Research Report
KTC-91-4

EVALUATION OF HIGHWAY GEOMETRICS RELATED TO LARGE TRUCKS

by

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in cooperation with

Kentucky Transportation Center
Commonwealth of Kentucky

and

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COMMONWEALTH OF KENTUCKY
TRANSPORTATION CABINET
FRANKFORT, KENTUCKY 40622

DON C. KELLY, P.E.
SECRETARY
AND
COMMISSIONER OF HIGHWAYS

BRERETON C. JONES
GOVERNOR

March 9, 1992

Mr. Paul Toussaint
Division Administrator
Federal Highway Administration
300 West Broadway, P.O. Box 526
Frankfort, Kentucky 40602

Dear Mr. Toussaint:

Subject: Implementation Statement (KYHPR-90-130) Research Study "Evaluation of Highway Geometrics Related to Large Trucks:

The subject study resulted in two research reports. These reports are KTC-91-2, "Development of Turning Templates for Various Design Vehicles," and KTC-91-4, "Evaluation of Highway Geometrics Related to Large Trucks."

The plotting information developed as part of KTC-91-2 will be used to prepare turning templates that can be used in the design process. The turning templates include nine design vehicles including the 48-foot and 53-foot semitrailer.

The accident analysis developed as part of KTC-91-4 gives a procedure which can be used to identify and investigate locations which have a high number and rate of truck accidents. The general accident statistics given in this report can be used in the investigation of high-accident locations to identify factors which may have contributed to the accident problem. The summary of information obtained from the review of literature can be used as a guide when determining the appropriate criteria to use in formalizing truck access criteria.

Sincerely,

Glen Kelly, P.E.
Acting State Highway Engineer

EXECUTIVE SUMMARY

As a result of recent provisions to allow longer and wider trucks to operate on some classes of highways, there has been increased concern regarding highway safety in general. Many of the concerns are associated with the operation of larger trucks on highways that may not be geometrically or structurally adequate to accommodate these vehicles. With the information currently available on Kentucky's uniform police accident report form, it is possible to identify specific truck types. This information will permit accumulation of data for detailed accident analyses.

One objective of this study was to determine the extent of highway safety and geometric problems associated with larger trucks using Kentucky's highways. The accident analysis involved both a general analysis of all truck accidents statewide as well as the identification of specific high-accident locations. A second objective was to identify criteria which can be used in identifying roadway sections that cannot safely accommodate large trucks.

The accident analysis given can be used to investigate locations which have a high number and rate of truck accidents. Critical accident numbers and rates for truck accidents were calculated based on the various combinations of highway system, truck classification, and volume. Specific locations having high numbers and accident rates were identified and locations with the highest critical rate factors are listed. Site inspections were conducted at selected high-accident locations.

General accident statistics related to trucks were summarized. This information can be used in the investigation of the high-accident locations to identify factors which may be contributing to the accident problem.

The summary of information obtained from the review of literature can be used as a guide when determining the appropriate criteria to use in formalizing truck access criteria. An annotated bibliography was prepared for 75 references which dealt with the general subject of highway geometrics related to large trucks. Information in these references that dealt with truck access criteria and design considerations was summarized and classified in several general factors that should be used as truck access criteria. For example, several references gave recommendations concerning lane width and horizontal curvature appropriate for highways that allowed large truck traffic.

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16. Abstract

One objective of this study was to determine the extent of highway safety and geometric problems associated with larger trucks using Kentucky's highways. The accident analysis involved both a general analysis of all truck accidents statewide as well as the identification of specific high-accident locations. A second objective was to identify criteria which can be used in identifying roadway sections that cannot safely accommodate large trucks.

The accident analysis given can be used to investigate locations which have a high number of truck accidents. The general accident statistics related to trucks can be used in the investigation of the high-accident locations to identify factors which may be contributing to the accident problem.

The summary of information obtained from the review of literature can be used as a guide when determining the appropriate criteria to use in formalizing truck access criteria. For example, several references gave recommendations concerning lane width and horizontal curvature appropriate for highways that allowed large truck traffic.

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Either all truck accidents or accidents involving combination trucks only were used in the rate calculations. The percentage of trucks on various types of highways were used to estimate truck volumes. This allowed rates to be calculated in terms of total traffic volume as well as in terms of truck volume. The highways on the designated truck network (DTN) were identified. Rates were calculated for the total highway system as well as the DTN.

Additional data concerning trucks were coded beginning in 1987. This included such information as number of trailers and truck length. An analysis of the characteristics of truck accidents was performed using accident data from 1987 through 1989.

Critical accident numbers and rates for truck accidents were calculated based on the various combinations of highway system, truck classification, and volume. Specific locations having high numbers and accident rates were identified. Site inspections were conducted at selected high-accident locations.

TRUCK ACCESS CRITERIA

A review of literature was conducted to identify information available to address the subject of highway geometrics related to large trucks. Specific attention was directed to identify truck access criteria and design considerations.

RESULTS

TRUCK ACCIDENT ANALYSIS

A summary of the number of truck accidents occurring each year from 1985 through 1989 on the total highway system is given in Table 1. The highest number of about 15,000 occurred in 1985. The number has remained fairly constant with an average of slightly over 11,000 for 1986 through 1989. The number of accidents involving trucks on highways with a known route number, mile points, and traffic volume is given in Table 2. Accidents are further classified as either all trucks or combination trucks only or the total highway system or the DTN.

A detailed computer summary for all accidents involving a truck was obtained for a three-year period (1987 through 1989). Starting in 1987, additional information was coded on the accident report providing data about any truck involved in an accident. This information included whether the truck was a single unit or combination, the number of trailers, the number of axles, and the length and width of the truck.

INTRODUCTION

Highway geometric problems related to accommodation of large trucks were compounded with enactment of the Surface Transportation Act of 1987 (STAA) which prohibited states from enforcing length limitations of less than 48 feet for semitrailers of combination vehicles. An overall vehicle width of 102 inches was also permitted on any segment of the Interstate System and any other qualifying Federal-aid highway. In addition, the Kentucky Transportation Cabinet has established length limitations of 53 feet for semitrailers for combination vehicles operating on highways designated as the Increased Dimension-Twin Trailer System (IDTT). For the vehicles having increased dimensions, regulations were adopted to designate highways on which they could operate in Kentucky. Included were the Interstate System and much of the Federal-Aid Primary System. The regulations also included a provision for a limit of traveling five miles off the designated network for the purpose of attaining reasonable access to terminals and other necessary facilities.

As a result of these provisions to allow longer and wider trucks to operate on some classes of highways, there has been increased concern regarding highway safety in general. Many of the concerns are associated with the operation of larger trucks on highways that may not be geometrically or structurally adequate to accommodate these vehicles. The question of reasonable access up to five miles off the designated system presents particular problems in some cases where highway geometrics decrease significantly on secondary routes. With the information currently available on the police accident report form, it is possible to identify specific truck types. This information will permit accumulation of data for detailed accident analyses.

One objective of this study was to determine the extent of highway safety and geometric problems associated with larger trucks using Kentucky's highways. The accident analysis involved both a general analysis of all truck accidents statewide as well as the identification of specific high-accident locations. A second objective was to identify criteria which can be used in identifying roadway sections that cannot safely accommodate large trucks.

PROCEDURE

TRUCK ACCIDENT ANALYSIS

Included in the information coded for each traffic accident is a code for the vehicle type. Accidents involving either a single unit or combination truck were identified using this code. Accidents for the time period of 1985 through 1989 were identified for the purpose of determining accident rates.

grades) and during darkness than the other truck types. The percentage of instances in which there was overturning was much higher for double trailers trucks. Double trailer trucks had the highest percentage of accidents on interstates while single unit trucks had the highest percentage on collector streets. The truck type having the highest percentage of hazardous cargo was the double trailer. Single unit trucks were involved in more accidents at intersections. Double trailer trucks had a higher percentage of same direction sideswipe accidents and accidents in which overturning was involved.

Most combination trucks had five axles while most single unit trucks had two axles. Most single unit trucks were less than 30 feet in length. The highest percentage of single trailer trucks were 50 to 59 feet in length while the highest percentage of double trailer trucks were 60 to 69 feet in length.

The accident data were used to classify the most common types of truck by vehicle make (Table 5). When all trucks are considered, the most common vehicle make is Ford followed by International. When only combination trucks are considered, the most common vehicle make is International followed by Freightliner and Mack.

Average accident rates were determined for one-mile sections and 0.3-mile spots for the various categories of truck category (all trucks or combination trucks only), highway system (total system or DTN), and volume (total volume or truck volume). Average rates for a one-mile section are given in Table 6 and rates for a 0.3-mile spot are given in Table 7. Additional accident rate data for the various highway types are given in Appendix A. This information includes total mileage, average daily traffic, total accident rate, injury accident rate, and fatal accident rate.

To identify high-accident locations, those locations having a critical number of accidents must be identified. The critical number of accidents is calculated considering the average number of accidents for a specific category and a specified level of statistical significance. Critical numbers of accidents for all trucks or combination trucks on either the total highway system or the DTN are given in Table 8.

Accident rates for locations meeting the critical number of accidents criteria were calculated and compared to critical accident rates. Critical accident rates were calculated using the average accident rate for the specific type of highway, the exposure (million vehicle miles for sections and million vehicles for spots), and a level of statistical significance. Locations having an accident rate above the critical accident rate were identified. A critical rate factor (CRF) was determined for each location. The CRF is the ratio of the critical rate to the accident rate for a given location. Lists of locations having the highest CRF for each of the various

Information concerning accidents in which a truck was involved is summarized in Table 3. Trucks were classified as either single unit or combination and, for combination trucks, there was an additional classification into one or two trailers. In the three-year period, there were 15,317 accidents involving a single-unit truck and 18,226 accidents involving a combination truck. Of those in which the number of trailers was known, 13,663 accidents involved a combination truck with one trailer while 238 involved a combination truck with two trailers. As may be seen, the number of accidents involving a combination truck with two trailers was small.

The severity of accidents involving combination trucks was slightly higher than that for single-unit trucks. This would be partially explained by the higher percentage of accidents involving combination trucks on the high-speed interstate highways. This was especially true for double trailer combinations.

When directional analysis was used to analyze type of accident, several differences were observed. Some of the differences could be related to the differences in travel by type of highway. More single-unit truck accidents occurred at intersections. Double trailer accidents more often were single vehicle accidents involving a fixed object, running off the road, or overturning.

There was a much higher percentage of combination truck accidents during darkness (especially during late night hours). There were more truck accidents during weekdays than on weekends.

The percentage of double trailer accidents during snow and ice conditions was much higher than either single unit or single trailer accidents.

Accidents involving combination trucks (especially double trailer trucks) occurred more often on "non-straight and level" roadway sections compared to single unit trucks.

When contributing factors were summarized, the percentages were relatively consistent by truck type except for the high percentage of double trailer accidents in which slippery surface was listed.

Accident data were also summarized by the type of truck involved in the accidents (Table 4). From 1987 through 1989, there were 16,674 single unit trucks, 14,623 combination trucks with one trailer, and 246 combination trucks with double trailers involved in accidents.

The percentage of double trailer trucks involved in an accident on snow or ice was much higher than for other truck types. Double trailer trucks were also involved in a higher percentage of accidents on curves and grades (especially were right angle accidents. The speed limit on US 641 is 55 mph. This accident history would be common for trucks at rural, high-speed intersections controlled by a traffic signal.

An urban, one-mile location was in Jefferson County on KY 61 between mile points 12.0 and 12.9 (Preston Street in Louisville). Of the 68 accidents at this location, 30 accidents (44 percent) were angle while 17 accidents (17 percent) were rear end. A 0.3-mile spot identified in this one-mile section was between mile points 12.1 and 12.3 (at the intersection of Preston Street and Broadway). Preston Street is a one-way couplet with several intersections in downtown Louisville. Several of the intersections (including the intersection with Broadway) are controlled by traffic signals.

Another one-mile, urban location was in Bourbon County on US 68X between mile points 1.1 and 2.0. Of the 52 accidents at this location, 21 accidents (40 percent) involved a parked vehicle. This route is a business route through Paris. This section of the route consists of a one-way couplet through downtown Paris. Parking is allowed through most of this section. Also, during the site visit, several trucks were parked in the street loading or unloading their goods. These factors would explain the high percentage of accidents involving a parked vehicle.

One urban, 0.3-mile spot was on Interstate 64 in Jefferson County between mile points 4.8 and 5.0. Of the 73 accidents at this location involving a combination truck, 46 (63 percent) were same direction sideswipe accidents. This section of urban interstate is between interchanges with I 65 and Third Street in Louisville. There would be a lot of lane changing and merging which would explain the high percentage of same direction sideswipe accidents.

Another urban, 0.3-mile spot was on Interstate 65 in Jefferson County between mile points 130.5 and 130.7. This location is at the interchange with Interstate 264 (Watterson Expressway). Of 153 accidents at this location, 76 (50 percent) were rear end. The high volume at this location is shown by noting that slightly over half of the rear-end collisions involved a stopped vehicle. The second most common accidents at this location were same direction sideswipe accidents with 33 percent of the accidents classified into this category. The lane changing and merging would explain the high number of sideswipe accidents. The number of accidents at this spot has decreased from 44 in 1985 to 18 in 1989 with the construction of additional lanes to relieve the congestion.

A different type of accident was noted at another urban, 0.3-mile spot on US 31W between mile points 21.0 and 21.2 in Louisville. Of 72 accidents at this location, 46 percent involved a single vehicle collision with a fixed object. Specifically, the fixed object was identified as a bridge. There is a railroad overpass at this location with a low clearance marked for 14 feet.

categories that were analysed are given in Tables 9 through 20. The sections and spots that were identified were scattered across the state and represented a wide range in types of roads. The high-accident locations identified ranged from high volume urban interstates to very low volume rural roadways. Information concerning the truck accidents occurring at these locations were obtained as part of the analysis procedure. This would allow an investigation of the types of accidents occurring and factors contributing to the accidents.

An accident analysis was conducted at a sample of some of the high-accident locations that were identified. Both one-mile sections and 0.3-mile spots were analysed to determine if a pattern could be identified. The locations were selected to represent a range in types of roads and location across the state.

Among several locations selected for detailed accident analysis was a one-mile section of KY 979 in Floyd County between mile points 13.4 and 14.3. Of the 29 accidents at this location, 16 accidents (55 percent) were opposite direction sideswipe accidents. Nine of the sideswipe accidents were in a 0.3-mile spot (from mile points 13.7 to 13.9) which was identified as a high-accident spot. Also, 15 accidents (52 percent) occurred during wet weather. An inspection of this location resulted in identification of a series of very sharp curves having restricted sight distance. The high-accident spot was at one of the sharp curves. The pavement width was about 20 feet with a painted centerline and edge lines. Curve warning signs with speed advisory plates as well as chevrons were present at several locations (including the high-accident spot). Numerous coal trucks were observed during the site visit.

Another rural, one-mile location was in Floyd County on KY 1020 between mile points 6.9 and 7.8. Of the 15 accidents at this location, 9 (60 percent) were opposite direction sideswipe accidents and 7 (47 percent) were wet weather accidents. This highway was a relatively narrow roadway with no pavement markings and no warning signs. There were several very sharp curves with restricted sight distance at the high-accident location with several coal trucks observed.

Another high-accident location in Floyd County was in Prestonsburg at the intersection of US 23 and KY 1428. This was a high-accident spot (between mile points 16.7 and 16.9 on US 23). This is a T-intersection which is signalized. There are four lanes on each approach. A high volume of combination trucks was noted. There were 32 accidents at this 0.3-mile spot of which 12 (38 percent) were angle accidents and 12 were rear-end accidents.

One 0.3-mile spot was in rural Marshall County on US 641 between mile points 1.0 and 1.2. This is at the intersection with KY 80 with right of way controlled by a traffic signal. Of the 8 accidents at this location, 6 (75 percent) highest number (13) was in Fayette County followed by 11 in Jefferson County and 7 in Floyd County.

TRUCK ACCESS CRITERIA

The primary focus in this area concerned a review of the literature in the general area of highway geometrics related to large trucks with emphasis on truck access criteria and design considerations. An annotated bibliography was prepared for 75 references which dealt with the general subject of highway geometics related to large trucks. This annotated bibliography is contained in Appendix B.

The references given in Appendix B are listed in Appendix C in alphabetical order. Information in these references that dealt with truck access criteria and design considerations was summarized. This information is given in Table 21 with the reference number listed corresponding to the number given in Appendix C.

The information given in Table 21 can be classified in several general factors that should be used as truck access criteria. Following is a list of the factors that were identified.

1. lane width;
2. shoulder width, type, and condition;
3. stopping sight distance;
4. passing sight distance;
5. sight distance at intersections;
6. sight distance at railroad crossings;
7. bridge widths;
8. horizontal curvature and superelevation;
9. slope and length of vertical curves;
10. accident history;
11. traffic volume;
12. composition of traffic;
13. roadway width;
14. abutting land use;
15. length of route;
16. number of lanes;
17. roadside design features;
18. design of intersections (turning maneuvers);
19. ramp design;
20. bridge load limits and clearance;
21. pavement condition and skid resistance;
22. parking; and
23. capacity.

One rural, 0.3-mile spot was on Interstate 75 in Boone County between mile points 175.2 and 175.4. This site was at the interchange with KY 338 and many of the accidents were related to the ramp. There were 15 rear-end accidents and 10 accidents involving a same direction sideswipe. Five accidents were single vehicle accidents involving the truck overturning.

Using all truck accidents, total highway system, and total traffic volume as criteria, 140 one-mile sections were identified as having a critical rate factor (CRF) of 2.0 or above. When these sections were summarized by county, the highest number (30) occurred in Jefferson County. The following counties in order of number of locations were Pike (11), Floyd (10), Boone (10), Harlan (7), and Martin (6). Several of these counties were in the southeastern part of Kentucky with the truck accidents related to the coal truck traffic.

Using all truck accidents, total highway system, and total traffic volume as criteria, 412 0.3-mile spots were identified as having a critical rate factor of 2.0 or above. The counties having the highest numbers of locations were similar to those identified when using one-mile sections. The highest number (84) occurred in Jefferson County followed by Kenton County (23), Floyd County (21), Pike County (21), Fayette County (20), Bullitt County (18), and Boone County (16). When considering only the DTN, the number of spots having a CRF of 2.0 or above was 150. The ordering of distribution by county was somewhat altered with the highest number of spots in Jefferson County (31) followed by Bullitt County (16), Fayette County (14), and Boone, Floyd, and Kenton Counties with 8 spots.

The distribution of counties was similar when only combination trucks were considered. Using the total system, there were 124 one-mile sections identified having a CRF of 2.0 or above. The highest number (11) occurred in Jefferson County followed by Floyd County (8), Martin County (7), and Boone County (6). There were 453 0.3-mile spots having a CRF of 2.0 or above. The highest number (57) was in Jefferson County followed by Fayette County (30), Boone (20), Bullitt (19), and Kenton (19). There were 429 0.3-mile spots on the DTN having a CRF of 2.0 or above. The highest number (44) was in Jefferson County followed by Fayette County (34), Kenton County (21), Boone County (20), Christian County (15), and Floyd County (15).

The distribution of counties was also similar when only truck volume was considered. Using the total system, there were 184 one-mile sections identified having a CRF of 2.0 or above. The highest number occurred in Jefferson County (29) followed by Floyd County (19) and Pike County (11). There were 417 0.3-mile spots with a CRF of 2.0 or above. The highest number was in Jefferson County (73) followed by Floyd County (39), Pike County (22), and Kenton County (16). There were 126 0.3-mile spots on the DTN having a CRF of 2.0 or above. The

TABLE 1. TOTAL NUMBER OF TRUCK ACCIDENTS ON TOTAL HIGHWAY SYSTEM

	NUMBER OF ACCIDENTS
1989	11,566
1988	11,110
1987	10,815
1986	11,642
1985	15,259
TOTAL	60,392

TABLE 2. SUMMARY OF ACCIDENTS INVOLVING TRUCKS ON HIGHWAYS HAVING A KNOWN ROUTE NUMBER, MILE POINTS, AND TRAFFIC VOLUME

	TOTAL ACCIDENTS			
	TRUCK AND HIGHWAY SYSTEM CATEGORIES			
YEAR	ALL TRUCKS TOTAL SYSTEM	ALL TRUCKS DTN*	COMB. TRUCKS** TOTAL SYSTEM	COMB. TRUCKS DTN
1989	7,243	3,275	3,963	2,142
1988	7,004	3,233	4,078	2,225
1987	7,012	3,233	4,063	2,232
1986	6,857	3,119	2,957	1,656
1985	9,892	4,198	3,696	2,103
TOTAL	38,008	17,058	18,757	10,358

* Designated truck network.

