TRUCK SPEEDS AND ACCIDENTS ON INTERSTATE HIGHWAYS

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The research reported in this paper was designed to evaluate the effectiveness and desirability of the differential truck speed limit on Interstate facilities in Maryland and to examine the operational implications of changing this limit. The research effort was directed toward (a) determining the degree to which trucks comply with existing speed limits, (b) developing a procedure for comparing truck speeds and accident rates on particular sections of highway, and (c) determining the likely operational impact of modifying differential truck speed limits on Interstate highways. Vehicular speed and accident data were collected and analyzed for 84 study sites located on Interstate, U.S., and state routes throughout Maryland. Multiple regression techniques were used to determine whether a significant relationship could be found among speed parameters, accidents, and accident rates. Attempts were made to develop models for the prediction of truck accident rates on limited-access facilities. The existence of a posted differential speed limit was not found to be related to truck accidents, although truck compliance with the differential limit was comparatively low. It was not possible to develop a statistically significant equation for the prediction of the overall rate of truck accidents. Significant equations that are capable of explaining truck accident and involvement variables by changes in traffic speed parameters were developed. The impact of modifying the differential truck speed limit could not be determined with certainty, but it was suggested that the limit be temporarily altered on a test section.

•AMONG the many factors cited as criteria on which judgment of the operating efficiency of the highway transportation system can be based, the most frequently mentioned parameters are speed of travel and economy of operation. Numerous studies have been undertaken in the broad domain of highway system analysis for the purpose of evaluating these parameters. Studies have spanned the spectrum from applied to theoretical and have ranged from specialized studies at a single location, with little general applicability, to extensive system-wide studies, frequently used as the basis for subsequent design, traffic operations, or analysis procedures. With some notable exceptions, the majority of the studies concentrate on passenger vehicle operation and tend to disregard trucks.

In the United States, trucks constitute more than 17 percent of all vehicle registration, are responsible for approximately 20 percent of all vehicle-miles of travel, and transport more than 20 percent of the intercity ton-miles of freight. Trucks are an important and sizable element in the highway transportation system, but they pose special problems in the evaluation of highway operating efficiency. These difficulties are primarily due to the differences between trucks and passenger vehicles, among which are the following:

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1. Truck weights are significantly greater than passenger car weights;
2. Primarily because of their weight (or more specifically, their power-weight ratio), trucks have poorer acceleration capabilities than passenger cars and have greater difficulty maintaining their speed on upgrades;
3. Trucks have a slower rate of deceleration in response to braking than do passenger cars;
4. Average operating and maintenance costs, on a per-mile basis, are higher for trucks than for cars;
5. A truck's operation on the street system is restricted to those locations where geometric design elements are sufficient for its passage;
6. The property damage costs for truck-involved accidents tend to be higher than for accidents involving only passenger cars; and
7. The average truck is 2 years older than the average car, with the result that new vehicle design standards require more time for implementation in the truck population.

Each of these factors introduces some complications into the evaluation of truck operation and may restrict alternatives for possible improvements. They are of special concern in a consideration of the speeds at which trucks can operate safely and efficiently. The literature indicates that attempts have been made to analyze some of these factors with attention being devoted to criteria for establishing truck climbing lanes in mountainous areas, to the effect of trucks on the capacity of a street or highway, and to operating costs for commercial vehicles.

However, one of the more obvious heterogeneities in the operating environment, the differential truck speed limit, has been the subject of only limited investigation. This type of speed limit restricts trucks to travel at speeds less than those posted for passenger cars. It is based on the premise that, from any given speed, a truck requires longer to decelerate to a lower speed or to brake to a complete stop than does a passenger car. The supposed objective of differential speed limits for trucks is to increase highway safety by making the differences in braking distance more compatible. However, there is valid concern that enforced speed differentials may cause a higher number of vehicular conflicts, and thus increase the likelihood of certain types of accidents (e.g., truck rear-end collisions).

Despite some confusion on the relative merits of differential speed limits, approximately one-half of the eastern states have enacted legislation providing for lower statutory speed limits for vehicles that exceed a certain size or weight. The research reported in this paper was undertaken to evaluate the effect of the existing differential truck speed limit on Interstate highways in Maryland and to examine the operational implications of altering this limit.

PREVIOUS RESEARCH

Most previous research on the topic of speed-safety relationships has concluded that higher speeds are more closely related to increased accident severity than to accident causation. The effect of speed on severity is especially noticeable at speeds greater than 50 mph, which are characteristic of limited-access facilities. The results of several studies on this topic are summarized in a 1969 report (6), which indicates that the ratio of persons injured to persons killed decreases sharply at higher speeds. Similarly, the National Safety Council reports that the improper driving category "speed too fast" is recorded for a higher percentage of fatal accidents than for either injury or all accidents. Several researchers have noted an increase in the percentage of single-vehicle accidents at higher speeds, as opposed to rear-end and angle collisions, the dominant types of collision at lower speeds

On the basis of intuition as well as numerous research studies, there is reason to believe that the relationship of speed to accidents is most closely related to variation from the average speed. Accident involvement rates are highest for vehicles traveling much less than the average speed and are lowest for a 10-mph speed range in the vicinity of the mean speed of travel. A plot of involvement rate as a function of variation from average speed produces a concave upward curve, with a minimum value in the vicinity of the average speed (7, 8). All of the reports stress that the relationship is not necessarily causative but that it could reflect the operating strategies of the drivers or other factors that were not investigated.

Several studies have focused on the operating speeds of trucks. Some of the work concerned with truck speeds on vertical grades has been used by the American Association of State Highway Officials to establish warrants and design criteria for truck climbing lanes. Other studies have found that accident rates are higher on grades than on tangent, level sections. Similar characteristics were found for truck accidents, especially rear-end collisions on upgrades. A recent study of truck climbing lanes presents data that indicate a fourfold increase in accidents when truck speeds are reduced to 10 mph below the average speed of traffic and a 16-fold increase with a 20-mph reduction.

