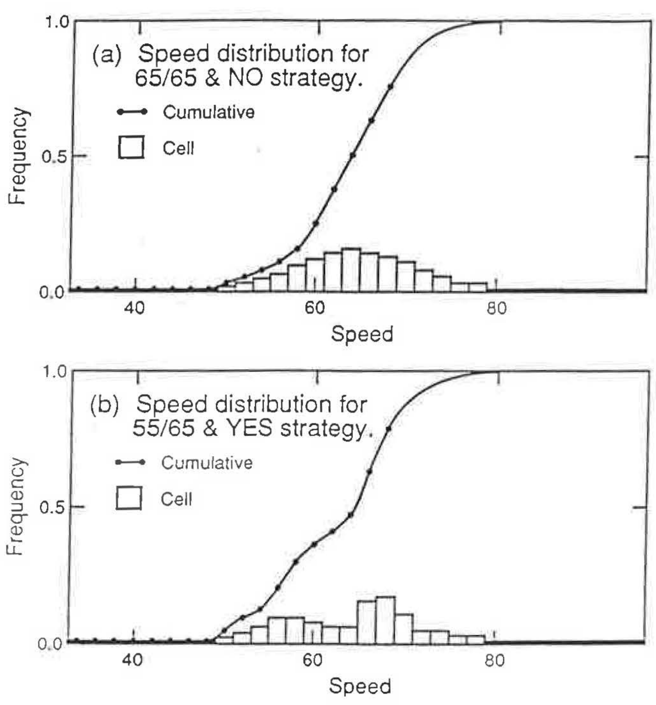

FIGURE 1 Effect of lane restriction on speed distributions on the right lane of Site 9.

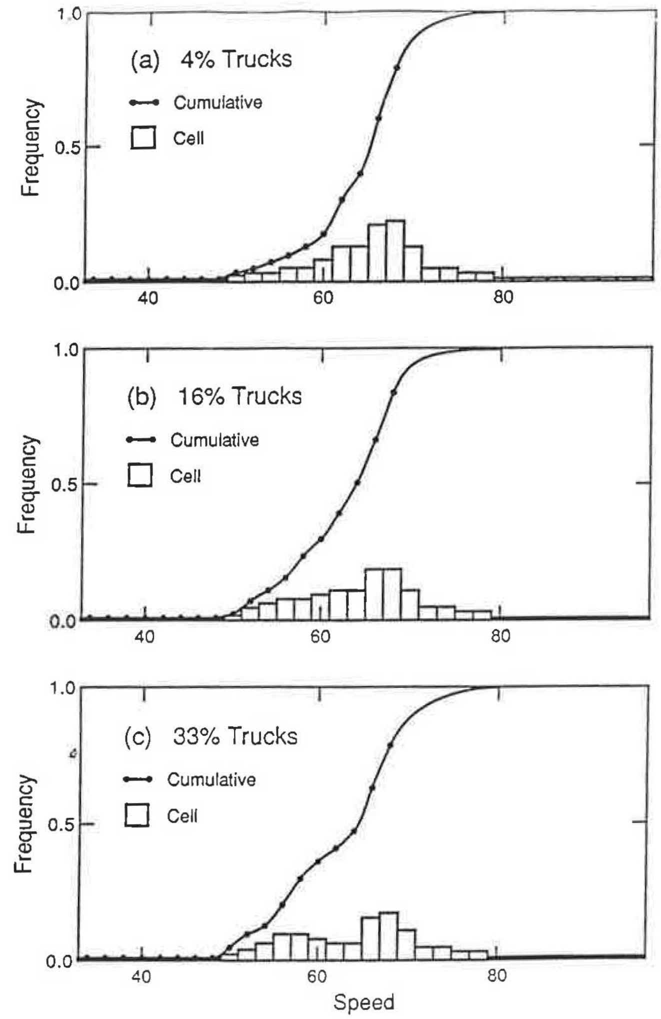

FIGURE 2 Speed distributions on the right lane at sites carrying different truck percentages.

changes in accident rates were determined using the hourly counts and truck volumes from the simulation results.

The results of ANOVA tests indicated that the accident rates did not change appreciably in any of the lanes, except in the cases of lane restriction, where the all-vehicle accidents as well as the truck-related accidents in the right lane increased slightly. However, none of the effects were significant at a 95 percent confidence level. Table 5 presents the average statistics computed from the results obtained for the right lane, due to different truck lane restrictions.

CONCLUSIONS

Conclusions from this research are as follows:

- The imposition of a DSL alone did not result in significant changes in the volume distribution of trucks and nontrucks among the different lanes of multilane highways.
- The imposition of a DSL in addition to lane restriction increased the interaction between cars and trucks and therefore the potential for accidents. With regard to reducing this interaction, the best speed strategy was 65/65, with the following ranking:

TABLE 5 EFFECTS ON ACCIDENT RATES FOR THE RIGHT LANE

Site	All vehicle Accidents		Truck Related Accidents	
	% Increase	Confidence level	% Increase	Confidence level
1	3.65	Low	3.93	64%
2	0.94	Low	1.72	Low
3	4.21	Low	2.89	Low
4	1.67	Low	2.12	Low
5	8.23	33%	6.23	49%
6	4.14	25%	4.79	Low
7	0.73	Low	2.14	38%
8	1.29	Low	3.01	51%
9	6.89	56%	15.72	77%

1. 65/65,
2. 55/55,
3. 60/65,
4. 55/65, and
5. 50/60.

• Restricting trucks to the right lane resulted in a decrease in vehicular headways in that lane. This decrease was significant on three-lane (one-direction) highways carrying AADT greater than 75,000 and a truck proportion greater than 3.6 percent and on two-lane (one-direction) highways having AADT greater than 23,000 and a truck proportion greater than 32 percent.

• The restriction of trucks to the right lane and imposition of a DSL skewed the speed distribution in the right lane. The degree of skewness increased with the magnitude of the speed differential and the percentage of trucks in the traffic stream.

• The imposition of DSLs and lane restrictions did not change the accident rates in the left lanes but slightly increased the accident rates in the right lane for both truck-related and all vehicle accidents, although these increases were not significant at the 5 percent significance level.

• No safety benefits were observed by implementing any of the truck strategies tested. However, the potential for increased accident rates was observed with the implementation of each strategy, particularly on highways with high AADT and a high percentage of trucks.

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REFERENCES

1. *Special Report 211: Twin Trailer Trucks.* TRB, National Research Council, Washington, D.C., 1986.
2. B. D. Greenshields. A Study of Highway Capacity. *HRB Proc.*, Vol. 14, 1934.
3. D. C. Pegden. *Introduction to SIMAN.* Systems Modeling Corporation, Nov. 1987.

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