** Combination trucks.

The issue of how to allow for truck turning requirements and pedestrian movements at signalized intersections was investigated. The literature was reviewed and selected states were contacted to determine if special provisions are made to accommodate the turning requirements of large trucks at signalized intersections when pedestrian movements must also be accommodated. The optimum design to accommodate the turning movement of large trucks would require large turning radii and this would be in conflict with the optimum design for pedestrians in which more narrow road widths would be preferred. Neither the review of literature nor the state contacts revealed any specific guidelines that are being used to address this conflict. Pedestrian facilities such as refuge islands are used. Rather than attempting to accommodate both pedestrians and trucks at a signalized intersection, there was an assortment of methods being used to minimize the conflict between pedestrians and traffic (including large trucks). These would include restricting turning movements at certain intersections, providing for pedestrian crosswalks at mid-block locations where road width is less, physically separating the vehicular and pedestrian traffic, and encouraging the development of businesses that would generate less pedestrian traffic on major arterials where there is heavy commercial traffic.

CONCLUSIONS

TRUCK ACCIDENT ANALYSIS

The accident analysis given can be used to investigate locations which have a high number of truck accidents. The general accident statistics related to trucks can be used in the investigation of the high-accident locations to identify factors which may be contributing to the accident problem.

TRUCK ACCESS CRITERIA

The summary of information obtained from the review of literature can be used as a guide when determining the appropriate criteria to use in formalizing truck access criteria. For example, several references gave recommendations concerning lane width and horizontal curvature appropriate for highways that allowed large truck traffic.

TABLE 3. COMPARISON OF ACCIDENTS INVOLVING TRUCKS (1987-1989 ACCIDENT DATA)

		Percent of Total			
		Type of Vehicle			
			Combination		
Variable	Category	Single-Unit Truck	One Trailer	Two Trailers	Unknown
Severity	Fatal	0.6	1.0	3.4	0.[illegible]
	Injury	16.0	16.5	19.7	16.[illegible]
Aid System	Rural				
	Interstate	2.2	11.1	34.9	3.[illegible]
	Arterial	10.7	15.8	8.4	11.[illegible]
	Collector	16.6	11.5	1.7	17.[illegible]
	Local	11.0	11.2	6.7	12.[illegible]
	Urban				
	Interstate	4.2	10.7	23.9	6.[illegible]
	Arterial	29.2	22.6	15.1	26.[illegible]
	Collector	4.6	2.9	1.7	4.1
	Local	11.0	5.8	2.9	9.[illegible]
	Parking Lot	10.7	8.5	4.6	7.[illegible]
Directional Analysis	Intersection				
	Angle	10.0	6.5	3.4	8.[illegible]
	Rear End	9.4	6.2	4.2	8.[illegible]
	Fixed Object	1.1	2.8	3.8	1.[illegible]
	Same Dir. Sideswipe	2.5	4.1	3.8	1.[illegible]
	All				
	Non-Intersection				
	Rear End	14.5	11.2	16.4	1[illegible]
	Same Dir. Sideswipe	6.9	11.5	16.4	[illegible]
	Opp. Dir. Sideswipe	7.3	5.1	1.3	[illegible]
	Driveway Related	3.4	2.5	1.3	[illegible]
	Parked Vehicle	7.9	4.3	4.2	[illegible]
	Fixed Object	5.2	7.6	6.7	[illegible]
	Ran off Road	2.8	3.5	5.0	[illegible]
	Overturned in Road	1.5	2.3	5.5	[illegible]
	Parking Lot	15.1	17.0	10.9	1[illegible]

TABLE 3. COMPARISON OF ACCIDENTS INVOLVING TRUCKS (1987-1989 ACCIDENT DATA (continued)

		Percent of Total			
		Type of Vehicle			
			Combination		
Variable	Category	Single-Unit Truck	One Trailer	Two Trailers	Unknown
	Bridge	0.1	0.2	1.3	0.1
	Interchange Ramp	0.2	0.5	0.8	0.3
	Train	0.1	0.2	0.0	0.1
Time of Day	Midnight-3:59 am	2.4	6.9	15.5	2.8
	4:00 am - 7:59 am	8.1	11.5	21.8	8.0
	8:00 am - 11:59 am	30.8	25.4	16.4	31.9
	Noon - 3:59 pm	34.6	28.0	15.1	34.7
	4 pm - 7:59 pm	18.2	17.8	15.5	16.9
	8 pm - 11:59 pm	5.9	10.5	15.5	5.7
Day of Week	Sunday	5.8	5.7	6.7	4.8
	Monday	17.4	18.0	10.9	18.6
	Tuesday	17.2	18.0	17.2	17.2
	Wednesday	17.1	17.6	18.9	17.5
	Thursday	17.1	17.7	23.1	17.2
	Friday	18.0	15.9	15.1	18.0
	Saturday	7.4	6.4	8.0	6.7
Number of Vehicles	One	15.7	24.8	29.4	16.8
	More than one	84.3	75.2	70.6	83.2
Land Use	Rural	35.3	40.1	51.4	39.3
	Business	41.4	39.3	21.4	36.5
	Industrial	1.2	2.0	1.4	1.7
	Residential	14.5	6.1	1.8	14.0
	School	1.4	0.6	0.9	1.4
	Park	0.3	0.1	0.5	0.2
	Private Property	3.4	3.6	4.5	3.2
	Limited Access	2.5	8.1	18.2	3.7

TABLE 3. COMPARISON OF ACCIDENTS INVOLVING TRUCKS (1987-1989 ACCIDENT DATA) (continued)

		Percent of Total			
		Type of Vehicle			
			Combination		
Variable	Category	Single-Unit Truck	One Trailer	Two Trailers	Unknown
Contributing Factors	Unsafe speed	3.4	3.5	6.7	3.4
	FTYROW	8.1	9.5	8.4	7.8
	Follow too closely	2.8	2.4	0.8	3.3
	Improper passing	0.6	0.5	0.4	0.5
	Disregard traffic ctrl	1.2	1.0	1.3	0.9
	Improper turn	2.3	4.1	1.3	2.8
	Alcohol	1.4	0.4	0.0	0.8
	Fell asleep	0.4	0.9	1.7	0.2
	Driver inattention	24.9	26.8	21.4	23.7
	Distraction	1.1	1.2	1.3	1.2
	Disability	0.1	0.1	0.4	0.1
	Defective brakes	3.0	1.9	2.1	3.3
	Lighting defective	0.6	0.3	0.0	0.6
	Steering defective	0.3	0.3	0.0	0.4
	Tire problem	0.8	1.1	2.9	0.9
	Tow hitch defective	0.2	0.3	1.7	0.2
	Load problem	1.1	2.1	1.3	1.8
	Animal	0.8	1.6	0.4	0.7
	Glare	0.5	0.4	0.0	0.3
	View obstruction	3.5	3.7	2.5	3.2
	Debris in road	0.4	0.6	1.3	0.4
	Defective shoulder	0.5	0.5	0.0	0.7
	Hole/bump	0.2	0.2	0.0	0.2
	Road construction	0.6	1.1	1.3	1.1
	Improperly parked	0.6	0.5	0.4	0.6
	Fixed object	0.4	0.5	0.0	0.2
	Slippery surface	5.7	5.3	18.5	5.1
	Water pooling	0.3	0.3	0.0	0.3

TABLE 3. COMPARISON OF ACCIDENTS INVOLVING TRUCKS
(1987-1989 ACCIDENT DATA) (continued)

		Percent of Total			
		Type of Vehicle			
			Combination		
Variable	Category	Single-Unit Truck	One Trailer	Two Trailers	Unknown
Road Surface Cond.	Dry	78.9	79.4	67.1	80.3
	Wet	16.9	16.0	14.8	15.2
	Snow/Ice	3.7	4.2	18.1	3.7
	Slush	0.2	0.2	0.0	0.2
	Muddy	0.3	0.2	0.0	0.5
Weather	Clear	66.5	64.9	50.4	67.4
	Raining	11.8	11.8	12.6	11.2
	Snowing	1.7	3.0	10.9	2.9
	Fog/Smog/Smoke	0.6	0.8	0.4	0.7
	Sleet/Hail	0.3	0.5	2.5	0.3
	Cloudy	19.1	19.0	23.1	17.5
Road Character	Straight & Level	61.7	59.6	50.2	59.7
	Straight & Grade	18.4	20.2	29.1	19.0
	Straight & Hillcrest	3.3	2.7	2.5	3.0
	Curve & Level	7.6	7.5	8.0	7.9
	Curve & Grade	7.6	9.2	8.9	9.1
	Curve & Hillcrest	1.4	0.9	1.3	1.3
Light Condition	Daylight	85.4	72.1	45.6	85.0
	Dawn	1.6	1.9	2.5	1.5
	Dusk	1.6	1.4	1.3	1.2
	Darkness-Lighted	5.4	10.2	18.6	6.1
	Darkness-Not Lighted	6.1	14.3	32.1	6.2
Speed Limit (mph)	35 or less	53.8	42.3	23.0	46.6
	40 to 45	11.9	9.8	7.4	12.5
	50 to 55	31.9	36.5	37.0	36.7
	Over 55	2.4	11.5	32.6	4.2

TABLE 4. COMPARISON OF CHARACTERISTICS OF ACCIDENTS BY TYPE OF VEHICLE (1987-1989 ACCIDENT DATA) (continued)

		Percent of Total			
		Type of Vehicle			
			Combination		
Variable	Category	Single-Unit Truck	One Trailer	Two Trailers	Unknown
Length (feet)	Less than 30	64.0			
	30 - 39	23.0	4.5		
	40 - 49	7.6	20.5		
	50 - 59	5.4	37.1	9.5	
	60 - 69		35.9	55.8	
	70 - 79		2.0	34.7	
Directional Analysis	Intersection				
	Angle	9.8	6.1	3.7	8.4
	Rear end	9.3	6.0	4.1	8.2
	Fixed object	1.1	2.6	3.7	1.5
	Same Dir. Sideswipe	2.5	3.9	3.7	3.3
	All	24.3	19.6	15.0	26.6
	Non-intersection				
	Rear end	14.7	11.2	15.9	13.6
	Same dir. sideswipe	7.0	11.0	17.1	8.5
	Opp. dir. sideswipe	7.5	5.1	1.2	7.2
	Driveway related	3.4	2.4	1.2	3.2
	Parked vehicle	7.8	5.5	4.5	7.3
	Fixed object	5.1	6.4	6.5	4.7
	Ran off road	2.9	3.3	4.9	3.0
	Overturned in road	1.5	1.9	5.3	2.0
	Parking lot	15.3	20.0	11.0	13.1

TABLE 4. COMPARISON OF CHARACTERISTICS OF ACCIDENTS BY TYPE OF VEHICLE (1987-1989 ACCIDENT DATA)

		Percent of Total			
		Type of Vehicle			
			Combination		
Variable	Category	Single-Unit Truck	One Trailer	Two Trailers	Unknown
Road Condition	Wet	17.0	15.8	14.6	15.1
	Snow-Ice	3.8	4.2	18.3	3.7
Road Character	Curve	16.4	17.1	18.3	18.2
	Grade	25.8	28.9	37.0	28.0
Light Condition	Dark	11.5	25.7	50.4	12.2
Overturn	Yes	5.2	6.6	15.4	6.5
Aid System	Rural				
	Interstate	2.3	11.0	35.0	3.8
	Arterial	10.8	15.3	8.1	11.5
	Collector	16.7	10.9	2.0	18.1
	Local	11.1	13.5	6.5	12.9
	Urban				
	Interstate	4.2	10.4	23.6	6.5
	Arterial	28.9	21.5	15.4	26.0
	Collector	4.5	2.7	1.6	4.1
	Local	10.7	5.5	2.8	9.2
	Parking Lot	10.8	9.2	4.9	7.8
Number of Axles	Two	61.8			
	Three	30.0	6.7		
	Four	8.1	10.6		
	Five		78.1	74.5	
	Six		4.0	20.0	
	More than six		0.8	5.5	
Hazardous Cargo	Yes	1.1	2.2	6.5	0.9

TABLE 6. AVERAGE ACCIDENT RATES FOR ONE MILE SECTION.

	AVERAGE ACCIDENT RATE (ACC/100 MVM)					
Type Truck System Volume	All Total Total	All DTN Total	All Total Truck	All DTN Truck	Combination Total Total	Combination DTN Total
Rural						
One-Lane	48.4	---	776	---	21.4	---
Two-Lane	27.0	28.2	324	253	12.5	15.9
Three-Lane	74.1	96.5	822	1,077	38.1	52.0
Four-Lane Divided (Non-I & P)	22.8	22.5	196	191	13.2	13.4
Four-Lane Undivided	30.7	27.2	305	258	15.9	14.6
Interstate	17.0	16.9	62	62	14.0	13.9
Parkway	17.3	17.2	125	146	13.6	14.4
ALL	23.9	20.7	178	106	13.0	14.5
Urban						
Two-Lane	46.2	56.6	883	863	18.3	28.2
Three-Lane	41.7	53.4	802	883	14.7	15.8
Four-Lane Divided (Non-I&P)	37.9	34.8	536	495	17.3	18.0
Four-Lane Undivided	56.6	54.5	1,004	870	17.9	22.4
Interstate	33.1	33.9	192	196	18.6	19.0
Parkway	23.7	21.5	194	176	18.7	16.8
ALL	41.2	36.8	432	291	18.1	19.5

TABLE 5. MOST COMMON TYPES OF TRUCK VEHICLE MAKES (1987-1988 ACCIDENT DATA)

	Number of Trucks	
Vehicle Make	**All Trucks**	**Combination Trucks**
Ford	4,802	1,499
International	4,301	2,862
Chevrolet	2,754	528
Mack	2,644	1,626
GMC	2,133	982
Freightliner	1,773	1,674
Kenworth	1,294	1,175
Peterbilt	1,167	1,077
White	912	798
Autocar	118	72

TABLE 8. CRITICAL NUMBER OF ACCIDENTS.

	CRITICAL NUMBER OF ACCIDENTS			
	0.3 MILE		1 MILE	
	RURAL	URBAN	RURAL	URBAN
All Truck Accidents Total Highway System	2	8	4	18
All Truck Accidents Designated Truck Network	4	11	8	27
Combination Truck Accidents Total Highway System	2	5	3	10
Combination Truck Accidents Designated Truck Network	3	7	7	17

TABLE 7. AVERAGE ACCIDENT RATES FOR 0.3 MILE SPOTS.

	AVERAGE ACCIDENT RATE (ACC/100 MVM)					
Type Truck System Volume	All Total Total	All DTN Total	All Total Truck	All DTN Truck	Combination Total Total	Combination DTN Total
Rural						
One-Lane	.145	---	2.33	---	.064	---
Two-Lane	.081	.085	0.97	0.76	.037	.048
Three-Lane	.222	.290	2.47	3.23	.114	.156
Four-Lane Divided (Non-I & P)	.068	.290	0.59	0.57	.040	.040
Four-Lane Undivided	.092	.082	0.91	0.77	.048	.044
Interstate	.051	.051	0.19	0.19	.042	.042
Parkway	.052	.052	0.37	0.44	.041	.043
ALL	.072	.062	0.53	0.32	.039	.043
Urban						
Two-Lane	.138	.170	2.65	2.59	.055	.085
Three-Lane	.125	.160	2.41	2.65	.044	.047
Four-Lane Divided (Non-I&P)	.114	.105	1.61	1.48	.052	.054
Four-Lane Undivided	.170	.164	3.01	2.61	.054	.067
Interstate	.099	.102	0.57	0.59	.056	.057
Parkway	.071	.065	0.58	0.53	.056	.051
ALL	.124	.111	1.29	0.87	.055	.058

TABLE 10. HIGH ACCIDENT LOCATIONS (1-MILE SECTIONS) CONSIDERING ALL TRUCK ACCIDENTS, DESIGNATED TRUCK NETWORK, AND TOTAL TRAFFIC VOLUME.

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Boyd	US 60	11.8	12.7	49	8,490	3.2	0.8	4.2
Floyd	US 23	16.6	17.5	66	21,450	1.7	0.4	4.1
Jefferson	I 65	136.0	136.9	273	84,000	1.8	0.4	4.0
Daviess	US 60	12.8	13.7	79	11,514	3.8	1.0	3.8
Marshall	US 641	8.0	8.9	28	7,219	2.1	0.7	3.1
Grayson	WK Pkwy	106.9	107.8	14	4,266	1.8	0.6	3.1
Allen	US 31E	9.1	10.0	13	2,250	3.2	1.1	3.0
Boone	I 75	175.1	176.0	65	48,800	0.7	0.3	2.9
Bullitt	I 65	116.0	116.9	46	31,600	0.8	0.3	2.9
Anderson	BG Pkwy	58.6	59.5	15	5,556	1.5	0.5	2.9
Jefferson	I 64	4.5	5.4	189	83,600	1.2	0.5	2.8
Adair	KY 55	10.4	11.3	19	4,750	2.2	0.8	2.7
Muhlenberg	WK Pkwy	57.9	58.8	12	4,076	1.6	0.6	2.7
Jefferson	I 65	130.0	130.9	186	85,500	1.2	0.4	2.6
Grayson	KY 259	12.1	13.0	12	3,010	2.2	0.8	2.6
Boone	KY 18	14.6	15.5	93	38,400	1.3	0.5	2.6
Christian	US 41A	3.9	4.8	29	13,195	1.2	0.5	2.5
Boyd	US 60	10.8	11.7	47	17,200	1.5	0.6	2.5
Lawrence	US 23	18.0	18.9	31	12,246	1.4	0.6	2.4
Floyd	US 23	15.6	16.5	36	19,800	1.0	0.4	2.3
Marshall	JP Pkwy	42.5	43.4	9	3,277	1.5	0.6	2.3
Bell	US 25E	1.4	2.3	33	11,765	1.5	0.7	2.3
Webster	Penn. Pky	62.1	63.0	12	5,912	1.1	0.5	2.2
Christian	I 24	85.2	86.1	16	9,414	0.9	0.4	2.2
Pulaski	US 27	16.4	17.3	53	23,525	1.2	0.6	2.2

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 9. HIGH ACCIDENT LOCATIONS (1-MILE SECTIONS) CONSIDERING ALL TRUCK ACCIDENTS, TOTAL HIGHWAY SYSTEM, AND TOTAL VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Jefferson	US 31W	21.1	22.0	194	22,763	4.7	0.6	7.7
Floyd	KY 979	13.4	14.3	29	1,930	8.2	1.1	7.4
Grant	KY 22	10.7	11.6	23	1,617	7.8	1.1	7.2
Jefferson	KY 61	12.0	12.9	68	5,918	6.3	0.9	7.1
Jefferson	KY 1631	1.0	1.9	74	8,420	4.8	0.8	6.0
Jefferson	US 31W	20.1	21.0	71	8,602	4.5	0.8	5.7
Boone	KY 338	0.0	0.9	29	3,197	5.0	0.9	5.5
Boone	US 42	13.6	14.5	43	4,482	5.3	1.0	5.4
Pike	KY 2061	2.1	3.0	11	518	11.6	2.2	5.4
Floyd	KY 2030	6.9	7.8	15	1,200	6.8	1.4	4.9
Jefferson	KY 61	11.0	11.9	45	5,156	4.8	1.1	4.4
Clay	US 421	15.4	16.3	14	1,290	6.0	1.4	4.4
Daviess	US 60	12.8	13.7	79	11,514	3.8	0.9	4.4
Harlan	US 421	3.8	4.7	11	872	6.9	1.6	4.2
Jefferson	KY 1631	4.3	5.2	83	16,316	2.8	0.7	4.2
Floyd	US 23	16.6	17.5	66	21,450	1.7	0.4	4.1
Boyd	US 60	11.8	12.7	50	8,490	3.2	0.8	4.1
Letcher	US 119	11.8	12.7	13	1,320	5.4	1.3	4.0
Scott	US 25	3.7	4.6	31	4,296	4.0	1.0	4.0
Jefferson	I 65	136.0	136.9	273	84,000	1.8	0.4	4.0
Fayette	US 25	13.2	14.1	110	26,300	2.3	0.6	3.8
Jefferson	KY 864	15.4	16.3	47	6,811	3.8	1.0	3.8
Bullitt	KY 44	12.9	13.8	19	2,975	3.5	0.9	3.8
Fayette	US 27	5.0	5.9	34	4,530	4.1	1.1	3.7
Hopkins	KY 813	9.7	10.6	5	183	15.0	4.1	3.7