Related work has sought to establish the relationship between truck operation and highway capacity. The currently accepted procedures for the determination of freeway capacity, as outlined in the Highway Capacity Manual (4), rely on passenger car equivalency factors. These factors depend on the percentage and length of upgrade and the percentage of trucks in the traffic stream. The effect of trucks on capacity is due primarily to their inability to maintain speed on extended upgrades, although a small effect is noted on level sections simply because of their larger size. With the exception of steep or lengthy downgrades where trucks are required to use low gears, the Manual notes that the effect of trucks on downgrades is minimal. The effect of truck speeds on operating economy has also been examined, and results indicate that the increased operating cost at higher speeds over long hauls may be balanced by savings in such areas as driver wages, fleet size, and terminal consolidation.

A recent study (3) of the differential truck speed limits on Interstate facilities in Virginia found that, at most study sites, the 85th percentile truck speed was in excess of the posted limit, although at only one site was the speed greater than 60 mph. Partially on the basis of this study the truck speed limit in Virginia was increased from 50 mph (differential speed limit of 65/50 at time of study) to 55 mph, and subsequently to 60 mph.

STUDY ACTIVITIES

Site Selection

To accomplish the objectives of the study, we selected site locations on the basis of posted speed limits (differential and equal), geometric design, and operational characteristics. A total of 55 sections of roadway in Maryland, some with two-directional studies, were analyzed on Interstate, U.S., and state routes, resulting in 84 study site locations (Fig. 1). The study sites were grouped according to their posted speed limits.

Along with the selection of representative study sites, it was necessary to determine an adequate sample size for data collection. The determination of sample size is dependent on the desired accuracy of the sample and the size of the sample standard deviation. Research indicated that the standard deviation is normally in the range of 5 to 10 mph with the higher value on steep upgrades. With a standard error of 0.5 mph and an estimated standard deviation of 7 mph, a sample size of approximately 200 vehicles (trucks) was required. Preliminary data analysis verified the adequacy of this sample size.

Data Collection

Based on other research, it was felt that data needs existed in four primary areas. The major data requirement was accurate spot speed information for trucks and (separately) for cars at each of the study sites. Also, traffic volume at the sites was an essential data factor. The accident experience, both at the study sites and on the total state-administered system, was of prime importance. Finally, the geometric characteristics for each site were needed. These four sets of data—speed, volume, accidents, and geometrics—formed the basis of the analysis.

The speeds of free-flowing cars and trucks were measured with a radar unit and simultaneously marked on a graphic recorder. Differentiations between passenger car and truck speeds were made on the recorder output, and at the same time traffic volume and vehicle classification data were recorded. Accident data for the years 1970 and 1971 and copies of the geometric design plans for each of the sites were furnished by the Maryland State Highway Administration.

Speed data for the trucks and cars were used to construct histograms showing the speeds of vehicles at each directional site. These served as an input to a computer program that performed the calculations to determine central tendency and dispersion parameters for the speeds of trucks, passenger cars, and a combined sample of trucks and cars at each site. The program also prepared a graph of the cumulative speed distributions.

Data Analysis

As a reference point for special speed studies, a study site was chosen where speeds could safely be measured from roadside and overpass vantage points. The site was also used for nighttime, wet-weather, and follow-up studies. Because of its high level of geometric design and its frequency of "free-flowing" traffic, I-95 at the Van Dusen Road overpass (site 051 NB) was selected for this purpose.

Initial data analysis was undertaken to determine whether the presence of roadside observers on an Interstate facility affected vehicular speeds. Analysis of extensive speed measurements indicated that both the mean and the 85th percentile truck speeds were statistically equivalent for roadside and overpass observations, whereas the mean passenger car speed showed a slight (1.5-mph) reduction for roadside observations. Because the primary emphasis in this study was truck speeds, we decided that overpass observations might be more desirable but that roadside observations would yield similar results and could be employed when necessary.

One of the most obvious findings in the examination of the data from all of the sites was the generally low level of compliance with the posted speed limit for both passenger cars and trucks. One criterion frequently used in determining and posting speed limits is the 85th percentile speed, although most references strongly recommend that consideration be given to design and control features and to accident experience. The assumption is that most drivers will exercise good judgment in the selection of their travel speed, especially if they are aware of the nature of the environment in which they are driving. In the case of limited-access facilities, however, the maximum speed limit is normally specified by state statute.

Table 1 gives the results of a comparison of passenger car and truck compliance with their respective posted speed limits. (Study sites with unusual geometric conditions, including long, steep grades or sharp horizontal curvature, are not included.) Of the 55 sites listed, the percentage of truck compliance exceeds the percentage of passenger car compliance at approximately half of the sites. At 12 of the sites (all on upgrades), more than 85 percent of trucks comply with the limit, while none of the sites exhibited a level of passenger car compliance in excess of 85 percent. For all the sites listed in Table 1, average truck compliance with the posted speed limit is 58 percent, whereas average car compliance is 56 percent. For the 17 sites with a 60/60 limit, the average level of truck compliance with the posted limit is 73 percent, while at sites with a differential speed limit, only 51 percent of the trucks are in compliance. The difference is statistically significant.

It should be noted that the sites with a 70-mph posted limit for cars tend to be of a higher level of geometric design, both in fact and as perceived by the driver. To further examine this point, we selected two representative sites for comparison: site 055 SB, on a rural Interstate facility that has a 70/60 speed limit and representative geometric and operational characteristics for sites with differential speed limits, and site 251 SB, located on a suburban Interstate section that has a 60/60 speed limit and is representative of sites without differential limits. Although the geometric design features at these two sites are similar, their environmental settings and the nature of the contiguous roadways are sufficiently different that the truck driver is inclined to choose a slightly higher operating speed at site 055 SB. The cumulative truck speed distributions at these two sites are shown in Figure 2.