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 12. HIGH ACCIDENT LOCATIONS (1-MILE SECTIONS) CONSIDERING ALL TRUCK ACCIDENTS, DESIGNATED TRUCK NETWORK, AND TRUCK VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Johnson	US 23	3.4	4.3	20	113	97.0	14.0	6.9
Floyd	US 23	16.6	17.5	66	1,636	22.1	4.1	5.3
Allen	US 31E	9.1	10.0	13	112	63.6	14.0	4.5
Boyd	US 60	11.8	12.7	49	527	51.0	11.3	4.5
Grayson	WK Pkwy	106.9	107.8	14	561	13.7	3.1	4.4
Adair	KY 55	10.4	11.3	19	245	42.5	9.8	4.3
Anderson	BG Pkwy	58.6	59.5	15	744	11.0	2.7	4.0
Daviess	US 60	12.8	13.7	79	712	60.8	15.7	3.9
Muhlenberg	WK Pkwy	57.9	58.8	12	536	12.3	3.2	3.9
Grayson	KY 259	12.1	13.0	12	207	31.8	9.0	3.5
Marshall	US 641	8.0	8.9	28	667	23.0	6.7	3.5
Marshall	JP Pkwy	42.5	43.4	9	375	13.2	3.8	3.5
Webster	Penn Pkwy	62.1	63.0	12	778	8.4	2.7	3.2
Allen	US 31E	7.7	8.6	9	116	42.5	14.0	3.1
Kenton	US 25	5.8	6.7	43	827	28.5	10.0	2.9
Jefferson	I 65	136.0	136.9	273	21,000	7.1	2.6	2.8
Campbell	US 27	20.6	21.5	35	403	47.6	18.1	2.6
Boone	KY 18	14.6	15.5	93	2,623	19.4	7.7	2.5
Boone	I 75	175.1	176.0	65	13,371	2.7	1.0	2.5
Bullitt	I 65	116.0	116.9	46	8,658	2.9	1.2	2.5
Floyd	US 23	15.6	16.5	36	2,009	9.8	3.9	2.5
Boyd	US 60	10.8	11.7	47	1,118	23.0	9.2	2.5
Pike	US 119	3.5	4.4	16	471	18.6	7.5	2.5
Fayette	KY 4	14.0	14.9	57	1,535	20.4	8.6	2.4
Christian	Penn Pkwy	11.6	12.5	8	644	6.8	2.9	2.3

* Accidents for five-year period of 1985 through 1989.
** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 11. HIGH ACCIDENT LOCATIONS (1-MILE SECTIONS) CONSIDERING ALL TRUCK ACCIDENTS, TOTAL HIGHWAY SYSTEM, AND TRUCK VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Floyd	KY 979	13.4	14.3	29	66	241	21.1	11.6
Jefferson	KY 61	12.0	12.9	68	257	145	15.1	9.6
Grant	KY 22	10.7	11.6	23	119	105	12.0	8.8
Jefferson	US 31W	21.1	22.0	194	1,412	75	9.3	8.1
Jefferson	US 31W	15.1	16.0	71	394	99	13.1	7.5
Jefferson	KY 1020	9.6	10.5	74	465	87	12.4	7.0
Jefferson	KY 1631	1.0	1.9	74	491	83	12.2	6.8
Jefferson	KY 61	11.0	11.9	45	154	160	25.0	6.4
Floyd	KY 2030	6.9	7.8	15	58	142	22.2	6.4
Johnson	US 23	3.4	4.3	20	113	97	15.9	6.1
Pike	KY 2061	2.1	3.0	11	33	183	30.5	6.0
Boone	US 42	13.6	14.5	43	262	90	15.0	6.0
Boone	KY 338	0.0	0.9	29	252	63	11.2	5.7
Floyd	US 23	16.6	17.5	66	1,636	22	4.2	5.3
Floyd	KY 1428	14.9	15.8	12	55	120	22.9	5.2
Kenton	KY 17	22.5	23.4	63	352	98	19.2	5.1
Scott	US 25	3.7	4.6	31	216	79	16.1	4.9
Floyd	KY 979	17.4	18.3	12	66	100	20.8	4.8
Jefferson	KY 61	10.0	10.9	24	148	89	18.7	4.8
Fayette	US 25	13.2	14.1	110	1,366	44	9.3	4.7
Jefferson	KY 1631	4.3	5.2	83	981	46	10.1	4.6
Jefferson	US 31W	21.0	21.0	71	804	48	10.6	4.6
Jefferson	KY 864	10.9	11.8	64	701	50	11.0	4.5
Grayson	WK Pkwy	106.9	107.8	14	561	14	3.1	4.4
Boyd	US 60	11.8	12.7	50	527	52	12.0	4.4

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 14. HIGH ACCIDENT LOCATIONS (1-MILE SECTIONS) CONSIDERING COMBINATION TRUCK ACCIDENTS, DESIGNATED TRUCK NETWORK, AND TOTAL VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Daviess	US 60	12.8	13.7	48	11,514	2.3	0.6	3.8
Boyd	US 60	11.8	12.7	26	8,490	1.7	0.4	3.5
Bell	US 25E	1.8	2.7	29	11,764	1.4	0.4	3.1
Lawrence	US 23	17.2	18.1	25	11,270	1.2	0.4	3.1
Henderson	US 41	16.7	17.6	67	40,257	0.9	0.3	3.0
Mason	US 62	16.9	17.8	27	14,134	1.0	0.4	3.0
Grayson	WK Pkwy	106.9	107.8	12	4,266	1.5	0.5	3.0
Boone	I 75	175.1	176.0	58	48,800	0.6	0.2	3.0
Boone	KY 18	14.6	15.5	62	38,400	0.9	0.3	2.9
Christian	US 41A	3.9	4.8	23	13,195	1.0	0.3	2.9
Allen	US 31E	9.3	10.2	9	2,221	2.2	0.8	2.9
Floyd	US 23	16.1	17.0	29	19,800	0.8	0.3	2.9
Jefferson	I 65	136.2	137.1	117	84,000	0.8	0.3	2.8
Bullitt	I 65	116.0	116.9	39	31,600	0.7	0.2	2.7
Laurel	US 25E	0.2	1.1	22	11,450	1.0	0.4	2.4
Boyd	US 23	10.2	11.1	17	11,100	0.8	0.4	2.4
Adair	KY 55	10.4	11.3	11	4,750	1.3	0.5	2.4
Pulaski	US 27	14.8	15.7	18	9,058	1.1	0.5	2.3
Union	US 60	16.3	17.2	14	7,945	1.0	0.4	2.2
Laurel	US 25E	1.2	2.1	19	11,123	0.9	0.4	2.2
Campbell	US 27	15.7	16.6	36	27,839	0.7	0.3	2.2
Lawrence	US 23	16.0	16.9	12	6,605	1.0	0.5	2.1
Kenton	I 75	189.5	190.4	82	80,883	0.6	0.3	2.1
Kenton	I 75	190.5	191.4	95	92,727	0.6	0.3	2.1
Lawrence	US 23	19.4	20.3	13	7,472	1.0	0.5	2.1

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 13. HIGH ACCIDENT LOCATIONS (1-MILE SECTIONS) CONSIDERING COMBINATION TRUCK ACCIDENTS, TOTAL HIGHWAY SYSTEM, AND TOTAL VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Floyd	KY 979	13.4	14.3	18	878	11.2	1.1	9.9
Boone	KY 338	0.0	0.9	25	3,197	4.3	0.6	7.5
Floyd	US 23	16.1	17.0	29	5,789	2.7	0.5	6.0
Logan	KY 79	11.5	12.4	11	686	8.8	1.6	5.7
Daviess	US 60	12.8	13.7	48	11,397	2.3	0.4	5.4
Letcher	US 119	11.8	12.7	11	1,280	4.7	0.9	5.1
Jefferson	KY 1631	1.0	1.9	36	8,420	2.3	0.5	5.0
Daviess	US 231	14.2	15.1	28	5,576	2.8	0.6	4.9
Hopkins	KY 813	9.7	10.6	5	183	15.0	3.2	4.7
Oldham	KY 53	5.6	6.5	11	1,583	3.8	0.8	4.5
Jefferson	US 31W	21.1	22.0	60	23,172	1.4	0.3	4.2
Martin	KY 292	2.5	3.4	5	310	8.8	2.2	4.0
Scott	US 25	3.7	4.6	19	4,296	2.4	0.6	4.0
Simpson	US 31W	1.9	2.8	18	6,130	1.6	0.4	3.8
Boyd	US 60	11.8	12.7	27	8,490	1.7	0.5	3.8
Lawrence	US 23	17.2	18.1	25	11,270	1.2	0.3	3.7
Henry	KY 157	1.4	2.3	6	742	4.4	1.2	3.5
Jefferson	US 31W	17.9	18.8	41	17,287	1.3	0.4	3.5
Floyd	US 23	15.0	15.9	16	5,429	1.6	0.5	3.4
Floyd	KY 2030	6.7	7.6	7	1,200	3.2	1.0	3.4
Hardin	KY 222	6.1	7.0	9	2,167	2.3	0.7	3.3
Bell	US 25E	1.8	2.7	29	11,764	1.4	0.4	3.3
Bourbon	US 68X	1.2	2.1	29	11,270	1.4	0.4	3.3
Allen	US 31E	9.3	10.2	9	2,221	2.2	0.7	3.3
Shelby	US 60	10.1	11.0	31	12,400	1.4	0.4	3.3

* Accidents for five-year period of 1985 through 1989.
** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 16. HIGH ACCIDENT LOCATIONS (0.3-MILE SPOTS) CONSIDERING ALL TRUCK ACCIDENTS, DESIGNATED TRUCK NETWORK, AND TOTAL TRAFFIC VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Jefferson	I 64	4.8	5.0	150	66,400	1.2	0.1	12.4
Floyd	US 23	16.7	16.9	32	5,789	3.0	0.3	10.4
Boone	I 75	175.2	175.4	49	45,300	0.6	0.1	9.8
Jefferson	I 65	130.5	130.7	153	85,500	1.0	0.1	9.8
Jefferson	I 264	12.1	12.3	113	91,100	0.7	0.1	6.8
Jefferson	I 65	136.4	136.6	101	84,000	0.7	0.1	6.6
Bullitt	I 65	116.6	116.8	23	32,950	0.4	0.1	6.3
Floyd	US 23	16.4	16.6	19	5,789	1.8	0.3	6.2
Anderson	BG Pkwy	58.6	58.8	15	5,556	1.5	0.3	5.7
Bullitt	I 65	116.9	117.1	20	34,300	0.3	0.1	5.3
Fayette	I 75	117.9	118.1	17	29,400	0.3	0.1	5.3
Jefferson	I 264	9.0	9.2	61	63,100	0.5	0.1	5.3
Grayson	WK Pkwy	106.9	107.1	12	4,266	1.5	0.3	5.0
Boyd	US 60	12.2	12.4	31	12,183	1.4	0.3	5.0
Jefferson	I 65	136.7	136.9	75	84,000	0.5	0.1	4.9
Bullitt	I 65	116.0	116.2	17	31,600	0.3	0.1	4.8
Bell	US 25E	2.1	2.3	29	11,765	1.4	0.3	4.7
Floyd	US 23	15.6	15.8	20	10,214	1.1	0.2	4.6
Muhlenberg	WK Pkwy	57.9	58.1	11	4,076	1.5	0.3	4.6
Jefferson	I 65	136.1	136.3	71	84,000	0.5	0.1	4.6
Jefferson	I 264	13.3	13.5	80	98,273	0.4	0.1	4.5
Campbell	US 27	16.4	16.6	30	14,167	1.2	0.3	4.5
Madison	I 75	80.8	81.0	13	29,945	0.2	0.1	4.2
Webster	Penn. Pky	62.5	62.7	11	5,912	1.0	0.3	3.9
Kenton	I 75	190.2	190.4	61	86,805	0.3	0.1	3.9

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 15. HIGH ACCIDENT LOCATIONS (0.3-MILE SPOTS) CONSIDERING ALL TRUCK ACCIDENTS, TOTAL HIGHWAY SYSTEM, AND TOTAL VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Jefferson	I 64	4.8	5.0	150	66,400	1.2	0.1	13.8
Jefferson	I 65	130.5	130.7	153	85,500	1.0	0.1	10.9
Floyd	US 23	16.7	16.9	32	5,789	3.0	0.3	10.4
Boone	I 75	175.2	175.4	49	45,300	0.6	0.1	9.8
Fayette	US 25	13.9	14.1	69	15,901	2.4	0.3	8.8
Jefferson	KY 1020	9.6	9.8	56	12,400	2.5	0.3	8.5
Jefferson	KY 1631	0.9	1.1	44	8,420	2.9	0.4	7.9
Floyd	KY 979	13.7	13.9	12	878	7.5	1.0	7.8
Jefferson	I 264	12.1	12.3	113	91,100	0.7	0.1	7.6
Grant	KY 22	11.0	11.2	15	[illegible]	3.6	[illegible]	[illegible]
Jefferson	I 65	136.4	136.6	101	84,000	0.7	0.1	[illegible]
Bullitt	KY 44	12.8	13.0	26	5,430	2.6	0.4	7.3
Boone	KY 338	0.0	0.2	25	5,620	2.4	0.3	7.2
[illegible]	[illegible]	[illegible]	[illegible]	23	32,950	0.4	0.1	6.3
Floyd	US 23	16.4	16.6	19	5,789	1.8	0.3	6.2
Jefferson	US 31W	20.1	20.3	34	8,358	2.2	0.4	6.2
Jefferson	KY 1020	12.7	12.9	48	15,763	1.7	0.3	6.2
Jefferson	US 31W	21.0	21.2	72	26,845	1.5	0.2	6.1
Jefferson	KY 864	11.4	11.6	44	13,956	1.7	0.3	6.0
Clark	US 60	4.6	4.8	27	6,218	2.4	0.4	6.0
Mason	KY 8	11.6	11.8	25	4,640	3.0	0.5	5.9
Jefferson	I 264	9.0	9.2	61	63,100	0.5	0.1	5.9
Jefferson	US 31W	21.6	21.8	56	10,500	[illegible]	[illegible]	[illegible]

* [illegible] five-year period [illegible] through [illegible]

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 18. HIGH ACCIDENT LOCATIONS (0.3-MILE SPOTS) CONSIDERING ALL TRUCK ACCIDENTS, DESIGNATED TRUCK NETWORK, AND TRUCK VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Floyd	US 23	16.7	16.9	32	775	22.6	2.6	8.8
Anderson	BG Pkwy	58.6	58.8	15	744	11.0	1.5	7.3
Grayson	WK Pkwy	106.9	107.1	12	561	11.7	1.8	6.6
Muhlenberg	WK Pkwy	57.9	58.1	11	536	11.2	1.8	6.1
Johnson	US 23	3.4	3.6	9	113	43.6	8.1	5.4
Floyd	US 23	16.4	16.6	19	775	13.4	2.6	5.2
Webster	Penn Pky	62.5	62.7	11	778	7.8	1.5	5.2
Jefferson	I 64	4.8	5.0	150	16,600	5.0	1.0	5.2
Marshall	JP Pkwy	42.5	42.7	8	375	11.7	2.3	5.1
Adair	KY 55	11.0	11.2	12	245	26.8	5.2	5.1
Boone	I 75	175.2	175.4	49	12,412	2.2	0.4	4.9
Boyd	US 60	12.2	12.4	31	814	20.9	4.4	4.8
Bell	US 25E	2.1	2.3	29	786	20.2	4.4	4.6
Jefferson	I 65	130.5	130.7	153	21,375	3.9	0.9	4.3
Fayette	US 27	8.4	8.6	25	694	19.7	4.7	4.2
Campbell	US 27	16.4	16.6	30	947	17.4	4.2	4.2
Floyd	US 23	15.6	15.8	20	1,384	7.9	2.0	4.0
Marshall	US 641	8.0	8.2	12	432	15.2	3.9	3.9
Nelson	BG Pkwy	33.1	33.3	9	1,047	4.7	1.3	3.7
Clay	US 421	16.8	17.0	11	528	11.4	3.1	3.7
Pulaski	US 27	15.4	15.6	20	605	18.1	4.9	3.7
Fayette	KY 922	1.1	1.3	23	822	15.3	4.4	3.5
Pulaski	US 27	16.6	16.8	39	1,823	11.7	3.4	3.5
Boone	KY 18	15.0	15.2	50	2,623	10.4	3.0	3.5
Metcalfe	Cum. Pky	27.3	27.5	4	158	13.9	4.0	3.4

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 17. HIGH ACCIDENT LOCATIONS (0.3-MILE SPOTS) CONSIDERING ALL TRUCK ACCIDENTS, TOTAL HIGHWAY SYSTEM, AND TRUCK VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Jefferson	KY 1020	13.0	13.2	37	227	89	7.9	11.3
Jefferson	KY 61	12.1	12.3	25	112	100	11.3	10.8
Fayette	US 25	13.9	14.1	69	881	43	4.5	9.5
Jefferson	KY 1020	12.7	12.9	48	549	48	5.4	8.9
Jefferson	KY 1631	0.9	1.1	44	491	49	5.6	8.7
Floyd	US 23	16.7	16.9	32	775	23	2.6	8.7
Jefferson	US 31W	20.1	20.3	34	334	56	6.6	8.4
Grant	KY 22	11.0	11.2	15	171	48	5.7	8.4
Floyd	KY 979	13.7	13.9	12	66	100	12.5	8.0
Jefferson	KY 1020	9.6	9.8	56	847	36	4.6	8.0
Bullitt	KY 44	12.8	13.0	26	412	35	4.6	7.6
Floyd	KY 979	14.0	14.2	11	66	91	12.5	7.3
Anderson	BG Pkwy	58.6	58.8	15	744	11	1.5	7.3
Jefferson	KY 864	11.4	11.6	44	701	34	4.9	7.0
Jefferson	KY 1020	11.4	11.6	23	227	56	7.9	7.0
Floyd	KY 2030	7.2	7.4	10	58	94	13.5	7.0
Boone	KY 338	0.0	0.2	25	444	31	4.4	7.0
Jefferson	KY 1747	0.6	0.8	48	851	31	4.6	6.8
Jefferson	US 31W	21.6	21.8	56	1,081	28	4.2	6.8
Grayson	WK Pkwy	106.9	107.1	12	561	12	1.8	6.6
Laurel	US 25	10.3	10.5	10	119	46	7.1	6.4
Oldham	KY 53	5.9	6.1	10	120	46	7.1	6.4
Clark	US 60	4.6	4.8	27	363	41	6.4	6.4
Jefferson	US 31W	21.0	21.2	72	1,744	23	3.6	6.3
Muhlenberg	WK Pkwy	57.9	58.1	11	536	11	1.8	6.1

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 20. HIGH ACCIDENT LOCATIONS (0.3-MILE SPOTS) CONSIDERING COMBINATION TRUCK ACCIDENTS, DESIGNATED TRUCK NETWORK, AND TOTAL VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Bell	US 25E	2.1	2.3	21	786	14.6	0.9	16.8
Daviess	US 231	14.6	14.8	19	379	27.5	1.7	16.4
Jefferson	I 64	4.8	5.0	73	16,600	2.4	0.2	16.1
Boyd	US 60	12.0	12.2	22	1,099	11.0	0.7	15.7
Boone	KY 18	15.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Henderson	US 41	16.8	17.0	26	2,415	5.9	0.4	13.7
Boone	I 75	175.2	175.4	43	12,412	1.9	0.1	13.6
Floyd	US 23	16.7	16.9	15	775	10.6	0.8	12.9
Mason	US 62	17.2	17.4	13	486	14.7	1.2	12.8
Jefferson	I 65	130.5	130.7	67	21,375	1.7	0.1	12.3
Fayette	US 27	8.4	8.6	14	694	11.0	1.0	11.6
Henderson	US 41	17.4	17.6	22	2,415	5.0	0.4	11.6
Daviess	US 60	13.0	13.2	17	776	12.0	1.0	11.5
Laurel	US 25E	1.7	1.9	14	701	10.9	1.0	11.5
Campbell	US 27	[illegible]	16.6	15	947	8.7	[illegible]	[illegible]
Lawrence	US 23	18.0	18.2	16	1,613	5.4	0.5	10.9
Adair	KY 55	11.0	11.2	9	245	20.1	1.9	10.4
Boone	KY 18	14.8	15.0	20	2,623	4.2	0.4	10.2
Daviess	US 60	13.3	13.5	15	760	10.8	1.1	10.2
Fayette	KY 922	1.1	1.3	13	822	8.7	0.8	10.2
Floyd	US 23	15.6	15.8	14	1,384	5.5	0.6	10.1
Jefferson	I 65	136.4	136.6	54	21,000	1.4	0.1	10.1
Boone	I 75	180.1	180.3	32	9,503	1.8	0.2	9.7
[illegible]	[illegible]	15.4	15.6	11	605	10.0	1.0	9.5
[illegible]	[illegible]	[illegible]	13.3	11	767	7.9	0.8	9.5

* Accidents for five-year period of 1985 through 1989.

** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 19. HIGH ACCIDENT LOCATIONS (0.3-MILE SPOTS) CONSIDERING COMBINATION TRUCK ACCIDENTS, TOTAL HIGHWAY SYSTEM, AND TOTAL VOLUME

County	Route	Beginning Milepost	Ending Milepost	Number of Accidents*	Average Daily Traffic	Accident Rate**	Critical Rate**	Critical Rate Factor
Jefferson	I 64	4.8	5.0	73	66,400	0.6	0.1	12.0
Boone	KY 338	0.0	0.2	23	5,620	2.2	0.2	11.8
Boone	I 75	175.2	175.4	43	45,300	0.5	0.1	10.4
Jefferson	I 65	130.5	130.7	67	85,500	0.4	0.1	8.6
Jefferson	KY 1747	0.6	0.8	25	28,407	0.5	0.1	8.0
Floyd	KY 979	14.0	14.2	8	878	5.0	0.7	7.2
Daviess	US 231	14.6	14.8	19	5,576	1.9	0.3	7.2
Jefferson	I 65	136.4	136.6	54	84,000	0.4	0.1	7.0
Oldham	KY 53	6.1	6.3	10	1,583	3.5	0.5	6.8
Boone	KY 18	15.1	15.3	28	38,400	0.4	0.1	6.7
Bullitt	I 65	116.6	116.8	20	32,950	0.3	0.1	6.6
Jefferson	KY 1631	0.9	1.1	22	8,420	1.4	0.2	6.5
Jefferson	KY 1020	9.8	10.0	28	15,833	1.0	0.2	6.5
Clark	US 60	4.6	4.8	19	6,218	1.7	0.3	6.4
Boone	I 75	180.1	180.3	32	56,740	0.3	0.1	6.2
Floyd	US 23	16.7	16.9	15	5,789	1.4	0.2	6.2
Jefferson	I 65	136.1	136.3	46	84,000	0.3	0.1	6.0
Henderson	US 41	16.8	17.0	26	40,257	0.4	0.1	5.8
Ballard	KY 51	3.2	3.4	12	8,237	0.8	0.1	5.7
Mason	KY 8	11.6	11.8	14	4,640	1.6	0.3	5.7
Fayette	I 75	117.9	118.1	15	29,400	0.3	0.1	5.6
Kenton	I 75	191.5	191.7	48	92,727	0.3	0.1	5.6
Hardin	KY 222	6.1	6.3	6	794	4.1	0.7	5.6
Bullitt	KY 44	12.8	13.0	12	5,430	1.2	0.2	5.5
Jefferson	US 31W	20.9	21.1	37	26,845	0.8	0.1	5.4

* Accidents for five-year period of 1985 through 1989.
** Rate given in terms of accidents per 1,000,000 vehicle miles (ACC/MVM).

TABLE 21. SUMMARY OF TRUCK ACCESS CRITERIA AND DESIGN CONSIDERATIONS LISTED IN THE LITERATURE (continued)

Reference Number	Truck Access Criteria and Design Considerations
21	1. Trucks on urban roads encroached into other lanes on streets with lane widths under 12 feet. 2. ~~Intersections with less than a 60-foot corner radii caused problems.~~ 3. On rural roads, lanes wider than 12 or 13 feet allowed oncoming vehicles to move further right to avoid trucks. 4. Shoulders wider than 4 feet allowed oncoming vehicles a greater margin of safety. 5. At sharp curves (7 to 15 degrees) opposing vehicles slowed down significantly and made other undesirable changes to pass large trucks. 6. Consideration should be given to reducing the sharpness of curves greater than 7 degrees and to allowing large trucks on two-lane rural roads with lanes at least 12-feet wide and shoulders greater than 4 feet.
22	Interchange problems include poor transitions to superelevation, abrupt changes in compound curves, short deceleration lanes preceding tight-radius exits, curbes on outside of ramp curves, low friction levels on high speed ramps, and substantial downgrades leading to tight ramp curves.
23	1. sight distance at railroad grade crossings
26	1. highway alignment (vertical or horizontal curves and/or grades)
27	1. offtracking effect on needed pavement width 2. lane or shoulder width adherence to standards 3. intersection sight distance
30	1. Offtracking has an effect on the needed pavement width. 2. Climbing lane is warranted on high-volume routes where the length of grade causes loaded vehicles to reduce speed 10 mph or more. 3. Curbs should not be used on ramps. 4. Driveways into commercial driveways need wide curb openings. 5. Emergency escape ramps should be constructed where needed. 6. Increase offsets to fixed object on inside of turn. 7. A 12-foot lane width is needed for a 102-inch vehicle unless lesser lane width is found to be safe. 8. A steep pavement crown can cause control problem. 9. A skid resistant surface is important for trucks. 10. Pavement edge dropoffs are critical for trucks. 11. Highway profiles at grade crossings should be nearly flat. 12. Sight distance at grade crossings must be adequate. 13. Rest area and weigh station parking spaces should be longer and turning radii greater. 14. Slopes should be flatter for trucks. 15. Trucks require 50 percent longer passing distance. 16. Trucks require greater intersection sight distance. 17. Placement of warning signs must consider truck characteristics. 18. Acceleration and deceleration lanes are longer for trucks. 19. Trucks are sensitive to deficiencies in superelevation or transitions with spiral transitions preferred.
31	1. geometrics 2. traffic composition 3. capacity
32	The increased stopping sight distance for trucks affects horizontal and vertical curvature, intersection sight distance, and railroad crossing sight distance.
33	Passing sight distance is longer for trucks.
34	1. sight distances 2. vertical curve length 3. intersection design 4. critical length of grade 5. lane width 6. horizontal curve design 7. vehicle change interval at traffic signal 8. sign placement 9. highway capacity

TABLE 21. SUMMARY OF TRUCK ACCESS CRITERIA AND DESIGN CONSIDERATIONS LISTED IN THE LITERATURE

Reference Number	Truck Access Criteria and Design Considerations
7	1. sight distance 2. severity and length of grades 3. pavement width 4. horizontal curvature 5. shoulder width 6. bridge clearances and load limits 7. traffic volumes and vehicle mix 8. intersection geometry 9. lane width of 12 feet or more or other consistent with highway safety 10. accident history 11. narrow bridges 12. roadside hardware
10	1. Highways on downtown two-lane streets that are 37 feet wide or less and have right-angle turns at one or more intersections should not be included in the designated highway system if there are large numbers of long trucks. 2. The optimum traffic volume that will accommodate the largest number of long trucks during rush hours is approximately 10,000 ADT on two-lane cross streets. 3. Parking along the first 100 feet of the critical lanes (the left-turning trucks's passenger side and the right-turning truck's driver side) hinders efficient traffic operation.
11	1. Minimum lane and shoulder widths were given. For two-lane rural highways with 10 percent or more trucks, the minimum recommended lane widths were 10 feet for roads with an ADT of 750 or less, 11 feet for an ADT of 751 to 2,000, and 12 feet for an ADT of over 2,000 while the recommended combined lane and shoulder width ranged from 12 feet for an ADT of 750 or less to 18 feet for an ADT of over 2,000. 2. Evaluate the reconstruction of horizontal curves when the design speed of the existing curve is more than 15 mph below the running speed of vehicles and the ADT is over 750. 3. Increase the superelevation of horizontal curves when the design speed of a curve is below the running speeds of vehicles and the existing superelevation is below the minimum specified by AASHTO. 4. Reconstruct vertical curves at hill crests to increase stopping sight distance when ADT is over 1,500 and the hill crest hides from view major hazards and the design speed is more than 20 mph below the running speed. 5. Bridges less than 100 feet long should be replaced or wodened when usable bridge width is less than the approach lanes for a road with an ADT of 750 or less, width of the approach lanes plus two feet for roads with an ADT of 751 to 2,000, width of the approach lanes plus four feet for roads with an ADT of 2,000 to 4,000, and the width of the approach lanes plus six feet for roads with an ADT of over 4,000.
12	1. horizontal curvature 2. superelevation 3. skid resistance 4. passing sight distance
13	Only 2,200 of the 181,000 miles on National Network had lane widths less than 12 feet.
14	1. horizontal curvature 2. grade 3. sight distance 4. roadside protective systems
17	1. intersection sight distance 2. turning radius
18	1. intersection sight distance 2. passing sight distance 3. stopping sight distance
20	1. grade

TABLE 21. SUMMARY OF TRUCK ACCESS CRITERIA AND DESIGN CONSIDERATIONS LISTED IN THE LITERATURE (continued)

Reference Number	Truck Access Criteria and Design Considerations
61	On the assumption that a large truck should not cross a lane line, expecially a centerline, when travelling around a curve, and allowing for some margin of error, a 400-foot minimum curve radius was established for the designated system, assuming a 12-foot traffic lane.
67	Large trucks are more sensitive to surface discontinuities than passenger cars.
70	1. stopping sight distance 2. passing and no-passing zones on two-lane highways 3. decision sight distance 4. intersection sight distance 5. intersection and channelization geometrics 6. railroad-highway grade crossing sight distance 7. crest vertical curve length 8. sag vertical curve length 9. critical length of grade 10. lane width 11. horizontal curve radius and superelevation 12. pavement widening on horizontal curves 13. cross-slope breaks 14. roadside slopes 15. vehicle change interval 16. sign placement

TABLE 21. SUMMARY OF TRUCK ACCESS CRITERIA AND DESIGN CONSIDERATIONS LISTED IN THE LITERATURE (continued)

Reference Number	Truck Access Criteria and Design Considerations
37	1. design of longitudinal barriers
38	Operational problems at intersections were associated with small curb radii, narrow lane widths, and narrow total street widths.
39	1. There is no national standard for determining access. 2. Select highways based on differences in STAA vehicles. 3. A slight increase in vehicle width has only a minor effect on safe operation except on narrow lanes of 10 feet or less.
40	1. Stopping distance is longer for trucks. 2. Side friction coefficient of .08 should be used rather than .13 for curve design. 3. Passing sight distance is greater for trucks. 4. Consider trucks in signal timing. 5. Increase intersection sight distance.
41	1. Longer acceleration lanes are needed for trucks. 2. Profile of railroad grade crossing should be as flat as possible. 3. Question whether the 20 second advance warning at railroad crossings is adequate for trucks. 4. Consider the road roughness factor for trucks. 5. Trucks have a greater problem on wet pavements.
45	Current MUTCD practice of marking passing zones for automobiles may not be adequate for trucks.
46	The design features of truck crash sites were inferior to those of system designated for use by large trucks.
47	1. Mounting height of signs must consider eye height for truck drivers. 2. Length of yellow time at traffic signal may be too short for trucks. 3. Passing zones for cars may be too short for trucks. 4. Design of grade crossings must consider trucks.
48	1. pavement condition 2. interchange spacing and geometrics 3. availability of services 4. bridge characteristics 5. lane widths 6. curves and grades 7. traffic levels
50	1. sight distance 2. horizontal alignment 3. vertical alignment 4. cross-section elements
51	Current intersection sight distance requirements are not adequate for trucks.
55	1. For roads with at least 11-foot lanes on tight curves, trucks will encroach on the adjacent lane to keep vehicle on roadway surface. 2. Offtracking causes a problem in roral area in the ramp terminal area at crossroad and for ramp curvature in urban areas. 3. On the non-Interstate system, intersection geometrics is the biggest problem area.
60	1. lane width 2. shoulder width and condition 3. bridge width 4. roadside slope and clear zone 5. pavement edge drop off 6. offtracking on curves 7. key geometric features are grouped into three categories: alignment features (sight distance for passing and stopping, slope and lengt of vertical grades, and horizontal curvature), cross-sectinal features (lane width, shoulder width, and roadside design features), and intersection, interchange, and ramp design elements (turns and sight distance at intersections sight distance at railroad-highway grade crossings, and interchange and ramp design)

APPENDIX A

ACCIDENT RATE SUMMARIES

TABLE A3. STATEWIDE TRUCK ACCIDENT RATES FOR "SPOTS" BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME) (1985-1989)

Rural or Urban	Highway Type	Number of Accidents	Number of Spots*	Million Vehicles Per Year	Accidents Per Million Vehicles Per Spot
Rural	One-Lane	61	791	0.11	0.145
	Two-Lane	13,933	74,319	0.46	0.081
	Three-Lane	68	52	1.17	0.222
	Four-Lane Divided (Non-Interstate or Parkway)	1,152	1,138	2.96	0.068
	Four-Lane Undivided	257	173	3.24	0.092
	Interstate	3,377	1,918	6.92	0.051
	Parkway	735	1,761	1.60	0.052
	All Rural	19,583	80,152	0.68	0.072
Urban	Two-Lane	6,436	3,979	2.34	0.138
	Three-Lane	88	42	3.35	0.125
	Four-Lane Divided (Non-Interstate or Parkway)	4,044	998	7.13	0.114
	Four-Lane Undivided	2,917	504	6.81	0.170
	Interstate	4,590	581	15.90	0.099
	Parkway	120	133	2.54	0.071
	All Urban**	18,425	6,274	4.73	0.124

* Average for the five years. The length of a spot is defined to be 0.3 mile.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A1. STATEWIDE RURAL TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
One-Lane	237	290	48.4	8	0.0
Two-Lane	22,296	1,270	27.0	8	0.5
Three-Lane	16	3,200	74.1	15	2.2
Four-Lane Divided (Non Interstate or Parkway)	341	8,100	22.8	8	0.6
Four-Lane Undivided	52	8,860	30.7	8	0.6
Interstate	575	18,950	17.0	5	0.3
Parkway	528	4,390	17.3	5	0.4
All	24,046	1,870	23.9	7	0.4

* Average for the five years.

TABLE A2. STATEWIDE URBAN TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	1,194	6,400	46.2	8	0.3
Three-Lane	13	9,180	41.7	7	0.5
Four-Lane Divided (Non Interstate or Parkway)	300	19,530	37.9	7	0.2
Four-Lane Undivided	151	18,650	56.6	9	0.0
Interstate	174	43,570	33.1	7	0.2
Parkway	40	6,970	23.7	6	0.0
All	1,882**	13,130	41.2	8	0.2

* Average for the five years.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A5. STATEWIDE RURAL TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	1,040	4,950	28.2	9	0.7
Three-Lane	12	3,150	96.5	19	1.5
Four-Lane Divided (Non Interstate or Parkway)	291	8,510	22.5	8	0.6
Four-Lane Undivided	29	12,200	27.2	8	0.6
Interstate	575	18,950	16.9	5	0.3
Parkway	430	5,390	17.2	4	0.4
All	2,377	8,930	20.3	6	0.5

* Average for the five years.

TABLE A6. STATEWIDE URBAN TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	111	9,010	56.6	11	0.5
Three-Lane	2	12,640	53.4	8	0.0
Four-Lane Divided (Non Interstate or Parkway)	181	20,570	34.8	7	0.2
Four-Lane Undivided	47	18,510	54.5	10	0.1
Interstate	170	43,560	33.9	7	0.2
Parkway	38	7,090	21.5	5	0.0
All	554**	24,300	36.8	7	0.2

* Average for the five years.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A4. STATEWIDE AVERAGE AND CRITICAL NUMBERS OF TRUCK ACCIDENTS FOR "SPOTS" AND ONE-MILE SECTIONS BY HIGHWAY TYPE CLASSIFICATION (1985-1989)* (TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME)

		Accidents Per Spot		Accidents Per One-Mile Section	
Rural or Urban	**Highway Type**	**Average**	**Critical Number**	**Average**	**Critical Number**
Rural	One-Lane	0.08	1	0.26	2
	Two-Lane	0.19	2	0.62	3
	Three-Lane	1.30	5	4.33	10
	Four-Lane Divided (Non-Interstate or Parkway)	1.01	4	3.37	3
	Four-Lane Undivided	1.49	5	4.96	11
	Interstate	1.76	6	5.87	13
	Parkway	0.42	3	1.39	5
	All Rural	0.24	2	0.81	4
Urban	Two-Lane	1.62	5	5.39	12
	Three-Lane	2.09	6	6.98	14
	Four-Lane Divided (Non-Interstate or Parkway)	4.05	10	13.50	23
	Four-Lane Undivided	5.78	12	19.28	31
	Interstate	7.91	16	26.35	40
	Parkway	0.90	4	3.01	8
	All Urban**	2.94	8	9.79	18

* Average for the five years. The length of a spot is defined to be 0.3 mile.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A8. STATEWIDE AVERAGE[illegible]D CRITICAL NUMBERS OF TRUCK ACCIDENTS FOR "SPOTS" AND ONE-MIL[illegible]ECTIONS BY HIGHWAY TYPE CLASSIFICATION (1985-1989)* (DESIGNA[illegible] TRUCK NETWORK) (TOTAL VOLUME)

		Accidents Per Spot		Accidents Per One-Mile Section	
Rural or Urban	**Highway Type**	**Average**	**Critical Number**	**Average**	**Critical Number**
Rural	One-Lane	112.50	140	375.00	425
	Two-Lane	0.77	4	2.55	7
	Three-Lane	1.66	5	5.54	12
	Four-Lane Divided (Non-Interstate or Parkway)	1.05	4	3.49	9
	Four-Lane Undivided	1.82	6	6.06	13
	Interstate	1.75	6	5.85	13
	Parkway	0.51	3	1.69	6
	All Rural	1.01	4	3.37	9
Urban	Two-Lane	2.79	8	9.30	18
	Three-Lane	3.69	9	12.31	22
	Four-Lane Divided (Non-Interstate or Parkway)	3.92	10	13.08	23
	Four-Lane Undivided	5.52	12	18.41	30
	Interstate	8.09	16	26.95	41
	Parkway	0.84	4	2.79	8
	All Urban**	4.90	11	16.34	27

* Average for the five years. The len[illegible] of a spot is defined to be 0.3 mile.

** Includes small number of miles of [illegible], five-, and six-lane highways.

TABLE A7. STATEWIDE TRUCK ACCIDENT RATES FOR "SPOTS" BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TOTAL VOLUME) (1985-1989)

Rural or Urban	Highway Type	Number of Accidents	Number of Spots*	Million Vehicles Per Year	Accidents Per Million Vehicles Per Spot
Rural	Two-Lane	2,654	3,468	1.81	0.085
	Three-Lane	65	39	1.15	0.290
	Four-Lane Divided (Non-Interstate or Parkway)	1,017	971	3.11	0.067
	Four-Lane Undivided	173	95	4.45	0.082
	Interstate	3,364	1,918	6.92	0.051
	Parkway	727	1,434	1.97	0.052
	All Rural	8,006	7,925	3.26	0.062
Urban	Two-Lane	1,033	370	3.29	0.170
	Three-Lane	27	7	4.61	0.160
	Four-Lane Divided (Non-Interstate or Parkway)	2,367	603	7.51	0.105
	Four-Lane Undivided	872	158	6.75	0.164
	Interstate	4,583	567	15.90	0.102
	Parkway	106	127	2.59	0.065
	All Urban**	9,053	1,847	8.87	0.111

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A11. STATEWIDE TRUCK ACCIDENT RATES FOR "SPOTS" BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TRUCK VOLUME) (1985-1989)

Rural or Urban	Highway Type	Number of Accidents	Number of Spots*	Million Vehicles Per Year	Accidents Per Million Vehicles Per Spot
Rural	One-Lane	61	778	0.01	2.33
	Two-Lane	13,921	74,162	0.04	0.97
	Three-Lane	68	52	0.11	2.47
	Four-Lane Divided (Non-Interstate or Parkway)	1,152	1,138	0.34	0.59
	Four-Lane Undivided	257	173	0.33	0.91
	Interstate	3,377	1,918	1.88	0.19
	Parkway	735	1,761	0.22	0.37
	All Rural	19,571	79,982	0.09	0.53
Urban	Two-Lane	6,427	3,959	0.12	2.65
	Three-Lane	88	42	0.17	2.41
	Four-Lane Divided (Non-Interstate or Parkway)	4,042	998	0.50	1.61
	Four-Lane Undivided	2,917	504	0.38	3.01
	Interstate	4,590	581	2.75	0.57
	Parkway	120	133	0.31	0.58
	All Urban**	18,414	6,252	0.46	1.29

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A9. STATEWIDE RURAL TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TRUCK VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
One-Lane	233	20	776	127	0.0
Two-Lane	22,248	110	324	97	5.8
Three-Lane	16	290	822	169	24.2
Four-Lane Divided (Non Interstate or Parkway)	341	940	196	68	5.1
Four-Lane Undivided	52	890	305	77	5.9
Interstate	575	5,160	62	17	1.1
Parkway	528	610	125	32	3.1
All	23,995	250	178	53	3.3

* Average for the five years.