Figure 1. Study site.

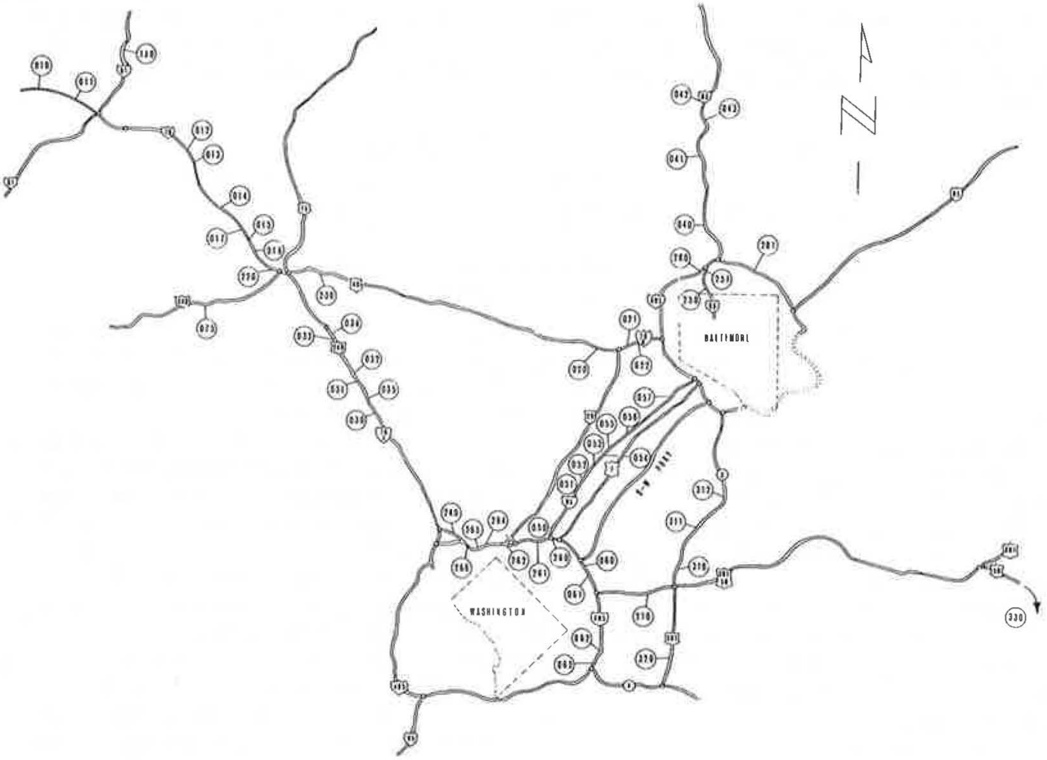


Table 1. Some variables used in speed-accident analyses.

Site	Speed Limit	Percentage of Compliance		Site	Speed Limit	Percentage of Compliance	
		Truck	Car			Truck	Car
261 WB[a]	60/60	97	46	033 SB	70/60	54	69
250 NB[a]	60/60	97	54	042 SB	70/60	53	79
031 SB[a]	70/60	96	83	055 SB	70/60	52	35
262 EB[a]	60/60	95	65	281 WB	60/60	49	30
262 WB[a]	60/60	94	60	060 WB	70/60	49	76
035 NB[a]	70/60	92	75	280 EB	60/60	47	34
220 WB[a]	60/60	91	39	110 SB	65/60	44	65
240 NB[a]	60/60	89	43	020 EB	70/60	41	69
063 SB[a]	70/60	88	60	061 EB	70/60	41	71
054 SB[a]	70/60	87	66	014 EB	70/60	40	71
030 SB[a]	70/60	87	84	110 NB	65/60	40	50
210 WB[a]	60/60	86	44	056 NB	70/60	39	39
011 EB[a]	70/60	79	60	042 NB	70/60	38	81
250 SB[a]	60/60	77	47	220 EB	60/60	38	11
055 NB[a]	70/60	74	44	011 WB	70/60	36	53
034 NB[a]	70/60	72	60	041 SB	70/60	36	66
251 SB[a]	60/60	71	30	010 WB	70/60	34	58
056 SB[a]	70/60	68	49	054 NB	70/60	34	38
021 EB[a]	70/60	67	65	030 NB	70/60	33	71
281 EB[a]	60/60	65	52	032 NB	70/60	33	54
041 NB	70/60	65	77	014 WB	70/60	30	59
240 SB[a]	60/60	65	32	022 WB	70/60	29	65
261 EB[a]	60/60	63	32	052 NB	70/60	29	50
020 WB	70/60	62	69	052 SB	70/60	29	57
051 NB	70/60	62	66	063 NB	70/60	24	57
260 WB[a]	60/60	61	30	062 NB	70/60	24	55
210 EB[a]	60/60	58	34	010 EB	70/60	22	51
051 SB	70/60	58	72	Average	60/60	73	40
				Average	70/60	51	62

[a] Sites where truck compliance is greater than passenger car compliance.

It has been well established that vehicular speeds are affected by roadway geometrics including grades and horizontal curvature. To examine the influence of geometrics on the Maryland Interstate System required that the study sites be divided into the following categories:

Type	Characteristic
Level	Grades between -0.75 and +0.75 percent
Downgrades	Grades between -7.0 and -0.8 percent
Upgrades	Grades between +0.8 and +4.5 percent
Special	Horizontal curvature > 5 deg
Other	Variable conditions

Analysis of truck speed data as a function of roadway geometrics is discussed in a separate report (2). Specifically, it was found that existing AASHO standards for the construction of speed profiles are deficient in that they actually represent the operation of the second percentile truck rather than the assumed 15th percentile truck.