TABLE A10. STATEWIDE URBAN TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TRUCK VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	1,188	340	883	159	4.8
Three-Lane	13	480	802	137	9.1
Four-Lane Divided (Non Interstate or Parkway)	299	1,380	536	103	2.5
Four-Lane Undivided	151	1,050	1,004	155	0.7
Interstate	174	7,540	192	38	1.2
Parkway	40	850	194	52	0.0
All	1,876**	1,250	432	79	2.0

* Average for the five years.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A13. STATEWIDE RURAL TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TRUCK VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	1,040	550	253	80	6.5
Three-Lane	12	280	1,077	215	16.6
Four-Lane Divided (Non Interstate or Parkway)	291	1,000	191	67	4.9
Four-Lane Undivided	29	1,290	258	78	6.0
Interstate	575	5,160	62	17	1.1
Parkway	528	520	146	38	3.6
All	2,475	1,680	106	31	2.3

* Average for the five years.

TABLE A14. STATEWIDE URBAN TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TRUCK VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	113	580	863	171	7.5
Three-Lane	2	860	883	131	0.0
Four-Lane Divided (Non Interstate or Parkway)	181	1,450	495	106	2.5
Four-Lane Undivided	47	1,160	870	166	1.0
Interstate	171	7,500	196	39	1.2
Parkway	37	900	176	41	0.0
All	555**	3,070	291	59	1.6

* Average for the five years.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A12. STATEWIDE AVERAGE AND CRITICAL NUMBERS OF TRUCK ACCIDENTS FOR "SPOTS" AND ONE-MILE SECTIONS BY HIGHWAY TYPE CLASSIFICATION (1985-1989)* (TOTAL HIGHWAY SYSTEM) (TRUCK VOLUME)

		Accidents Per Spot		Accidents Per One-Mile Section	
Rural or Urban	**Highway Type**	**Average**	**Critical Number**	**Average**	**Critical Number**
Rural	One-Lane	0.08	1	0.26	2
	Two-Lane	0.19	2	0.63	3
	Three-Lane	1.30	5	4.33	10
	Four-Lane Divided (Non-Interstate or Parkway)	1.01	4	3.37	9
	Four-Lane Undivided	1.49	5	4.96	11
	Interstate	1.76	6	5.87	13
	Parkway	0.42	3	1.39	5
	All Rural	0.24	2	0.82	4
Urban	Two-Lane	1.62	5	5.41	12
	Three-Lane	2.09	6	6.98	14
	Four-Lane Divided (Non-Interstate or Parkway)	4.05	10	13.50	23
	Four-Lane Undivided	5.78	12	19.28	31
	Interstate	7.91	16	26.35	40
	Parkway	0.90	4	3.01	8
	All Urban**	2.95	8	9.82	18

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A16. STATEWIDE AVERAGE AND CRITICAL NUMBERS OF TRUCK ACCIDENTS FOR "SPOTS" AND ONE-MILE SECTIONS BY HIGHWAY TYPE CLASSIFICATION (1985-1989)* (DESIGNATED TRUCK NETWORK) (TRUCK VOLUME)

		Accidents Per Spot		Accidents Per One-Mile Section	
Rural or Urban	**Highway Type**	**Average**	**Critical Number**	**Average**	**Critical Number**
Rural	One-Lane	112.50	140	375.00	425
	Two-Lane	0.77	4	2.55	7
	Three-Lane	1.66	5	5.54	12
	Four-Lane Divided (Non-Interstate or Parkway)	1.05	4	3.49	9
	Four-Lane Undivided	1.82	6	6.06	13
	Interstate	1.75	6	5.85	13
	Parkway	0.41	3	1.38	5
	All Rural	0.97	4	3.23	8
Urban	Two-Lane	2.73	7	9.10	17
	Three-Lane	4.14	10	13.80	24
	Four-Lane Divided (Non-Interstate or Parkway)	3.92	10	13.08	23
	Four-Lane Undivided	5.52	12	18.39	30
	Interstate	8.06	16	26.85	41
	Parkway	0.87	4	2.89	8
	All Urban**	4.89	11	16.30	27

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A15. STATEWIDE TRUCK ACCIDENT RATES FOR "SPOTS" BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TRUCK VOLUME) (1985-1989)

Rural or Urban	Highway Type	Number of Accidents	Number of Spots*	Million Vehicles Per Year	Accidents Per Million Vehicles Per Spot
Rural	Two-Lane	2,654	3,468	0.20	0.76
	Three-Lane	65	39	0.10	3.23
	Four-Lane Divided (Non-Interstate or Parkway)	1,017	971	0.37	0.57
	Four-Lane Undivided	173	95	0.47	0.77
	Interstate	3,364	1,918	1.88	0.19
	Parkway	727	1,759	0.19	0.44
	All Rural	8,006	8,250	0.61	0.32
Urban	Two-Lane	1,032	378	0.21	2.59
	Three-Lane	27	7	0.31	2.65
	Four-Lane Divided (Non-Interstate or Parkway)	2,367	603	0.53	1.48
	Four-Lane Undivided	872	158	0.42	2.61
	Interstate	4,583	569	2.74	0.59
	Parkway	106	122	0.33	0.53
	All Urban**	9,052	1,851	1.12	0.87

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A19. STATEWIDE COMBINATION TRUCK ACCIDENT RATES FOR "SPOTS" BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME) (1985-1989)

Rural or Urban	Highway Type	Number of Accidents	Number of Spots*	Million Vehicles Per Year	Accidents Per Million Vehicles Per Spot
Rural	One-Lane	27	791	0.11	0.064
	Two-Lane	6,443	74,319	0.46	0.037
	Three-Lane	35	52	1.17	0.114
	Four-Lane Divided (Non-Interstate or Parkway)	665	1,138	2.96	0.040
	Four-Lane Undivided	133	173	3.24	0.048
	Interstate	2,777	1,914	6.92	0.042
	Parkway	578	1,761	1.60	0.041
	All Rural	10,658	80,148	0.68	0.039
Urban	Two-Lane	2,559	3,979	2.34	0.055
	Three-Lane	31	42	3.35	0.044
	Four-Lane Divided (Non-Interstate or Parkway)	1,843	998	7.13	0.052
	Four-Lane Undivided	921	504	6.81	0.054
	Interstate	2,578	581	15.90	0.056
	Parkway	95	133	2.54	0.056
	All Urban**	8,099	6,274	4.73	0.055

* Average for the five years. The length of a spot is defined to be 0.3 mile.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A17. STATEWIDE RURAL COMBINATION TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
One-Lane	237	290	21.4	3	0.0
Two-Lane	22,296	1,270	12.5	4	0.3
Three-Lane	16	3,200	38.1	8	1.1
Four-Lane Divided (Non Interstate or Parkway)	341	8,100	13.2	5	0.4
Four-Lane Undivided	52	8,860	15.9	4	0.1
Interstate	574	18,960	14.0	4	0.3
Parkway	528	4,390	13.6	3	0.3
All	24,044	1,870	13.0	4	0.3

* Average for the five years.

TABLE A18. STATEWIDE URBAN COMBINATION TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	1,194	6,400	18.3	3	0.1
Three-Lane	13	9,180	14.7	2	0.5
Four-Lane Divided (Non Interstate or Parkway)	300	19,530	17.3	4	0.1
Four-Lane Undivided	151	18,650	17.9	2	0.0
Interstate	174	43,570	18.6	4	0.2
Parkway	40	6,970	18.7	5	0.0
All	1,882**	13,030	18.1	3	0.1

* Average for the five years.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A21. STATEWIDE RURAL COMBINATION TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	1,040	4,950	15.9	5	0.5
Three-Lane	12	3,150	52.0	10	1.5
Four-Lane Divided (Non Interstate or Parkway)	291	8,510	13.4	5	0.4
Four-Lane Undivided	29	12,200	14.6	4	0.2
Interstate	574	18,960	13.9	4	0.3
Parkway	528	4,110	14.4	4	0.3
All	2,474	8,520	14.5	4	0.3

* Average for the five years.

TABLE A22. STATEWIDE URBAN COMBINATION TRUCK ACCIDENT RATES BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TOTAL VOLUME) (1985-1989)

			Accident Rates (Accidents per 100 MVM)		
Highway Type	**Total Mileage***	**AADT**	**All**	**Injury**	**Fatal**
Two-Lane	111	9,010	28.2	6	0.3
Three-Lane	2	12,640	15.8	0	0.0
Four-Lane Divided (Non Interstate or Parkway)	181	20,570	18.0	4	0.1
Four-Lane Undivided	47	18,510	22.4	4	0.1
Interstate	170	43,560	19.0	4	0.2
Parkway	38	7,070	16.8	4	0.0
All	554**	24,290	19.5	4	0.2

* Average for the five years.
** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A20. STATEWIDE AVERAGE AND CRITICAL NUMBERS OF COMBINATION TRUCK ACCIDENTS FOR "SPOTS" AND ONE-MILE SECTIONS BY HIGHWAY TYPE CLASSIFICATION(1985-1989)* (TOTAL HIGHWAY SYSTEM) (TOTAL VOLUME)

		Accidents Per Spot		**Accidents Per One-Mile Section**	
Rural or Urban	**Highway Type**	**Average**	**Critical Number**	**Average**	**Critical Number**
Rural	One-Lane	0.03	1	0.11	1
	Two-Lane	0.09	1	0.29	2
	Three-Lane	0.67	3	2.23	7
	Four-Lane Divided (Non-Interstate or Parkway)	0.58	3	1.95	6
	Four-Lane Undivided	0.77	4	2.57	7
	Interstate	1.45	5	4.84	11
	Parkway	0.33	2	1.09	4
	All Rural	0.13	2	0.44	3
Urban	Two-Lane	0.64	3	2.14	6
	Three-Lane	0.74	3	2.46	7
	Four-Lane Divided (Non-Interstate or Parkway)	1.85	6	6.15	13
	Four-Lane Undivided	1.83	6	6.09	13
	Interstate	4.44	10	14.80	25
	Parkway	0.72	3	2.38	7
	All Urban**	1.29	5	4.30	10

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A24. STATEWIDE AVERAGE AND CRITICAL NUMBERS OF COMBINATION TRUCK ACCIDENTS FOR "SPOTS" AND ONE-MILE SECTIONS BY HIGHWAY TYPE CLASSIFICATION (1985-1989)* (DESIGNATED TRUCK NETWORK) (TOTAL VOLUME)

		Accidents Per Spot		Accidents Per One-Mile Section	
Rural or Urban	**Highway Type**	**Average**	**Critical Number**	**Average**	**Critical Number**
Rural	One-Lane	56.25	76	187.50	223
	Two-Lane	0.43	3	1.43	5
	Three-Lane	0.90	4	2.98	8
	Four-Lane Divided (Non-Interstate or Parkway)	0.63	3	2.09	6
	Four-Lane Undivided	0.98	4	3.26	8
	Interstate	1.45	5	4.82	11
	Parkway	0.32	2	1.08	4
	All Rural	0.68	3	2.25	7
Urban	Two-Lane	1.39	5	4.64	11
	Three-Lane	1.09	4	3.65	9
	Four-Lane Divided (Non-Interstate or Parkway)	2.03	6	6.76	14
	Four-Lane Undivided	2.27	7	7.56	15
	Interstate	4.54	11	15.13	26
	Parkway	0.65	3	2.17	6
	All Urban**	2.59	7	8.64	17

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

TABLE A23. STATEWIDE COMBINATION TRUCK ACCIDENT RATES FOR "SPOTS" BY HIGHWAY TYPE CLASSIFICATION (DESIGNATED TRUCK NETWORK) (TOTAL VOLUME) (1985-1989)

Rural or Urban	Highway Type	Number of Accidents	Number of Spots*	Million Vehicles Per Year	Accidents Per Million Vehicles Per Spot
Rural	Two-Lane	1,492	3,468	1.81	0.048
	Three-Lane	35	39	1.15	0.156
	Four-Lane Divided (Non-Interstate or Parkway)	608	971	3.11	0.040
	Four-Lane Undivided	93	95	4.45	0.044
	Interstate	2,767	1,914	6.92	0.042
	Parkway	571	1,759	1.50	0.043
	All Rural	5,569	8,246	3.11	0.043
Urban	Two-Lane	515	370	3.29	0.085
	Three-Lane	8	7	4.61	0.047
	Four-Lane Divided (Non-Interstate or Parkway)	1,223	603	7.51	0.054
	Four-Lane Undivided	358	158	6.75	0.067
	Interstate	2,573	567	15.90	0.057
	Parkway	83	127	2.58	0.051
	All Urban**	4,789	1,847	8.87	0.058

* Average for the five years. The length of a spot is defined to be 0.3 mile.

** Includes small number of miles of one-, five-, and six-lane highways.

APPENDIX B

ANNOTATED BIBLIOGRAPHY

The number of fatal crashes involving a truck has been nearly constant since 1977, while the number of crashes per 100 million vehicle miles traveled declined steadily during this period. The first harmful event in seven percent of fatal truck crashes and seven percent of injury truck crashes was a collision with a fixed object. This compares to 28 percent of fatal passenger vehicle crashes and 17 percent of injury passenger vehicle crashes. In about three-fourths of the rear-end fatal crashes involving one truck and one passenger vehicle, the car struck the truck. In multi-vehicle fatal crashes involving trucks, 91 percent of the fatalities were occupants of the other vehicle, in part because of the larger mass of the truck.

Truck drivers involved in fatal and injury crashes are rarely reported by police as being impaired by drugs, fatigue or alcohol. The number of drivers impaired by drugs and fatigue may be inaccurate. Police reported alcohol involvement by passenger vehicle drivers in fatal crashes is eight times more likely than alcohol involvement by truck drivers. For all severities of crashes, the likelihood of being charged for being under the influence of alcohol or drugs is five times more likely for passenger vehicle drivers than truck drivers.

Trucks are much less likely than passenger vehicles to be involved in non-fatal injury or property-damage-only crashes.

Beilock,R.; Capelle, R.B.; and Page, E.B.; "Speed and Training Factors Associated with Heavy Truck Accidents", Transportation Quarterly, Vol. 43, No. 4, October 1989.

Two factors most commonly associated with heavy vehicle accidents are speed too fast for conditions and the level of driver training. The main thrust of this article was to identify and promote safe operating speed and driver training.

Speed in excess of posted speed limits or "too fast for conditions" is cited as a factor in one-fifth of all heavy truck accidents which is more than any other single factor. Economic pressure can result in excessive speed for trucks. There can be pressure on the driver to speed as a way to improve productivity. This may be communicated to the driver via tight scheduling or by productivity-based or piece-rate payment or both.

Only 42 percent of truck drivers involved in accidents had received any training, and untrained drivers are overinvolved in fatal accidents. Training ranges from one-time courses, often with little hands-on instruction, to comprehensive, continuing programs, such as at United Parcel Service. The former appears to be of little value in preventing accidents, while the latter can dramatically reduce accident rates.

Billing, J. R. and Mercer, W. R.; "Swept Paths of Large Trucks in Right Turns of Small Radius", Transportation Research Board Record 1052, 1986.

This paper describes a method that permits computation of the swept path of a vehicle combination of arbitrary configuration as it makes a right turn of small radius.

"A Study of the Operating Practices of Extra-Long Vehicles," Transportation Research and Marketing, AAA Foundation for Traffic Safety, December 1990.

The objective of this report was to evaluate the operations of the Extra-Long Vehicles (ELVs) in the states of Oregon, Idaho, Utah, and Nevada. The ELVs were 28.5-foot triple trailers, 45-foot double trailers, and 48- and 28.5-foot Rocky Mountain Doubles.

Major findings of this study were that ELVs fall into two distinct configurations (long doubles and triple trailer) and their operating characteristics on the highway differ in several ways of important significance to highway safety.

Long double trailer combinations travel at automobile speed or higher (65 mph or over on rural interstates and only slightly less in urban areas) which are frightening to other motorists while triples run at an average speed of 58-60 mph and create few problems. Road and bridge damage particularly results from heavy trucks at high speed.

One out of every ten trucks encountered in the study was an ELV. The ELVs were being used for both long-haul freight and local use.

Rocky Mountain Doubles were observed to be the most inconsistent vehicles in equipment quality and combination trailers used.

Drivers of ELVs operated their vehicles in the same manner as other highway users with acts of rudeness in driving behavior similar to all other driver behavior observed. The good safety record of ELVs may be due to the fact that other motorists consistently try to stay away from the larger vehicles, sometimes involving other vehicles in unsafe situations. Splash and spray from long doubles can cause problems.

Truck traffic has resulted in damage to the Interstate Highway System. Ruts in interstate pavements are such that truckers are asked to use the left lanes of the highway in some states in certain stretches of the highway.

Four out of five transport drivers queried said that they do not want to drive ELVs. Two-thirds of the transport drivers think ELVs are much less safe than the 5-axle semi-trailer.

"A Summary of Fatal and Nonfatal Crashes Involving Medium and Heavy Trucks in 1988," National Highway Traffic Safety Administration, DOT-HS-807-609, February 1990.

This report describes the crash experience of medium and heavy trucks (trucks with a gross vehicle weight rating over 10,000 pounds). There were an estimated 331,000 police-reported crashes involving medium and heavy trucks in 1988. Of those, 4,893 were fatal and 80,500 resulted in a nonfatal injury. Nearly four million single-unit and 1.5 million combination trucks were registered. Combination trucks averaged nearly six times as many miles traveled per vehicle compared with passenger vehicles or single-unit trucks.

accidents for all truck types, with the exception of doubles, occurred when the truck driver was changing lanes. The largest percentage of straight-truck accidents occurred as rear-end accidents. For accidents involving a merge maneuver on a freeway, the truck was not usually the vehicle performing the merge maneuver. The fatality rate was higher for accidents involving trucks.

An estimate of the total annual cost of urban freeway truck accidents was determined to be $634,000 per freeway mile. This cost consisted of accident costs of $182,000, delay costs of $440,000, clean-up costs of $3,000, and operating costs of $9,000 per freeway mile.

Carsten, O.; "Safety Implications of Truck Configuration,", Transportation Research Board Record 1111, 1987.

This paper examines the relative safety of single and double tractor-trailer combinations based on the performance characteristics of the two classes of vehicle. The accident data are searched for evidence of a safety deficit for the doubles resulting from the phenomenon of rearward amplification.

The findings from actual highway experience do not show a higher fatal or injury accident involvement rate for doubles. A factor which must be considered is that doubles are used more in safer operating environments. The accident data did indicate handling-related problems for doubles in that there was a large over involvement of doubles in rollovers at the property damage level as compared with singles. The comparison of singles and doubles demonstrates the influence of vehicle characteristics on accident experience.

Chirachavala, T.; Cleveland, D. E.; and Kostyniuk, L. P.; "Severity of Large-Truck and Combination-Vehicle Accidents in Over-the-Road Service: A Discrete Multivariate Analysis," Transportation Research Board Record 975, 1984.

The severity of large-truck and combination-vehicle accidents was investigated by using 1980 Bureau of Motor Carriers Safety data. The analysis was based on 19,263 accident involvements of such vehicles engaged in over-the-road operation. A two-stage discrete multivariate analysis procedure was used. Differences in the effect of the variables for the four predominant truck types (straight trucks, singles with van, singles with flatbed or tanker, and doubles) led to their separate analysis.

The interactions involving road class and environment, and road class and collision type, were usually important. No driver characteristics were found to be significant. Particularly severe accidents were collisions involving passenger cars and doubles, straight trucks, or loaded flatbed or tanker singles on undivided rural roads; collisions involving cars and van singles on undivided rural roads at night; and collisions involving cars and doubles on divided rural roads.

This method, the steering-path method, requires a good estimate of the path of the rear of the vehicle if the swept path is to be realistic. The method has been programmed in FORTRAN for a large-scale IBM computer system.

When a large truck makes a turn of large radius, the driver may make a steady steering input and the swept path of the vehicle through the turn may be computed by an offtracking procedure. However, when a large truck must make a turn of small radius, such as a right turn at an urban intersection, the driver must devise a more complex steering input that minimizes intrusion of the vehicle into the space of other vehicles and also keeps the trailer vehicle units from encroaching on the curb. Determination of the steering input necessary for such a turn is defined as a steering-path problem.