To approximate the results, for each site, of a spot speed study that would not have distinguished among vehicle types, we calculated a combined sample after the speed parameters had been separately calculated for trucks and passenger cars. Analysis of these modified data verifies the minimal effect of grades on passenger car operation. However, the averages of the 85th percentile truck speeds for upgrade, level, and downgrade sections were respectively 57.5, 64.2, and 67.0 mph. This is a clear indication that, under certain conditions, a sizable percentage of trucks that are legally limited in Maryland to 60 mph are capable of maintaining higher speeds.

Another important factor related to truck performance on limited-access highways is the weight-horsepower ratio. Existing highway design criteria assume a 400:1 ratio, that is, a weight of 400 lb/unit (net) horsepower. It was clear from the initial studies that trucks maintaining higher speeds (>50 mph) on sustained grades were single-unit trucks rather than fully loaded tractor trailer units. In fact, heavily loaded vehicles were occasionally found to be traveling at less than 20 mph, and the 15th percentile truck speeds at five sites were less than 25 mph. Data supplied by the American Trucking Association indicate that 550 hp would be required for a fully loaded (73,280-lb) unit to maintain a speed of 50 mph on a sustained 3 percent grade. Trucks with this power rating are not commercially available and, if they were, would be expensive to operate.

In an attempt to relate the operating characteristics of trucks to their weight, a special study was conducted. Because there are no truck weighing stations on the Maryland Interstate System, it was necessary to use a site on US-301. The site is located on a slight (-0.4 percent) downgrade approximately 1 mile north of the weigh station. Trucks were identified as they passed the study site, and the speeds of free-flowing vehicles were recorded. At the weigh station, the weight and axle configuration of each truck were recorded. Regression techniques were used to determine the existence of possible relationships between truck weight and speed and between percentage of legal loaded weight and speed. Although the general trend for both analyses at this site indicates that heavier trucks travel at higher speeds, the average difference between the lightest and the heaviest trucks was small, and no statistically significant relationship could be found. Others have used an alternate approach that employs portable roadside weighing scales and the measurement of truck speeds in advance of the weighing station. This approach may provide better information on truck speed-weight relationships.

SPEED AND ACCIDENTS

There are several manners in which vehicular speeds can be considered important in accident causation. Speed, per se, is closely related to stopping distance, the braking distance being a function of the square of vehicular speed. Even a comparatively small difference in speed can have a significant effect, as evidenced by the fact that the stopping distance at 65 mph is 15 percent greater than the stopping distance at

60 mph. It has also been noted that speed differences contribute to accidents, especially rear-end and lane-changing accidents. In the case of trucks, these speed differences may be brought about by an inability to maintain speed, as on an upgrade, or by enforced differential truck speed limits.

The analysis of speed and accidents undertaken as part of this study was based on two separate criteria: the measured values for truck speed, primarily the mean and 85th percentile truck speed, and the speed difference, obtained by subtracting the mean truck speed from the mean car speed (or the 85th percentile truck speed from the 85th percentile car speed). Preliminary analysis indicated a high degree of correlation between the mean and 85th percentile truck speeds and between the speed difference variables obtained by using these parameters.

At only one of the study sites (on a -7.0 percent grade) was the 85th percentile truck speed greater than the 85th percentile car speed. At three sites, the mean truck and car speeds were equivalent. For all of the remaining study sites, the previously defined speed difference was a positive value. Whereas the speed differences at one site were as high as 26 mph, it was found that the (mean) speed difference was equal to or less than +4 mph at more than half of the study sites. Of the 53 sites with a posted differential truck speed limit, more than two-thirds have a mean speed difference of +6 mph or less and an 85th percentile speed difference of +8 mph or less. All of the sites that have an 85th percentile difference in excess of +12 mph are on upgrades of 3.0 percent or steeper. In other words, the actual speed difference is normally less than the posted 10-mph differential except in those cases where trucks cannot maintain their speeds because of roadway geometrics.

Three interrelated approaches were used in an attempt to determine the relative operating safety at locations with different speed characteristics. Initially, analysis was conducted on a site basis, with consideration being given to all accidents (on the main roadway) within 1 mile on either side of the study site. Second, comparisons were also made among groups of sites with similar characteristics. Because of the indecisiveness of the results of these first two procedures, a third type of analysis was undertaken for extended subsections of Interstate routes.

Approximately 3,700 accidents (total for 1970 and 1971, two directional) occurred within the set of 1-mile sections surrounding the study sites. As shown in Figure 3, trucks were involved in 15.5 percent of all accidents on roadway sections with a differential speed limit and 19.5 percent of all accidents on roadway sections without a differential speed limit. The figure indicates that the major portion of the difference in percentage of truck-involved accidents is found in the category of truck-passenger car accidents.

The average Interstate accident rate for 1970-1971 in Maryland was found to be 1.7 accidents per million vehicle-miles (acc/MVM). In the vicinity of the study sites on the Interstate System, the 2-year accident rates were grouped as follows:

Accident Rate (acc/MVM)	Percentage of Study Sites
>0.55	24
0.55 to 1.10	29
1.10 to 1.70	31
>1.70	16

It was noted that, at the study sites with an accident rate greater than 1.7 acc/MVM, the percentage of truck-involved accidents is less than the average percentage of truck involvement for all sites. On the other hand, all of the sites with an above-average percentage of truck involvement have comparatively low accident rates. Neither the accident rate nor the percentage of truck-involved accidents was significantly different from the average at those Interstate study sites that were initially chosen on the basis of a high number of truck accidents.

The investigating officer's accident report, which forms the basis for the Maryland computerized accident record system, provides for the citing of a "probable cause" of

Figure 2. Truck speed distributions at two representative sites.

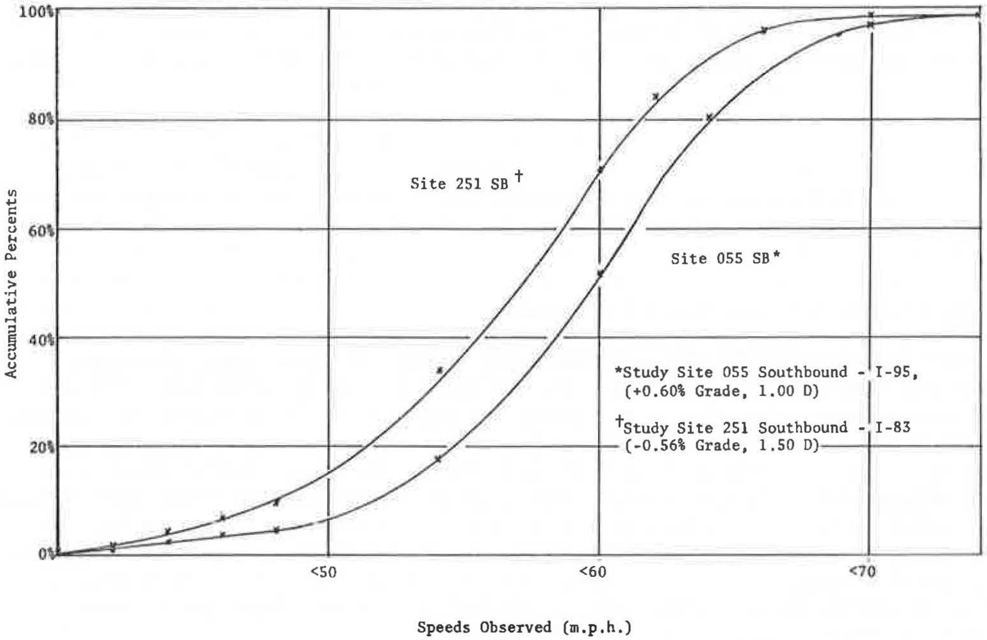
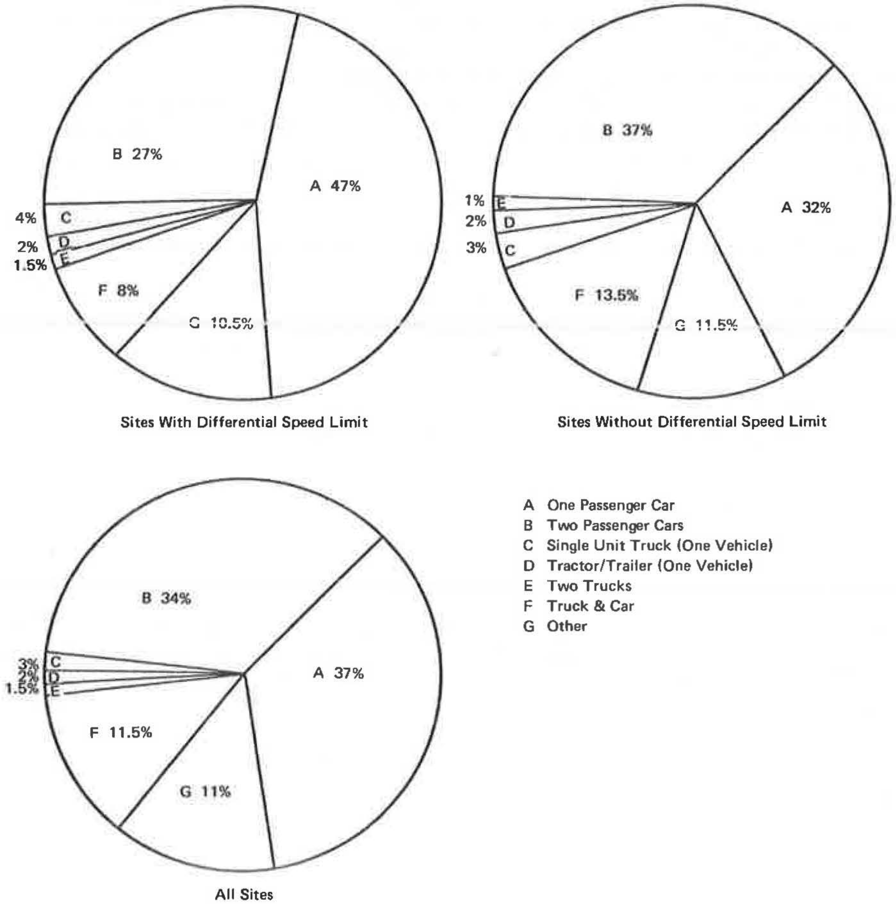


Figure 3. Summary of accident characteristics near study sites (not including ramp accidents).



Sites With Differential Speed Limit

Sites Without Differential Speed Limit

All Sites

the accident. From these data it was found that, in approximately 12.9 percent of all truck-involved accidents on Interstate facilities, the cited probable cause was "driving at speeds considered unsafe for existing conditions" or "other speeds and exceeding 60 mph." The probable cause "failing to reduce speed" was attributed to trucks in an additional 7.6 percent of the accidents in which they were involved. The total of 20.5 percent is less than the percentage of all rural accidents in which the National Safety Council (1) reports that speed was the element of improper driving involved. In other words, despite the comparatively poor level of compliance with posted speed limits, vehicular speed is not cited as a probable cause in an unusual portion of truck-involved accidents in Maryland.

On a site-by-site basis, no significant relationship could be found among vehicular speed, mean or 85th percentile speed differences, total accident rate, and percentage of truck involvement. This was due in part to the gross nature of the previously discussed analysis, which did not distinguish direction of travel or manner of collision. In addition, the small number of reported accidents at some sites precluded in-depth analysis. To circumvent some of these problems, we identified 17 extended sections of highway in the vicinity of each study site. Each of these designated sections was characterized by relatively uniform operational and design characteristics. When speed data were available at two or more sites within a section, they were averaged and assumed to be representative of operation on the section. All analysis was done by direction of travel. Six traffic volume variables, 19 speed parameter variables, and 21 accident and accident rate variables were calculated for each section. The variables that proved to be important in subsequent analyses are given in Table 2.