The analysis demonstrates that there is a direct computational method for estimating the swept path of a truck combination in a small-radius right turn, a situation for which an offtracking procedure is often inappropriate.

Blue, D. W. and Kulakowski, B. T.; "Effects of Horizontal-Curve Transition Design on Truck Roll Stability," Journal of Transportation Engineering, Vol. 117, No. 1, January/February 1991.

In this article the roll performance of tractor-semitrailer trucks on horizonal curves with three different types of transitions was investigated using computer simulation, and the results were used to develop guidelines for horizontal-curve transition design. The roll dynamics of a truck traveling on a transition and a superelevated curve were described, and the effect of superelevation on the rollover threshold of tractor-semitrailer trucks was described. Three evaluation parameters (roll stability margin, acceleration overshoot, and critical speed) were proposed and used in evaluating different transition types. Three types of transition were investigated: one in which 2/3 of the maximum superelevation is developed before the start of the curve, one in which the superelevation is fully developed at the start of the curve, and one in which superelevation is developed in a short spiral section. A test matrix consisting of different truck speeds, different radius curves, and different transitions was used. The spiral transition was shown to be the most desirable type of transition.

Bowman, B.L. and Lum, H.S.; "Examination of Truck Accidents on Urban Freeways," Institute of Transportation Engineers Journal, October 1990.

This article described the nature and extent of urban truck freeway (minimum 100,000 average daily traffic and five percent large-truck traffic) accidents and their consequences as a function of vehicle type and traffic and roadway characteristics. The major categories of trucks were trucks over 10,000 pounds gross vehicle weight and tractor/trailer combinations.

More truck accidents occurred on Friday than any other day for all truck types combined. Cargo spillage occurred in 5.1 percent of the accidents. Tractor/semitrailers had 52.5 percent of their accidents occur as sideswipes. The greatest number of sideswipe

6. The route does not have any unusual characteristics causing current or anticipated safety problems.

When requesting to delete a Federal-aid primary route (other than interstate) from the National Network, the following questions should be answered.

1. Did the route segment prior to designation carry combination vehicles or 102-inch buses?
2. Were truck restrictions in effect on the segment on January 6, 1983?
3. What is the safety record of the segment, including current or anticipated safety problems? Is the route experiencing above normal accident rates or severity and has the addition of larger trucks aggravated existing accident problems?
4. What are the geometric, structural or traffic operations features that might preclude safe, efficient operation? Specifically describe lane widths, sight distance, severity and length of grade, horizontal curvature, shoulder width, narrow bridges, bridge clearances and load limits, traffic volumes and vehicle mix, intersection geometrics and vulnerability of roadside hardware.
5. Is there a reasonable alternate route available?
6. Are there operational restrictions that might be implemented in lieu of deletion?

Concerning reasonable access, no state may enact or enforce any law denying reasonable access to vehicles with dimensions authorized by the STAA between the National Network and terminals and facilities for food, fuel, repairs, and rest. In addition, no State may enact or enforce any law denying reasonable access between the National Network and points of loading and unloading to household goods carriers and any truck tractor-semitrailer combination meeting the STAA length and width criteria. The State or local government may impose any reasonable restriction, based on safety considerations, on access to points of loading and unloading for trucks meeting the STAA length and width criteria.

The STAA length provisions are that no State shall impose a length limitation of less than 48 feet on a semitrailer operating in a truck tractor-semitrailer combination or less than 28 feet on any semitrailer or trailer operating in a truck tractor-semitrailer-trailer combination. The STAA width provisions is that no State shall impose a width limitation of more or less than 102 inches on a vehicle operating on the National Network.

Council, F. M. and Hall, W. L.; "Large Truck Safety: An Analysis of North Carolina Accident Data," University of North Carolina, Highway Safety Research Center, Annual Meeting of the Association for the Advancement of Automotive Medicine, October 1989.

In this study, North Carolina accident data from 1981 through 1987 were analyzed relative to vehicle, driver and roadway-related issues.

Council, F. M. and Hall, W. L.: "Large Truck Safety in North Carolina: The Identification of Problem Locations on the Designated Route System," University of North Carolina, Highway Safety Research Center, HSRC-PR165, October 1989.

The purpose of this report was to develop a systematic process to identify and analyze specific locations on the State system where truck accidents were overrepresented. After identifying locations, the general accident characteristics of those locations were examined to see if treatment development could be initiated.

A series of computer runs was conducted in which a critical per mile rate of truck accidents was input and the output within the various highway classes was analyzed to see how many locations were identified, and the rate was then increased to limit the number of high accident locations chosen. The sites were identified by road class (rural and urban Interstate routes, rural and urban U.S. roadways, and rural and urban N.C. roadways). The rates used truck accidents and total traffic volume. A separate analysis was conducted for twin trailer rigs.

The concentration was on the Designated Route System because of the high truck volume found there. Numbers of both sections and intersections were identified. These locations were analyzed by accident patterns, traffic flows, and other variables in order to begin to develop information which could be used in field examinations.

Code of Federal Regulations, Part 658 - Truck Size and Weight, Route Designations - Length, Width and Weight Limitations, Federal Highway Administration, 1990.

The purpose of this part is to identify a National Network of highways authorized by provisions of the Surface Transportation Assistance Act of 1982 (STAA). The policy is to provide a safe and efficient National Network of highways that can safely and efficiently accommodate the large vehicles authorized by the STAA including the Interstate System plus other qualifying Federal-aid Primary System Highways.

Routes designated as part of the National Network are designated on the basis of their general adherence to the following criteria.

1. The route is a geometrically typical component of the Federal-Aid Primary System, serving to link principal cities and densely developed portions of the States.
2. The route is a high volume route utilized extensively by large vehicles for interstate commerce.
3. The route does not have any restrictions precluding use by conventional combination vehicles.
4. The route has adequate geometrics to support safe operations, considering sight distance, severity and length of grades, pavement width, horizontal curvature, shoulder width, bridge clearances and load limits, traffic volumes and vehicle mix, and intersection geometry.
5. The route consists of lanes designed to be a width of 12 feet or more or is otherwise consistent with highway safety.

in an urba setting, evaluate the operations of typical medium- to high-volume urba intersections that do not conform to minimal design standards, establish realistic intersection design and redesign criteria for urban intersections, establish criteria for location of traffic control devices and other on-street appurtenances where there is a high percentage of truck traffic, and develop engineering analyses based on statistical inference and mathematical models that would enable assessment of the future impacts of longer-wheelbase trucks as their proportion in the vehicle population increases.

The actual operating characteristics of a typical mixture of long vehicles were determined. Also, the impact of various dimensions of these assemblies were investigated as they related to offtracking, overall swept width, opposite lane encroachment, intersection traffic operation, and intersection design d location of traffic appurtenances.

The following conclusions and recommendations were noted:

1. Critical maneuvers on the designated highway system are right turns in downtown areas.
2. Highways on downtown two-lane streets that are 37 feet wide or less and have right-angle turns at one or more intersections should not be included in a designated highway system if there are large numbers of long trucks in the traffic stream.
3. Installing signals at downtown intersections on the designated highway system can cause serious operational problems for both left- and right-turning trucks.
4. The best apparent traffic control configuration for downtown intersections is one that m ximizes free traffic flow on the heavy-volume approaches and minimizes pedestrian conflicts by placing crosswalks on minor-volume approaches.
5. The optimum traffic volume that will accommodate the largest number of long trucks during rush hours is approximately 10,000 ADT on two-lane cross streets.
6. Parking along the first 100 feet of the critical lanes (the left-turning truck's passenger side and the right-turning truck's driver side) hinders efficient traffic operation if there are high percentages of left- or right-turning trucks during peak hours.
7. Before resorting to full-scale intersection revision or signalization, numerous well-known measures should be tried. These measures include: removing parking, offsetting the location of the centerline, prohibiting rush-hour parking, reducing restrictive traffic control measures, increasing sight distances, minimal widening, diverting traffic, metering cross-traffic flow through installation of upstream signals, prohibiting long-truck operation during rush hours, restricting right turns, and restricting operation to vehicles with special equipment (such as steerable rear axles).

"Designing Safer Roads, Practices for Resurfacing, Restoration, and Rehabilitation," Transportation Research Board, Special Report 214, 1987.

This report includes the results of a study of the safety cost-effectiveness of geometric design standards and recommends minimum standards for resurfacing, Heavy truck accident involvement in North Carolina was growing faster than for the remainder of the vehicle fleet. Heavy trucks were involved in three times the proportion of fatal accidents than passenger vehicles.

Different types of trucks were found to be overrepresented in different ways when compared to the average truck and to each other. Vans were found to be slightly over-involved in lane change and sideswipe collisions. Accidents involving tankers were more severe than any other truck type. Flat bed trucks were over-involved in overturn, fixed object hits, and their drivers were cited with more violations than the drivers of other vehicles. Bobtails, with their slightly younger drivers, appeared to be involved in the most high-risk driving as characterized by following-too-closely violations and a much higher percentage of drinking drivers. Twins were found to be overrepresented in rollover collisions, ran-off-road and angle collisions, and collisions on snowy and icy roads.

In construction zones, very little difference was found in the truck involvement percentage as compared to passenger vehicles. The analyses of shoulder problems indicated some overrepresentation for the large trucks. At interchange ramps, twins appear to have the most problems, predominantly involving the ramp terminal. The guardrail severity analyses confirmed that there was less protection for trucks with the finding that truck drivers were approximately four times as likely to be killed in collisions involving guardrails.

While truck drivers were injured slightly less than other vehicle drivers, they were killed a slightly higher percentage of the time. A lower alcohol involvement was found in truck crashes than with the remaining vehicle fleet. There were no patterns indicating that younger drivers were involved in more than their share of accidents on lower-design roadways.

Areas having the greatest possibility for effective intervention would include increased attention to enforcement and education as related to drivers of bobtail rigs. Countermeasures for the high proportion of rollovers for twin-trailer configurations are needed. There is a need to develop a system of obtaining truck exposure data.

DeCabooter, P. H. and Solberg, C. E.; "Operational Considerations Relating to Long Trucks in Urban Areas," Transportation Research Board Record 1249, 1989.

The STAA of 1982 mandated the operation of large trucks and twin tractor-trailer combinations on most Interstates and many primary highways. Many states have expanded the highway system for longer vehicles by adding secondary highways, many of which involve urban streets and intersections. Many of the intersections are substandard if compared with the ideal 62-foot wheelbase turning template. When intersections are so seriously deficient that the operation of long trucks through them endangers public safety, a rational way to identify them should be available to engineers, local officials, and decision makers.

The objectives of this study were to determine the operating characteristics of long trucks (generally 102 inches wide and 41 feet from kingpin to rear axle) at intersections

Improvements at intersections should be organized on the basis of three primary design objectives: reduction of potential vehicle conflicts (traffic signals and turning lanes); improvement of driver decision-making (longer lines of sight and lane markings); and improvement of the braking capability of vehicles in the intersection (warning signs to reduce approach speed and increased pavement skid resistance).

It was also noted that, on resurfacing projects, the pavement overlays should be constructed with normal pavement crowns that match new construction standards.

Donaldson, G. A.; "Safety of Large Trucks and the Geometric Design of Two-Lane, Two-Way Roads," Transportation Research Board Record 1052, 1986.

The Surface Transportation Assistance Act of 1982 resulted in the designation of primary highways for use by longer, wider, and heavier tractor-trailer trucks, and a high percentage of these roads have deficient geometric and cross-sectional design features. Studies indicate the severe accident overinvolvement potential of larger, especially tandem-trailer, trucks on both rural undivided and urban divided highways. Large trucks have the potential for certain types of accidents because of their design characteristics and their incompatibility with the substandard operating conditions found especially on older two-lane, two-way rural arterials.

The safety-deficient design characteristics of larger trucks are reviewed and the incompatibility of their operation with horizontal curvature, superelevation, skid resistance, and, in particular, passing sight distance deficiencies is surveyed. Research has shown that sight distance formulas for the successful execution of the passing maneuver at higher speeds on two-lane, two-way roads are inadequate, especially for automobiles passing trucks. Trucks are not accommodated in their stopping distance requirements in current design standards. The importance of spiral transitions in the design of horizontal curves is discussed.

The lack of accident data collection on large trucks, the need for better on-site investigation of large-truck accident causation, and the necessity of more research on the behavior of large trucks on each functional class of roadway are discussed.

Eicher, J.P.; Klimek, T.E.; and Strickland, S.G.; "National Network for Trucks: Development, Performance, and Outlook," Transportation Research Board Record 1052, 1986.

The dimensional limits established by the Surface Transportation Assistance Act (STAA) of 1982 relate to weight (on the Interstate system must allow 20,000 pounds on a single axle, 34,000 pounds on a tandem, and a gross weight cap of 80,000 pounds), width (a 102-inch width limit), and length (a 48-foot semitrailer, doubles with up to 28 1/2 foot unit, and no overall length limit).

The term "National Network" designates the combination of the Interstate system and portions of the federal-aid primary (FAP) system on which STAA vehicles would be restoration, and rehabilitation projects on existing federal-aid highways, except freeways. One category of recommendations dealt with design practices for key highway features. The highway features included were:

1. minimum lane and shoulder widths,
2. horizontal curvature and superelevation,
3. vertical curvature and stopping sight distance,
4. bridge width,
5. sideslopes and clear zones,
6. pavement edge drop and shoulder type,
7. intersections, and
8. normal pavement crown.

For two-lane rural highways having 10 percent or more trucks, the minimum recommended lane widths were 10 feet for roads having an average daily traffic (ADT) of 750 or less, 11 feet for an ADT of 751 to 2,000, and 12 feet for and ADT of over 2,000. For this percentage of trucks, the recommended combined lane and shoulder width ranged from 12 feet for and ADT of 750 or less to 18 feet for and ADT of over 2,000.

It was recommended to evaluate the reconstruction of horizontal curves when the design speed of the existing curve is more than 15 mph below the running speeds of vehicles and the ADT is over 750. It was also recommended to increase the superelevation of horizontal curves whenever the design speed of a curve is below the running speeds of vehicles and the existing superelevation is below the allowable maximum specified by AASHTO.

Reconstruction of vertical curves at hill crests to increase stopping sight distance should be evaluated when the ADT is over 1,500, the hill crest hides from view major hazards such as intersections, sharp horizontal curves, or narrow bridges, and the design speed of the hill crest (based on the minimum stopping sight distance provided) is more than 20 mph below the running speeds of vehicles on the crest.

Bridges less than 100 feet long should be considered for replacement or widening when the usable bridge width was: the width of the approach lanes for a road having an ADT of 750 or less, the width of the approach lanes plus two feet for roads having an ADT of 751 to 2,0000, the width of the approach lanes plus four feet for roads having an ADT of 2,000 to 4,000, and the width of the approach lanes plus six feet for roads having an ADT of over 4,000.

Concerning sideslopes and clear zones, it was recommended that sideslopes of 3:1 or steeper be flattened where run-off-road accidents are likely to occur such as on the outside of sharp horizontal curves and that isolated roadside obstacles be removed, relocated, or shielded.

For pavement edge drops, it was recommended to either selectively pave shoulders at points where out-of-lane vehicle excursions and pavement edge drop problems are likely to develop such as at horizontal curves or to construct a beveled or tapered pavement edge shape at these points.

some instances it may not be cost-effective to provide such protection for large trucks, given present technology.

8. The 55-mph national speed limit reduced large-truck accident rates on multi-lane highway facilities.
9. Truck accidents tend to be more severe during the late night and early morning hours and during other periods when poor lighting conditions exist.

Ervin, R. D.; MacAdam, C. C.; and Barnes, M.; "Influence of the Geometric Design of Highway Ramps on the Stability and Control of Heavy-Duty Trucks," Transportation Research Board Record 1052, 1986.

A research study was described in which accidents experienced by tractor-semitrailers on expressway ramps were determined to depend largely on the interaction between highway geometrics and vehicle dynamic behavior. The accident rates of tractor-semitrailers on expressway ramps in five states were scanned to select 14 individual ramps that exhibited an unusual incidence of serious accidents involving these vehicles. The geometrics of each ramp were fully defined in a computer simulation in such a way that the dynamic behavior of example tractor-semitrailers could be examined.

The results of combined study of accident data, simulated vehicle response, and geometric details of ramp design are presented. The findings of the study indicate that the maneuvering limits of certain trucks are quite low relative to those of automobiles so current practice in ramp design leaves an extremely small margin for control of heavy vehicles. The primary design issues relate to the nominal side friction factor achieved at each curve, the transition geometry, and the layout and signing of curve segments in order to assure that truck speeds are suitably reduced for negotiating small-radius curves.

Ervin, R. D.; Nisonger, R. L.; MacAdam, C. C.; and Fancher, P. S.; "Influence of Size and Weight Variables on the Stability and Control Properties of Heavy Trucks," Federal Highway Administration, Report No. FHWA/RD-83/029, July 1986.

This study examined the influence of variations in truck size and weight constraints on the stability and control properties of heavy vehicles. The size and weight constraints of interest included axle load, gross vehicle weight, length, width, type of multiple-trailer combinations, and bridge formula allowances. Variations in location of the center of gravity of the payload were also considered as a separate subject. The influence of these parametric variations on stability and control behavior was explored by means of both full-scale vehicle tests and computer simulations.

The performance categories which have been most firmly related to accident involvement were (a) the roll stability exhibited by all types of vehicles and (b) the rearward amplification behavior of multiple-unit vehicle combinations.

Following is a summary of some of the results of the study related to the factors given.

permitted to operate. All FAP routes having the highest standards (multilane, divided, full-control-of-access highways) were put on the National Network with states adding other routes. As of 1984, 181,000 of the 256,000 miles of non-Interstate FAP roads were included in the National Network. Only 2,200 of the 181,000 miles had lane widths less than 12 feet. Access must be provided off the National Network to terminals. About 60 percent of eligible Federal-Aid mileage is available to STAA vehicles.

The definition of reasonable access has been debated. Policies on access range from 21 states allowing unlimited access to ten states having limits of two to 20 miles, four states with less than one mile, nine states with 1/2 to two miles for food, fuel, and lodging with permits for terminal access, five states requiring terminals to apply for access rights, two states having no access policy, and one state having access to all terminals via the shortest practical route.

The truck industry is changing to use of the 48-foot semi-trailer with the 102-inch width. It is estimated that by 1990, the total truck vehicle miles travelled will be 1.2 percent less than if the STAA had not been passed.

Eicher, J. P.; Robertson, M. D.; and Toth, G. R.; "Large Truck Accident Causation," National Highway Traffic Safety Administration, Report DOT HS 806 300, July 1982.

This report identifies the driver, vehicle, and the highway/environmental factors and the operational practices which contribute to the frequency and severity of accidents involving large trucks. Large trucks were those more than 10,000 pounds gross vehicle weight. Large trucks account for about 5.7 percent of all accidents but approximately 11.8 percent of all fatal accidents. Analyses did not reveal any single solution which, if implemented, would guarantee alteration of the truck accident problem. Areas were found in which the greatest probability exists of reducing the number of truck accidents and their consequences.

The following findings were listed in the area of highway/environmental factors:

1. The safety benefits of full control of access apply as well to trucks as to all other vehicles.
2. More truck rollovers occur in large-truck accidents at freeway on- and off-ramps than in accidents at other locations.
3. Accidents involving large trucks occur more frequently at freeway off-ramps than at on-ramps.
4. Fatal accidents that involve combination trucks appear to occur more frequently on highway grades than on level sections.
5. Many more of the most serious large-truck single-vehicle accidents occur on curved sections of highway than on straight sections.
6. Criteria used to establish and mark passing zones on two-lane roads often do not accommodate large-truck sight distance requirements.
7. Roadside protective systems such as guardrails, median barriers and impact attenuators generally are not designed to accommodate large-truck impacts; in

f. The maximum values of high-speed offtracking are achieved with vehicle units having wheelbases in the vicinity of 23 feet so the combinations exhibiting the largest total offtracking are those having the most trailing units in that range of wheelbase.

5. Types of Multiple-Trailer Combinations

a. There appears to be very little basis for expecting a significant difference in the stopping-distance performance of various types of combinations.
b. Various types of multiple-trailer combinations have no significance to yaw stability.
c. There is a definite relationship between both high-speed and low-speed offtracking characteristics and the type of multiple-trailer configuration.
d. The rearward amplification behavior varies sharply by type of multiple-trailer combination.

6. Vehicle Width

a. Increases in the width at which tires and springs are placed constitute one of the most powerful means of improving the rollover resistance of heavy vehicles.
b. The incidence of rollovers could be reduced by 20 percent by increasing the width of the semitrailer to 102 inches and could be reduced by 35 percent by increasing both the tractor and semitrailer to 102 inches.
c. The most beneficial application of an increased width allowance is in the case of full trailers.

Fambro, D. B.; Mason, J. M.; and Neuman, T. R.; "Accommodating Larger Trucks at At-Grade Intersections," American Society of Civil Engineers, Accommodation of Trucks on the Highway: Safety in Design, 1988.

When an intersection serves a high volume of large truck traffic, design considerations should reflect the presence of those larger vehicles. Three intersec n design elements that are affected by large trucks are discussed in this paper. Th elements are: intersection sight distance, capacity, and channelization. Guideline nd considerations for accommodating these larger vehicles at at-grade intersections given.

The following design considerations are given for intersection sight dista

1. On new design of high-speed uncontrolled access highways, designers sh strive to minimize the algebraic difference in grades which will maximize avail intersection sight distance.
2. Designers should examine locations of intersections relative to the availa ight distance.
3. On existing highways undergoing reconstruction, opportunities for localiz improvements to sight distance should focus on intersections and their re onship to mainline alignment.

1. Axle Load Limits

a. For trucks having the "representative, as-designed" type of brake system behavior, increased axle loading results in small reductions in stopping distance.
b. Increases in axle load limit, implemented by simply increasing the load carried on non-steering axles, consistently result in a reduction in the understeer quality of trucks and tractors.
c. The rollover threshold is decidedly reduced by increases in axle load limit (a 10 percent increase in axle load limit yields an average of 0.025 g reduction in the rollover threshold).
d. The influence of the various biased loading conditions on the rearward amplification behavior of the double is relatively small.

2. Gross Vehicle Weight

a. There is a very minor, but favorable, influence of increased gross weight on the stopping distance performance.
b. Gross weight increases reduce the roll stability with greater reductions in rollover threshold from the placement of a greater fraction of the load on the tractor's steering axle.
c. Increasing values of gross weight tend to result in a minor increase in the rearward amplification of a conventional doubles configuration.

3. Simple Variations in Payload Placement

a. There was a 3 to 6 percent increase for semitrailers and a 5 to 11 percent increase for doubles in stopping distance as the payload center of gravity increased over the range examined.
b. Increasing payload center of gravity height resulted in a declined understeer level.
c. Increasing payload center of gravity height reduced rollover threshold by about 0.01 g per inch of payload center of gravity height.
d. Rollover threshold declined strongly with increasing payload offset.
e. Partial unloading degraded the stopping capabilities.

4. Influence of Length Variations

a. Increases in trailer wheelbase tend to improve stopping capability.
b. Variations in tractor wheelbase had a negligible influence on stopping performance.
c. Longer tractor wheelbases enhance the driver's ability to arrest jackknife motion.
d. Amplification ratio generally goes up with number of articulation points and goes down as either dolly tongue length or trailer length increases.
e. Magnitude of the swept path increases with length (or wheelbase) of trucks, tractors, and trailers.

3. if controlled stops without jackknifing, trailer swinging, or vehicle spins are to be performed by truck drivers, the required stopping sight distances at high speeds are much longer than those recommended in the AASHTO policy.

Fancher, P. S. and Mathew, A.; "Safety Implications of Various Truck Configurations," Federal Highway Administration Report FHWA-RD-8[illegible]018, January 1990.

The purpose of this report was to examine changes to size and weight limits in order to determine their effects on the designs and configurations of heavy vehicles, the performance capabilities of the resulting vehicles, and the safety implications. By treating a number of projected size and weight scenarios, the study has developed a basis for generalizing to sets of principles that can be used in evaluating the possible safety consequences of changes in size and weight regulations. Following is a listing of the conclusions.

1. When going to more weight-productive size and weight rules, do not allow heavier loads on existing vehicles.

2. Axle load constraints should not be eliminated from size and weight rules.

3. In order to allow trucks to make maximum use of the space available on roads, an offtracking rule could be used as a length constraint.

4. As a first step in developing rules for more productive vehicles, constraints on the number of axles and axle spreads would prevent the possibility of promoting very long vehicles having excessive friction demands in tight turns.

5. The five-axle tractor-semitrailer having tandem axle sets on both the rear of the tractor and the semitrailer is a well-optimized configuration for the current size and weight rules allowing 80,000 pounds.

6. A six-axle tractor-semitrailer with a tridem-axle set on the semitrailer would allow more load up to 88,000 pounds while maintaining good intrinsic safety.

7. In the case of doubles, there are both minimum and maximum wheelbases that bound the range of designs providing good performances. Twin 28-foot cargo boxes are too short. Doubles having twin 35-foot cargo boxes would be better.

8. Innovative dollies having special hitching arrangements may be needed to control rearward amplification, especially for triples and short doubles.

9. The wheels-unlocked braking performance of empty trucks needs to be improved.

10. The rollover immunity of more productive heavy trucks would be maintained or improved if the tire stiffness per axle and the suspension roll stiffnesses per axle were maintained at the same levels of those properties for current tires and suspensions.

Firestine, M.; Hughes, W.; and Demaree, R. V.; "New Methods for Determining Requirements for Truck-Climbing Lanes," Federal Highway Administration Report No. FHWA-IP-89-022, September 1989.

This report summarizes major findings of a study which investigated the design of hill-climbing lanes. The study revealed that current guidelines may be resulting in the overdesign of highways, adding and maintaining unnecessary hill-climbing lanes.

4. Where intersection sight distance is restricted by horizontal alignment, the driver's eye height is not a factor in increasing available sight distance. Designers should avoid placing intersections within or near sharp (greater than 5 degrees) horizontal curves.
5. On existing highways having intersections near existing horizontal curves, clearing the inside of the curve to provide for intersection sight distance should be considered.

There is a need to distinguish between truck types when analyzing the capacity of a signalized intersection. Large, five-axle truck combinations were found to have a significantly higher effect on the capacity of a signalized intersection than the small single unit trucks. The heavy vehicle adjustment factor equation in the 1985 Highway Capacity Manual should be modified to analyze the effects of both light and heavy trucks in addition to buses and recreational vehicles. An equation is presented.

The optimum turning radius for each curb return was defined as the smallest turning radius which the design vehicle could negotiate without running over the inside curb, while at the same time minimizing cross street encroachment. The cross street width occupied was defined as the amount of encroachment plus a 12-foot lane width. Encroachment was defined as the distance that the vehicle trespassed beyond the 12-foot lane stripe in order to complete its turn. Swept path width was defined as the differences in paths of the front-most outside wheel of a vehicle as it negotiated a turn. A table was developed giving cross street width occupied by turning vehicle for various intersection angles and curb radii. Conditions were identified where the curb radius combined with the optimum turning radius in such a way as to leave room for an island 100 square feet in size (the minimum size of channelization island recommended by the AASHTO Green Book).

Fancher, P. S.; "Sight Distance Problems Related to Large Trucks," Transportation Research Board Record 1052, 1986.

In this paper are discussed the influences of the properties of large trucks on:

1. sight distances for accelerating across intersections,
2. passing sight distances on two-lane highways, and
3. stopping sight distances for crest vertical curves.

The vehicle properties considered include power-to-weight ratios (acceleration capabilities), overall lengths, driver eye heights, and braking capabilities.

The findings presented indicate that:

1. current policy of AASHTO may be used to obtain conservative estimates of the time required to accelerate across intersections,
2. longer periods of time in the left lane are needed for passing longer trucks, and

The four major findings were:

1. current design guidelines are conservative for single-unit trucks and tractor-semitrailers and current lengths of grade are thus shorter than these two truck types would warrant,
2. single-unit trucks with trailers and doubles do not perform nearly as well as single-unit trucks and tractor-semitrailers, which may indicate that the performance of the latter two types of trucks match current guidelines,
3. critical length of grade should be based on the weight-to-available power ratio of current truck mix, rather than on assumptions about the performance of a 300-lb/hp truck which was typical in 1965, and
4. highway designers need more comprehensive methods for deciding when hill-climbing lanes are warranted.

Firestine, M.; Hughes, W.; and Natelson, N.; "Operating Larger Trucks on Roads with Restrictive Geometry: Summary Report," Federal Highway Administration Report No. FHWA-IP-89-025, September 1989.

Changes in the 1982 Surface Transportation Assistance Act (STAA) allowing wider and longer trucks on the National Network raised questions about highway safety. This report summarizes the findings of a study which investigated the performance of trucks of various lengths and widths on roads with restrictive geometry.

Field studies at both urban and rural sites indicated that truck drivers compensate for the reduced operating capabilities of larger trucks. Despite driver skill, however, trucks on urban roads encroached into other lanes on streets having lane widths less than 12 feet. Intersections having less than 60-foot corner radii caused some problems for most truck types, especially those wider than 102 inches. Prohibiting large trucks from turning onto narrow urban streets, employing turn movement templates in roadway design, adjusting signal and/or left-turn lengths, and manufacturing 48-foot semitrailers with axles forward only may minimize these and other problems.

On rural roads, lanes wider than 12 or 13 feet allowed oncoming vehicles to move further right to avoid trucks, and shoulders wider than 4 feet allowed oncoming vehicles a greater margin of safety. At sharp curves (7 to 15 degrees), opposing vehicles slowed down significantly and made other undesirable changes to pass large trucks. Consideration should be given to reducing the sharpness of curves greater than 7 degrees and to allowing large trucks on two-lane rural roads having lanes at least 12-feet wide and shoulders greater than 4 feet.

Firestine, M.; McGee, H.; and Toeg, P.; "Improving Truck Safety at Interchanges," Federal Highway Administration Report No. FHWA-IP-89-024.

This report offers guidance in designing interchanges so as to reduce the likelihood of truck accidents on highway interchanges. It summarizes research showing that the interaction between truck dynamics and interchange geometry can contribute to rollovers, jackknifes, and other loss-of-control accidents.

Corrective actions can be applied to six specific ramp design features that were found to contribute to truck accidents:

1. poor transitions to superelevation,
2. abrupt changes in compound curves,
3. short deceleration lanes preceding tight-radius exits,
4. curbs placed on the outside of ramp curves,
5. lowered friction levels on high speed ramps, and
6. substantial downgrades leading to tight ramp curves.

Countermeasures for these design problems include:

1. incorporating a greater safety margin into formulations for side friction factors,
2. improving curve condition and downgrade signs at interchanges,
3. increasing deceleration lane length,
4. overlaying curbs with wedges of pavement or eliminating curbs completely,
5. resurfacing ramps with high-friction overlays, and
6. redesigning sites where accidents are common.

Fitzpatrick, K.; Mason, J. M., Jr.; and Glennon, J. C.; "Sight Distance Requirements for Trucks at Railroad-Highway Grade Crossings," Transportation Research Board Record 1208, 1989.

The sight distance requirements for large trucks at railroad-highway grade crossings are compared with current AASHTO policy. The key elements affecting sight distance requirements include driver characteristics such as perception-reaction time and vehicle characteristics such as vehicle speed, length, acceleration, and braking distance. The results from sensitivity analyses are compared with current policy and are summarized for each sight distance consideration.

The findings imply that current criteria for sight distance along the highway and along the tracks for a moving highway vehicle may not be adequate for large trucks. In contrast, the current AASHTO values for sight distance along the tracks for a stopped highway vehicle adequately reflect current truck performance capabilities.

To provide an adequate margin of safety for truck drivers at railroad-highway grade crossings, current sight triangle values for moving vehicles should be increased to allow for longer trucks and for some measure of the greater stopping distances of trucks compared with passenger vehicles. This may result in many more crossings than previously thought having physical constraints that make the available sight triangle unacceptable.

Fong, K. T. and Chenu, D. C.; "Simulation of Truck Turns with a Computer Model", California Department of Transportation, Report 86-1, January 1986.

This paper describes a computer model developed for analyzing and evaluating truck offtracking. Offtracking results from the computer simulation model are first compared with results derived from the Tractrix Integrator, field observations, and mathematical formulae. The computer model is then used to analyze the offtracking characteristics for several of the newer, longer trucks. Finally, applications of the computer model to evaluate some special offtracking situations or problems are discussed.

Freitas, M. D.; "Large-Truck Safety Research," Transportation Research Board Record 1052, 1986.

This paper describes some of the critical issues that have surfaced during implementation of the Surface Transportation Assistance Act (STAA). One study concluded that doubles experienced higher accident rates than semis and increased truck weight did not increase truck accident rates, but these results have been disputed. Other results from this study were: loaded vehicles and doubles travel slower and deviate more from the average of other traffic causing following vehicles to decelerate faster and leave shorter headways on upgrades than empty trucks and singles; truck length does not have a significant effect on traffic operations; the most serious safety problems caused by large trucks are on upgrades; and only about one-third of the effects of trucks on traffic operations could be explained by differences in truck size and weight.

Other studies did not indicate any serious driver behavioral problems associated with the presence of large trucks. Rearward amplification is a problem for multiunit vehicles where a quick evasive maneuver is amplified rearward to such an extent that the rearmost unit could be caused to roll over. Increasing truck width to 102 inches could result in improvements in rollover thresholds of up to 18 percent. The problem of trucks with shifting cargo such as tankers has been investigated.

One study concluded that larger trucks did not create significantly greater spray patterns. A grade severity rating system has been developed to provide information to truck drivers related to the problem of runaway trucks on steep downgrades. An evaluation of truck stopping sight distance revealed that truck stopping distance is not adequate on a large number of crest vertical curves but deficiencies occur on only a small portion of the curve.

A user-friendly offtracking program has been developed where a turning template is generated where the path and configuration of a truck is given. Ramps have been observed to be a high-accident location for trucks. A method of predicting performance of trucks on upgrades is under study. Trailer coupling mechanisms for multitrailer units are being studied to decrease rollover problems. The geometric and traffic conditions under which various large trucks become unsafe are being studied.

Planned research includes the effectiveness of truck roadway and lane restrictions, safety implications of future configurations, and evaluation of accidents involving larger combination trucks on designated federal-aid highways.

Garber, N. J. and Gadiraju, R.; "The Effect of Truck Strategies on Traffic Flow and Safety on Multilane Highways," Transportation Research Board Annual Meeting, 1990.

The objective of this research was to provide information about the nature and impact of restricting trucks to a specific lane or lanes or imposing a lower speed limit for trucks. The impacts related to traffic flow, speed, headways, and accident patterns. Simulation was used to study the effects of implementing different strategies on multilane highways. The basis for the study was to determine if imposing certain restrictions on truck operations on multilane highways could reduce the effect of increased operation of trucks on these roads.

The results did not indicate any safety benefits from the imposition of any of these strategies but suggested that the potential for an increase in accident rate will be created, particularly when the strategies are imposed on highways having high volumes, a high percentage of which is trucks.

Garber, N. J. and Joshua, S.; "Characteristics of Large-Truck Crashes in Virginia," Transportation Quarterly, Vol. 43, No. 1, January 1989.

Since 1983, annual vehicle miles travelled (VMT) for large trucks in Virginia have been increasing at a rate higher than those for non-large trucks. The lengths and size of large trucks have also increased, particularly after enactment of the Surface Transportation Act of 1982. This combination of increased size and VMT is associated with an increase in fatal crashes involving large trucks. Fatal crashes for all large trucks increased from 3.81 to 5.88 per 100 million VMT and for tractor-trailers from 2.81 to 5.36 per 100 million VMT between 1982 and 1984, while that for non-large trucks remains practically constant below 0.30 per 100 million VMT.

Although the frequency of non-large truck crashes is not significantly affected by the day of the week, the frequency of large-truck crashes is affected by the day of the week, in that fewer truck crashes tend to occur on weekends. This may be due to lower truck VMT on weekends. Countermeasures that are designed to reduce large truck crashes primarily due to a driver-related cause such as police enforcement to reduce speeding will therefore be more effective when implemented during the week than on weekends.

Seasonal effects do not appear to significantly affect large-truck crashes; no significant difference was observed in the monthly percentage distribution of crashes.

Large-truck crashes tend to involve more than a single vehicle, and when a large truck is involved in a two-vehicle crash, there is a 94 percent chance that the second vehicle is not a large truck.

Based on the VMT of each type of vehicle, large-truck/non-large-truck crashes are overrepresented when compared with the expected frequency for two-vehicle crashes. Large-truck/non-large-truck fatal crashes are also significantly overrepresented when compared with the expected frequency for two-vehicle fatal crashes. The overrepresentation of large-truck/non-large-truck crashes suggests than an effective countermeasure would be to separate large-truck traffic from non-large-truck traffic. This, however, requires a detailed study to determine the feasibility of such a measure for specific highway systems and its impact on the overall traffic operation on the system.

Driver-related factors are mostly responsible for large-truck crashes; they are associated with an average of about 75 percent of all large-truck crashes and about 91 percent of large-truck fatal crashes. Driver error is associated with over 50 percent of large-truck fatal accidents; speeding accounts for 21 percent and alcohol for 15 percent of these accidents. Also, large-truck crashes, particularly fatal crashes for which driver error is listed as a factor, occur predominantly on stretches of highways with vertical or horizontal curves and/or grades. This strongly suggests that drivers are more likely to make maneuvering errors at locations with certain geometric characteristics.

The identification of highway alignment as a predominant factor influencing the occurrence of crashes resulting from driver error suggests a study that will identify those geometric characteristics that contribute to these crashes. The results of such a study could be used to develop engineering countermeasures that will be effective in reducing this type of crash.

Garber, N. J. and Joshua, S. C.; "Traffic and Geometric Characteristics Affecting the Involvement of Large Trucks in Accidents; Vol. 1: Accident Characteristics and Fault Tree Analysis," Virginia Transportation Research Council, VTRC 91-R17, January 1991.

Annual vehicle miles driven for large trucks in Virginia has been increasing at a rate higher than for all other vehicles. The fatal accident rate for tractor trailers is higher than for other vehicle types and has been increasing.

The lower vehicle miles travelled on weekends means that countermeasures designed to reduce large-truck crashes resulting from driver-related causes will be more effective during the week than on weekends. No significant difference was observed in the monthly percentage distribution of truck accidents. Large-truck accidents tend to involve more than a single vehicle.

Driver-related factors appear to be the primary associated factors for truck accidents and occur predominantly on stretches of highways with vertical or horizontal curves and/or grades.

Most truck/other vehicle accidents are same-direction-sideswipe collisions whereas most large-truck/large-truck accidents and straight truck/other vehicle accidents are rear-end collisions.

Tractor trailer involvement in accidents has increased across all types of highways since 1982, with the highest increase on non-STAA primary routes. The next highest increase was on STAA primary routes, and the smallest increase was on interstate routes.

Preventive measures for driver-related failures, vehicle-relate failures, and environmental-related failures are listed.

Gericke, O. F. and Walton, C. M; "Effect of Increased Truck Size and Weight on Rural Highway Geometric Design (and Redesign) Principles and Practices," Transportation Research Board Record 806, 1981.

A summary is presented of a study of the effects that an increase in legal truck limits would have on highway geometric design elements and of the cost implications should various segments of the Texas highway system require redesign and modification to facilitate their safe and efficient operation. The paper includes:

1. a review of past and current research concerning the effects of a possible change in legal vehicle dimensions and weights on the geometric design of rural roads,
2. an identification of those geometric elements most affected by a change in truck dimension and weight,
3. an assessment of the effects a change in legal truck size and weight will have on these geometric design elements for a variety of operating conditions, and
4. an estimate of the cost required to redesign and modify the highway section.

No change from current policy on stopping sight distance was foreseen. The current pavement marking policy for no-passing zones would be unaffected. Due to increased offtracking, additional pavement width would be needed on curves, sharp turns, turning roadways, and median openings. No adverse effect on the climbing ability of trucks was expected. Although no change in current policy on lane or shoulder width was expected, strict adherence to current desirable standards would be necessary which would be very costly for some road classes. Additional sight distance would be needed to cross an intersection because of the increase in truck length and the additional time to cross an intersection.

Gillespie, T. D.; " Start-Up Accelerations of Heavy Trucks on Grades," Transportation Research Board 1052, 1986.

Predicting truck clearance times in intersections requires an understanding of the mechanics of the start-up process and how it is influenced by grade. The objective of this paper was to present an analysis of these mechanisms and apply the methods to the problem of predicting truck clearance times at rail-highway grade crossings. The analysis is limited to heavy highway trucks typified by the 80,000 pound tractor-semitrailer.

The acceleration performance of heavy trucks starting on grades represents an important boundary consideration in highway design. Trucks generally possess the lowest levels of acceleration performance. This, in combination with their length, makes them the highway vehicle class that requires the greatest time to proceed across intersections. Especially at railroad-highway grade crossings, truck performance establishes bounds on the timing requirements for warning devices.