A standard statistical program processed the data and calculated a correlation matrix for all variables and multiple regression equations for a set of 12 dependent variables. Because of their obvious interdependence, several of the variables exhibited a high degree of correlation. For example, truck mean speed and truck 85th percentile speed had a correlation of +0.97. The majority of the 1,058 correlation coefficients were low (between -0.6 and +0.6). Given the sample sizes involved, it is possible to determine at the 5 percent level of significance that a relationship does exist between two variables if their correlation coefficient is less than -0.35 or greater than +0.35. However, the specification of a mathematical relationship between the variables is misleading unless the absolute value of the correlation coefficient is somewhat higher.

A detailed examination of the speed and accident variables led to the following conclusions.

1. The 85th percentile speed of the combined sample and the rate of dry-weather truck rear-end accidents are negatively correlated (-0.67).
2. None of the truck speed variables is significantly related to the number or rate of truck accidents.
3. The speed difference variables are negatively correlated with truck and total accident rates.
4. The presence of a posted differential speed limit is not significantly related to any of the accident or accident rate variables.

The absence of a linear relationship between speed and accident variables is in general accord with the results of other research. Part of the difficulty in identifying such a relationship is the nature in which the data are quantified. Extreme values for either speed or accident variables at one or two sites can noticeably affect the analysis of the data and disguise relationships among the parameters. This difficulty was relieved in part through the use of a rank order comparison, in which the truck speeds in each direction on the 17 extended sections were arranged in ascending order and assigned a rank value, with 1.0 assigned to the lowest speed and 34.0 assigned to the highest speed. Ranks were assigned in a similar manner to an accident rate variable for these sections. A Spearman rank order correlation coefficient was used to evaluate the nature of the relationship between the rankings of the speed and accident variables. When this procedure was used at the 5 percent level of significance, a negative relationship was found between the ranks of the truck mean speed and the rate of truck involvement. On the basis of these data, hypotheses that the rate of truck accident involvement is independent of truck speed, or that it increases with higher truck speeds, must be rejected. When truck speed is used as a single dependent variable, however, it is not possible to develop a reliable predictive equation for the rate of truck accident involvement.

Because variables other than truck speed can have an influence on truck accidents, an attempt was made to determine the possible existence of a multiple-independent variable equation that would adequately predict accident variables. Using a standard computer program, we performed a set of multiple regression analyses with accidents and accident rates as the dependent variables. As might be expected, the regression equations developed to estimate truck accidents primarily depend on a measure of truck travel.

Attempts to use multiple regression techniques to predict rates of total and passenger car accidents did not produce useful results. However, multiple regression equations for the rate of truck involvement and the rate of all dry-weather accidents yielded multiple correlation coefficients between 0.67 and 0.70. Given the number of degrees of freedom, these equations are on the borderline of statistical significance at the 5 percent level.

It was possible to develop statistically significant equations to predict three of the truck accident rate variables. In order of increasing significance these were the rate of dry-weather truck accidents (RDTAC), the rate of dry-weather truck accident involvement (RDTINV), and the rate of dry-weather rear-end truck accidents (RDTRED). A five-variable equation for RDTAC is given by

$$\begin{aligned}\text{RDTAC} = 6.548 - 0.391(\text{ASD}) - 0.094(\text{CM}) + 0.306(\text{A85})\\ -0.264(\text{C85}) - 3.112(\text{TPER})\end{aligned} \tag{1}$$

The multiple correlation coefficient R for this equation is 0.60, but the F-ratio test indicates that the equation is significant at the 0.05 level. This result must be interpreted carefully by considering the following points:

1. The possibility should not be ruled out that other variables not included in the regression model could better explain the rate of daytime truck accidents and
2. Relationships among the independent variables may be such that they are not truly independent.

The second point is relevant to the regression equation shown above. Data given in Table 3 indicate the high degree of positive correlation between the combined sample mean speed (CM) and the passenger car 85th percentile speed (A85), between the combined sample 85th percentile speed (C85) and A85, and between C85 and CM. Because of the high degree of correlation, these pairs of variables are not independent, and the assumptions underlying the development of the equation are not met. As a result, Eq. 1 should not be used for predictive purposes.

The following five-variable equation was developed for the prediction of RDTINV. It has a multiple R of 0.66 and is significant at the 0.01 level:

$$\begin{aligned}\text{RDTINV} = 2.290 - 0.136(\text{TSD}) - 0.057(\text{T85}) + 0.052(\text{APC})\\ -2.513(\text{TPER}) + 0.242(\text{DUMMY})\end{aligned} \tag{2}$$

Table 4 indicates that the correlation coefficients between the terms in this equation are comparatively low and that they can be assumed to be independent. The equation indicates that increases in the truck standard deviation (TSD), the truck 85th percentile speed (T85), and/or percentage of trucks (TPER) are associated with a reduction in the rate of dry-weather truck accident involvement. It can also be seen that RDTINV increases slightly with the percentage of passenger cars in the modified 10-mph pace (APC). The existence of a differential speed limit, included in the equation through the use of the variable DUMMY, has a positive effect on RDTINV.

The relative importance of the independent variables in this equation becomes clear only when the actual values of these variables are inserted into the equation. The mean values for the five variables used in Eq. 2 show the following relationship:

$$T85 > APC > TSD > DUMMY > TPER$$

From a practical viewpoint, the variables that can be most easily changed are DUMMY and T85. Eliminating the posted differential limit would change DUMMY from 1 to 0, whereas the level of enforcement of speed regulations will affect the value of T85. The other three variables, TSD, APC, and TPER, are characteristics of the traffic that are difficult to control.

Two of the extended study sections had an 85th percentile truck speed of 69.0 mph. In comparison with the averages for all sites, the values for TSD on these two sections were slightly higher than average, the values for APC were less than average, and the values for TPER were approximately equal to the average. Both sections currently have a 70/60 differential speed limit. When the data values from these sites are used in predictive Eq. 2, the estimated value for RDTINV is significantly less than for all sites. Actual accident data from these sites are in good agreement with the results of this equation.

The best multiple linear regression equation developed from the data was for the prediction of the rate of dry-weather rear-end truck accidents (RDTRED). This equation, which has a multiple R of 0.78 and a very high F-ratio significant at the 0.01 level, is given by

$$\begin{aligned} RDTRED = 5.467 + 0.069(TM) + 0.290(CSD) - 0.149(C85) \\ -4.414(TPER) + 0.001(MVM) \end{aligned} \tag{3}$$

Data given in Table 5 indicate that, with the possible exception of a negative relationship between TM and combined sample standard deviation (CSD), the variables in this equation are independent. The mean values for the five variables used in this equation show the following relationship:

$$MVM > C85 > TM > CSD > TPER$$

When modified by the appropriate coefficients in Eq. 3, the term that contributes the most (in absolute value) to the equation is C85, followed in descending order by TM, CSD, and TPER. The variable MVM has a very small impact on the results obtained by using the equation. Data from the 34 study sites were inserted into the equation, and the predicted values of RDTRED were compared to the actual rates at these sites. Figure 4 shows this comparison. It can be seen from the figure that 70 percent of the predicted values are within ±0.2 acc/MVM of the actual rate.

For fixed values of TPER and MVM, tests with the model indicated a general reduction in values for RDTRED with increasing speed values. This is in accord with research conducted by others (8). However, it is interesting to note that none of the speed difference variables was important enough to be included in the five-variable regression equation. Previous research has concluded that speed difference is an important parameter in accident causation, but the regression equations developed by using the data collected in this study indicate that other parameters may be more important in predicting truck accident rates on limited-access facilities.

The models described in Eqs. 2 and 3 are statistically significant. This means that to a reasonable extent they are capable of explaining the variation in their respective dependent variables by changes in traffic volume and speed parameters. For the data collected in this study, they are the most consistent models that can be developed. It should be remembered, however, that other variables not included in the model could be of equal or greater importance. This is especially important in this type of model, which attempts to predict a discrete occurrence (i.e., an accident or a specific type of accident) on the basis of general factors related to roadway operation, such as speed and travel. The speed measurements taken at each site are representative of the operation at a particular location and are reproducible, as verified by follow-up studies at several sites. However, it is difficult to identify the speed characteristics of a particular vehicle involved in an accident. A truck involved in an accident at a particular site could have been traveling at the 10th, 50th, or 85th percentile speed.

Table 2. Vehicle compliance with posted speed limits.

Variable	Description	Average
TM	Truck mean speed (mph)	56.4
TS	Truck speed standard deviation (mph)	6.7
T85	Truck 85th percentile speed (mph)	62.8
ASD	Passenger car speed standard deviation (mph)	6.1
A85	Passenger car 85th percentile speed (mph)	70.4
APC	Modified passenger car 10-mph pace[a] (percent)	62.2
CM	Combined sample mean speed (mph)	63.3
CSD	Combined sample standard deviation (mph)	7.2
C85	Combined sample 85th percentile speed (mph)	69.9
DELMTA	Passenger car mean speed minus truck mean speed (mph)	8.3
DEL85A	Passenger car 85th percentile speed minus truck 85th percentile speed (mph)	7.5
TPER	Percentage of trucks in traffic stream	14.4
MVM	Mean 1970-71 travel (MVM)	104.4
DUMMY	0 = no differential speed limit; 1 = differential speed limit	0.8
RTINV	Rate of truck involvements	1.7
RDTAC	Rate of dry-weather[b] truck accidents	0.9
RDTINV	Rate of dry-weather[b] truck involvements	0.9
RDTRED	Rate of dry-weather[b] truck rear-end accidents	0.5
RDACC	Rate of dry-weather[b] total accidents	0.6

Note: 27 other variables were included in the study analyses.

[a] Percentage of vehicles in 10-mph range immediately below the 85th percentile speed.

[b] Dry pavement surface and driver condition reported normal.

Table 3. Correlation coefficients for variables in RDTAC model.

Variable	ASD	A85	CM	C85	TPER
ASD	1.00	0.56	0.34	0.56	0.47
A85		1.00	0.94	0.99	0.37
CM			1.00	0.95	0.33
C85				1.00	0.40
TPER					1.00

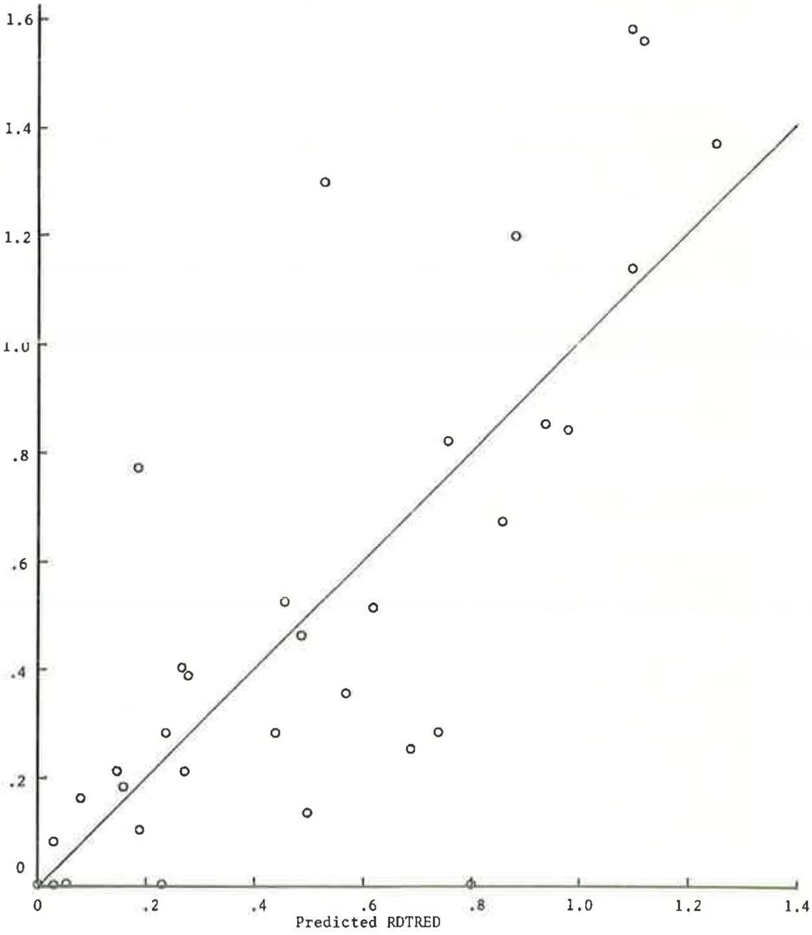
Table 4. Correlation coefficients for variables in RDTINV model.

Variable	TSD	T85	APC	TPER	DUMMY
TSD	1.00	-0.71	-0.26	-0.30	0.29
T85		1.00	-0.01	0.41	0.17
APC			1.00	-0.48	-0.54
TPER				1.00	0.11
DUMMY					1.00

Table 5. Correlation coefficients for variables in RDTRED model.

Variable	TM	CSD	C85	TPER	MVM
TM	1.00	-0.73	0.47	0.40	0.12
CSD		1.00	0.23	-0.03	-0.17
C85			1.00	0.40	0.01
TPER				1.00	-0.17
MVM					1.00

Figure 4. Predicted versus actual rates of dry-weather truck rear-end accidents.



The only input that exists with respect to this point is the "probable cause" of the accident cited on the investigating officer's report. These data indicated a less than average amount of speed-related "probable causes" in truck-involved accidents on Interstate facilities.

There is reason to believe that accidents that occur at higher speeds are more severe in terms of both injuries and costs. This is reflected in part by the fact that, for all Interstate truck accidents, the ratio of injuries to accidents is 0.52; whereas, for those Interstate truck accidents with speed factors cited as the "probable cause," the ratio is 0.66 injury/accident. However, a study of costs for truck-involved accidents on the Interstate System produced some conflicting results. The data base for this analysis was the investigating officer's estimate of "total amount of damage." It was found that, for two-vehicle and multiple-vehicle truck-involved accidents on Interstate highways, total estimated amount of damage was $200 to $400 higher for those accidents with speed factors cited as the "probable cause" than for all truck-involved accidents on Interstate highways. However, for single-vehicle truck accidents, which constitute approximately 30 percent of the truck accidents on Interstate highways, the reverse situation was found, with the damage costs for those accidents with speed cited as a "probable cause" estimated at $200 less than for all single-vehicle truck accidents. Although it is possible that there are errors in the estimated damage costs, it is hypothesized that these would be common to all truck accidents and would thus not significantly affect this comparison.

CONCLUSIONS

The study supplements other research in finding that the geometric design of the facility is clearly an important factor in determining vehicular speed and that one geometric element, percentage of grade, has a minimal effect on passenger car speeds, but a much larger effect on limiting truck speeds. It was found that, on level or downgrade sections, however, trucks are capable of traveling faster than the 60-mph speed to which they are limited in the state of Maryland. Prior to the recent speed limit reductions brought about by the fuel shortage, 22 states posted truck speed limits greater than 60 mph on Interstate highways and 13 of these states posted speed limits at 70 mph or more (5).

It was determined that the actual speed difference was less than the 10-mph posted speed limit differential except on upgrades. The existence of a posted differential speed limit that contributed to an actual speed differential was not found to be related to truck accidents.

Regression techniques were used to develop models for the prediction of truck accident rates on limited-access facilities. Although it was not possible to develop a statistically significant equation for the prediction of the rate of truck involvement in accidents, a rank order correlation test suggested that lower rates of truck involvement are associated with higher truck speeds. Two significant models were developed for the prediction of the rate of truck accidents that occur on dry pavement. Both the models, for RDTINV and RDTRED, indicate that lower truck accident rates can be expected with higher truck speeds.

Although the models do a good job of indicating trends, a discrete event such as an accident is very difficult to predict. Thus, even though the predicted rates obtained by using the models may differ to some extent from actual observed values, the trends suggested by the models are valid. It would be unwise to conclude, however, that other factors, such as vehicle defects, vehicle (truck) weight, roadway design, or driver characteristics, have no effect on the occurrence of truck accidents. The unexplained variance in the models might be reduced if such factors were included in the analysis.

It would be contrary to intuition to suggest that the trends indicated by the models would continue to extremely high speeds. Only four of the 84 directional sites had an 85th percentile truck speed as high as 69 mph, and less than 3 percent of all measured truck speeds were in excess of 70 mph. Though removal of the differential truck speed would result in higher truck speeds on some roadway sections, it would not bring about increased speeds on extended upgrades, where truck speeds are limited by the vehicles' capabilities.

On the basis of this study, it was recommended that the truck speed limit be temporarily increased to 70 mph on two segments of the Interstate System in Maryland. The results of this change, including the effects on both speeds and accidents, were to be examined. The recent fuel shortage and the subsequent reduction in posted speed limits for all vehicles have made the implementation of this recommendation unfeasible at the present time.

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