The analysis is applied to the problem of clearance times at rail-highway grade crossings where regulations mandate travel in the start-up gear and the time-distance relationships are determined by the gear required for starting on the grade. The analysis reveals that attainable speed decreases with increasing grade and affects the clearance times that should be allowed.

Glauz, W. D. and Harwood, D. W.; "Superelevation and Body Roll Effects on Offtracking of Large Trucks," Transportation Research Board Annual Meeting, January 1991.

This paper investigated how the presence of superelevation contributes to offtracking, as well as investigating the effect on offtracking of rolling of the body of the truck relative to the suspension. The effect of superelevation was determined to be proportional to the amount of superelevation and independent of the vehicle speed.

Superelevation was determined to increase low speed, negative offtracking of trucks by 10 to 20 percent for typical amounts of superelevation. Superelevation also tends to reduce the amount of high speed outward offtracking. The magnitude of the effect is independent of speed. The effect is greater with more heavily loaded trucks, trucks having newer tires, and trucks with larger roll steer coefficients. The negative contributions to offtracking are more than compensated by increased positive effects at higher speeds.

Body roll was determined to affect both high speed offtracking and the superelevation contribution to total offtracking. Trucks having softer suspensions are more affected. The net effect is to increase outward offtracking at normal and high speeds, and to slightly increase negative offtracking at very low speeds.

"Guide for Monitoring and Enhancing Safety in the National Truck Network," Federal Highway Administration, American Society of Civil Engineers, Accommodation of Trucks on the Highway: Safety in Design, 1988.

The Surface Transportation Assistance Act (STAA) of 1982 requires that:

1. state weight limits equate to Federal maximums,
2. width limit of 102 inches on the National Network,
3. length limit of at least 48 feet for semitrailers,
4. doubles must be allowed on the National Network,
5. must allow length of 28 feet for trailer used in a double,

6. the overall length of singles or doubles may not be limited on the National Network, and
7. reasonable access must be provided off the National Network.

The National Network was completed in 1984. There are no overall length requirements for STAA vehicles. States must require minimum trailer lengths of 48 feet for singles and 28 feet for doubles. The most common length allowed over 48 feet is 53 feet with the longest 59 1/2 feet. The STAA increased the trailer width from 96 to 102 inches. Tractors have remained at the 96-inch width. The STAA did not affect vehicle height. Height limits range from 12 feet, 6 inches to 14 feet, 6 inches with 13 feet, 6 inches most common. Weight provisions of the STAA only apply to interstates with limits of 80,000 pounds gross, 34,000 pounds per tandem axle, and 20,000 pounds per single axle. Many states allow higher gross weight limits off the interstate system.

The extra cube in a 48-foot long, 102-inch wide trailer can result in over $15,000 per year in gross revenue. A set of twins (28-feet long and 102-inches wide) can yield $34,500 additional gross revenue over a standard 45-foot, 96-inch trailer.

The AASHTO Green Book has four design vehicles for trucks (single unit (SU), WB-40 and WB-50 semitrailers, and WB-60 doubles). The WB signifies wheelbase measured between the front axle and the rearmost axle. AASHTO has not adopted a design vehicle representing the STAA semitrailer. The most widely used semitrailer is the WB-63 developed by CALTRANS which is 70-feet long with a 48-foot trailer.

Low-speed offtracking (each axle follows a path that lies inside of the preceding axle) occurs during turns. High-speed offtracking (trailer tracks to the outside of the tractor) occurs primarily on interchange ramps. High-speed offtracking on a 600-foot radius curve ranges from 0.5 foot for semitrailers to 1.4 feet for doubles and 2 feet for triples. Low-speed offtracking is greater for longer vehicles and those having fewer articulation points. Other factors are wheelbase, kingpin offset, axle-to-pintle hook distance, and towbar length. For a 300-foot radius curve, offtracking values are 2.0 feet for a WB-50 and two 28-foot trailers (STAA double) with a 10.5-foot swept path (the sum of the offtracking plus vehicle width). Offtracking causes problems at 90-degree intersections where offtracking for a WB-50 and STAA double would be 12.5 feet with a swept path of 21 feet compared to offtracking of 8.4 feet for a WB-40 with a swept path of 16.9 feet.

Doubles have problems backing compared to semitrailers. A controlled steering B-dolly aids the backing of doubles.

Vehicles having more articulation points are more likely to become unstable if their wheels lock. Empty or lightly loaded trucks have a greater tendency to jackknife or hydroplane and require greater distances to stop than heavily loaded trucks since their braking system is sized for a loaded condition. Bobtail tractors exhibit the worst performance. Typical coefficient of friction values for stopping at 60 mph on dry pavement are 0.67 for a car, 0.53 for a bus, 0.41 for a loaded combination truck, 0.34 for a loaded single unit truck, 0.30 for an unloaded single unit or combination truck, and 0.24 for a bobtail tractor.

Rearward amplification occurs in multi-trailer trucks where the lateral acceleration of the tractor is amplified rearward to the point where the rear trailer could roll over. Semitrailers do not have this problem. However, for doubles, the trailer experiences twice the lateral acceleration of the tractor such that an evasive maneuver that feels safe to the driver could cause the rear trailer to roll over.

The 102-inch wide trailer provides about 14 percent more resistance to rollover compared to the 96-inch trailer. The rollover threshold of a loaded semitrailer (about 0.4 g) is about one-third that for a typical mid-sized car (about 1.2 g). Yaw stability is the movement of the vehicle around its vertical axis which can result in jackknifes. This is a function of the tractor and unaffected by the number of trailers.

The Texas Tall Wall (90-inches high) and the New Jersey Tall Wall (42-inches high) are barriers designed for larger vehicles. The design of barriers must consider the center of gravity of different vehicles. The center of gravity varies from 18 to 24 inches for a car to 60 to 78 inches for a loaded truck (45 inches for an unloaded truck). Light poles and sign foundations should not be mounted on top of concrete barriers less than 42 inches in height since they may be hit by trucks. Breakaway sign supports are not a problem for trucks, but the location of the sign panels can be a problem if they are close to the driver eye height of about 8 feet which could result in a sign penetrating the windshield.

A principal disadvantage of not enforcing vehicle weight limits is damage by overstressing existing bridges which decreases their service lives. A bridge designed for a 50-year life will only last 12-17 years if subjected to a 36 percent overstress.

A climbing lane is warranted on high-volume routes where the length of grade causes loaded vehicles to reduce speed 10 mph or more resulting in unreasonable delays. Curbs should not be used on ramps since they may "trip" the trailer and result in rollover. Driveways into commercial developments need wide curb openings. Emergency escape ramps can be used in locations having a history of large vehicle run-away accidents.

Designing an impact attenuator must take into account the characteristics of large trucks and with present technology such a device is not practical. Increased offsets are needed from the inside radius of a turn at intersections (to a fixed object) to allow for offtracking. This increases the distance the pedestrian must travel across the intersection. The blind area on the right side of the truck when making a left turn must be considered.

The STAA requires a 12-foot lane width for use by the 102-inch vehicle unless a lesser lane width is determined to be safe at a particular location. Loading docks should be located far enough from the access street to minimize lane encroachment. Steep pavement cross slopes in combination with vehicle lean and side-to-side sway result in vehicles tilting and hitting roadside obstacles that are located immediately behind curbs. Steep pavement crown can result in excessive side-to-side sway making vehicle control difficult at high speeds.

Reliable truck weight data must be used in pavement designs and vehicle weight limits must be observed and enforced since a single truck loaded to 80,000 pounds is equivalent to 9,600 cars. Paved shoulders provide edge support.

Skid resistant surface courses are important for trucks. Edge dropoffs can result in rollover in high center of gravity vehicles. Tire damage can also result from dropoffs which may later result in tire failure.

Highway profiles at grade crossings should be constructed to prevent a truck from "hanging up". Pulloff lanes could be provided. Sight distances must be checked.

Larger parking spaces and greater turning radii may be necessary in rest areas and weigh stations. Because of the high center of gravity, shifting loads, and higher rollover potential of trucks, slopes flatter than those acceptable for cars are desirable.

Although truck drivers have an eye height advantage over drivers of cars, this may not compensate for other disadvantages of loaded trucks. Trucks need 50 percent more distance to complete a passing maneuver than cars and large vehicles require more time to transverse uncontrolled intersections than do cars. Warning signs placement must provide truck drivers time to perceive, react, and execute a maneuver without undue vehicle or load instability. Signs several miles in advance of restrictions for trucks should be provided. Night visibility of signs and markings is slightly less for truck drivers than car drivers because of the relative position of the truck's headlights compared to the driver's eye height. Overhanging vegetation must be cleared considering the driver eye height for the truck driver (about 8 feet).

Left turn signal detectors may not be actuated if the truck must swing wide to accomplish a turn. Acceleration and deceleration lanes adequate for cars may not be adequate for trucks. Turning lane storage lengths may have to be lengthened to account for trucks. Trucks are more sensitive than cars to deficiencies in superelevation or transitions to superelevated sections. Spiral transitions are preferred. Guidelines on radii ratios and compounding considerations should be followed. Large trucks are overrepresented in fatal accidents in work zones.

Harkey, D. L. and Robertson, H. D.; "Local Access for Longer Combination Vehicles," University of North Carolina at Charlotte, Transportation Publication Report No. 2, 1989.

This report examines local access provisions for longer combination vehicles (LCVs). Two approaches to access were considered: direct access and staging areas. Each approach was examined from both an engineering standpoint, including geometric design and safety, and an economic standpoint in terms of cost.

Three models were developed representing fixed, operating, and accident costs. A least cost analysis using equivalent uniform annual costs was employed to compare the two approaches to providing local access for LCVs.

The results indicated the direct access approach to be better than the staging area approach. However, it was concluded that within a given State and set of circumstances, either approach could prove to be the better. Thus the final selection of the most appropriate approach would be a function of the specific access route with respect to geometrics, traffic composition, and capacity.

Harwood, D. W.; Glauz, W. D.; and Mason, J. M.; "Stopping Sight Distance Design for Large Trucks," Transportation Research Board Record 1208, 1989.

This paper compares the stopping distance requirements for large trucks with current AASHTO stopping sight distance criteria. Key elements affecting stopping sight distance for trucks include perception-reaction time, truck braking distance, and truck driver eye height. The paper stresses the variability of truck driver braking performance and the safety benefits associated with antilock brake systems for trucks.

Findings indicate that trucks having conventional brake systems may require stopping sight distances greater than those recommended by current AASHTO policy. The increased values potentially affect all related stopping sight distance design considerations (horizontal and vertical curvature, intersection sight distance, and highway-railroad grade crossings). The magnitude of increase is highly dependent on individual driver brake performance capabilities. For drivers whose emergency braking performance is equivalent to the worst performance observed in braking tests for conventional brake systems, substantially greater stopping sight distance and longer vertical curves would be needed than are used under current AASHTO criteria. Drivers having braking performance equivalent to the best performance observed in braking tests for conventional brake systems require only slightly longer stopping sight distance than current AASHTO criteria and require vertical curve lengths that are shorter than current AASHTO criteria. If antilock brake systems are eventually mandated for trucks, current AASHTO stopping sight distance policy would adequately accommodate the needs of large trucks.

A truck with a conventional brake system driven by a worst-performing driver requires up to 425 feet more stopping sight distance at 70 mph and requires longer crest vertical curves than current AASHTO policy recommends. Trucks having antilock brake systems require less stopping sight distance and significantly shorter crest vertical curves than current AASHTO policy recommends. Trucks having antilock brake systems can stop in the same or less distance than a passenger car.

Harwood, D. W. and Glennon, J. C.; "Passing Sight Distance Design for Passenger Cars and Trucks," Transportation Research Board Record 1208, 1989.

Current design and marking criteria for passing zones on two-lane highways are reviewed in this paper. Safe and effective passing zones on two-lane highways require both adequate sight distance to opposing vehicles and adequate passing zone length. A model of the kinematic relationships among the passing, passed, and opposing vehicles was employed to evaluate the current design and marking criteria. The model is used both to evaluate the current criteria, which are based solely on passenger cars, and to consider the passing requirements when the passed vehicle, the passing vehicle, or both, are large trucks.

Successively longer passing sight distances are required for a passenger car passing a truck, a truck passing a passenger car, and a truck passing a truck. There is no general agreement concerning which of these situations is the most reasonable basis for designing and operating two-lane highways. The passing sight distance criteria derived were all shorter than the AASHTO design criteria, which are based on very conservative assumptions. The analysis results indicate that, if a passenger car passing a passenger car is retained as the design situation, only minor modifications are needed to the MUTCD passing sight distance criteria. If a more critical design situation is selected, such as a passenger car passing a truck, passing sight distances up to 250 feet longer than the current MUTCD criteria would be required. The increased driver eye height of trucks partially, but not completely, offsets the increased passing sight distance requirements when the truck is the passing vehicle.

There are no current criteria for passing zone lengths, except for the default 400-foot guideline set by the MUTCD. Research may justify an increase in minimum passing zone length to at least 800 feet for highways having a prevailing speed over 40 mph.

Harwood, D. W.; Mason, J. M.; Glauz, W. D.; Kulakowski, B. T.; and Fitzpatrick, K.; "Truck Characteristics for Use in Highway Design and Operation," Federal Highway Administration Report FHWA-RD-89-226, December 1989.

This report reviews existing data for the truck characteristics that need to be considered in highway design, including truck dimensions, braking distance, driver eye height, acceleration capabilities, speed-maintenance capabilities on grades, turning radius and offtracking characteristics, suspension characteristics, and rollover threshold. The highway design and operational criteria evaluated include sight distances, vertical curve length, intersection design, critical length of grade, lane width, horizontal curve design, vehicle change intervals at traffic signals, sign placement, and highway capacity. An assessment has been made of the need to change the current highway design and operational criteria to accommodate trucks. The cost effectiveness of proposed changes in design and operational criteria is evaluated.

Other design vehicles were recommended to be included in the 1984 AASHTO Green Book. These include a 45-foot semitrailer, a STAA single with 48-foot semitrailer, a STAA double with two 28-foot trailers, and a 53-foot semitrailer.

Current AASHTO criteria are not adequate to accommodate trucks with conventional braking systems and poor performance drivers. Increased stopping distance criteria to accommodate trucks with conventional braking systems are given. For example, at a design speed of 50 mph, the stopping sight distance is increased from 475 feet to 675 feet. Stopping distance criteria are adequate for trucks having antilock brake systems. For trucks having conventional brake systems and the best performance driver, current

AASHTO criteria are adequate at vertical sight restrictions with about 50 feet of additional stopping sight distance needed at horizontal sight restrictions.

Passing scenarios involving a passenger car passing a truck, a truck passing a passenger car, and a truck passing a truck require progressively more passing sight distance than a passenger car passing a passenger car. Since passing maneuvers involving trucks require longer sight distance than passing maneuvers involving just passenger cars, they also require longer vertical curves if a passing zone is to be maintained over a crest. There are no current criteria for passing zone lengths, except for the default 400-foot guideline set by the MUTCD which is too short in most instances for trucks. Changes in passing sight distance criteria to accommodate a truck as the passing vehicle may not be needed because most passing zones on two-lane highways are not long enough to accommodate delayed passes by trucks.

Trucks require more decision sight distance than passenger cars. The higher driver eye height for trucks partially offsets the increased decision sight distance requirement at vertical sight restrictions, but not at horizontal sight restrictions. A change in decision sight distance criteria to accommodate trucks by using longer vertical curves on the approach to major decision points would be cost effective only in unusual situations having extremely high accident rates.

For intersections having no control, trucks may require up to 69 percent more sight distance than passenger cars. For intersections having yield control, the intersection sight distance requirements for trucks are the same as those recommended for the stopping sight distance. Larger trucks currently on the road require up to 17.5 percent more sight distance for an intersection crossing maneuver than the current AASHTO criteria based on a WB-50 truck. For left- and right-turn maneuvers at intersections, use of truck characteristics in the current AASHTO models can require sight distances up to 139 percent greater than a passenger car.

Intersection and channelization geometrics should be based on the low-speed offtracking characteristics of the larger design vehicles.

Current criteria for the sight distance at railroad crossings should be increased for trucks having conventional brake systems. Criteria are adequate for trucks having antilock brakes.

The AASHTO criterion for truck weight-to-power ratio used to define the critical length of grade should be reduced from 300 lb/hp to 250 lb/hp.

The current AASHTO lane width criteria are adequate to accommodate trucks.

Current AASHTO criteria for horizontal curve radius and superelevation at particular design speeds are adequate to accommodate trucks. Increased emphasis is needed on the realistic selection of design speeds for horizontal curves, particularly on freeway ramps. Revised criteria for pavement widening on horizontal curves to accommodate an STAA single 48-foot semitrailer truck are given.

Trucks require vehicle change intervals between 40 and 110 percent longer than passenger cars, depending on approach speed, approach grade, and intersection width.

Advance warning sign placement criteria for trucks having conventional brake systems should be longer than the current criteria which are based on consideration of passenger cars.

Harwood, D. W.; St. John, A. D.; and Warren, D. L.; "Operational and Safety Effectiveness of Passing Lanes on Two-Lane Highways," Transportation Research Board Record 1026, 1985.

An operational and safety evaluation of passing lanes and short four-lane sections was performed by using traffic operational field data collected at 15 sites and traffic accident data for 76 sites. Passing lanes and short four-lane sections are installed to provide increased opportunities for passing slow-moving vehicles on two-lane highways.

It was determined that passing lanes decrease the percentage of vehicles platooned on two-lane highways and that the magnitude of this benefit varies with passing-lane length, traffic volume, and the level of platooning upstream of the passing lanes. Passing lanes increase the rate of passing maneuvers on two-lane highways but have only a small effect on mean travel speeds. Passing lanes and short four-lane sections do not increase accident rates above the levels determined for comparable untreated two-lane highways and probably improve safety.

Heald, K. L.; "Use of the WHI Offtracking Formula," Transportation Research Board Record 1052, 1986.

This paper describes the data requirements and use of the Western Highway Institute (WHI) offtracking formula. Offtracking is the phenomenon that occurs when the trailing axles of a turning vehicle increasingly migrate toward the curve center until they finally reach a maximum steady-state offset from the steering alignment path. Steady-state offtracking is achieved when the projected extensions of all fixed axles pass through the curve center. For turns of 120 degrees or less, maximum offtracking observed will seldom fully achieve that of the steady state; however, the clean geometric relationships that exist at the steady-state condition make it possible to readily quantify and use this worst-case performance as a basis of comparison for various vehicle configurations. The WHI offtracking formula provides a relatively straightforward method of closely approximating the steady-state expectations for any given vehicle or combination.

Hirsch, T. J.; "Longitudinal Barriers for Buses and Trucks," Transportation Research Board Record 1052, 1986.

This paper describes an effort to develop longitudinal traffic barriers or rails capable of restraining and redirecting buses and large trucks. Theory and crash test results are presented to demonstrate the magnitude of the impact forces these traffic rails must resist and how high they must be to prevent vehicle rollover. Typical designs of longitudinal barriers that have been successfully crash tested in accordance with recommended procedures are presented.

The information presented shows that longitudinal barriers (guardrails, median barriers, and bridge rails) can be designed and constructed to restrain heavy vehicles such as buses and trucks. To redirect an 80,000-pound tractor-trailer at 50 mph and a 15-degree angle, the barrier should be capable of resisting about 190,000 pounds.

To redirect school and intercity buses without rollover, barriers should be about 38 to 42 inches high. Van-type trucks need a barrier from 50 to 54 inches high to minimize rollover at 50 mph and 15-degree angle impact. Tank-type trucks need a barrier from 78 to 90 inches high to prevent rollover at the same speed and angle. Barriers having a vertical face on the traffic side are much better for resisting vehicle rollover.

Hummer, J. E. and Zegeer, C. V.; "Effects of Turns by Larger Trucks at Urban Intersections," University of North Carolina at Charlotte, Transportation Publication Report No. 24, 1988.

This paper includes results and conclusions from a study of the safety and operational effects of larger truck combinations. Computer simulation and manual observations at six intersections were used to investigate turns by larger trucks at urban intersections. The encroachment of a truck into adjacent lanes during a turn was studied using the computer simulation. The field data examined on a particular truck turn included the encroachment, the time to complete the turn, and the conflicts with other vehicles in the traffic stream caused by the truck. Field observations were made of turning trucks in the traffic stream and also of a control truck of known size driven repeatedly through a study intersection by a professional driver who knew the purpose of the experiment.

The results showed that small curb radii, narrow lane widths, and narrow total street widths were among the geometric features associated with increased operational problems. The results also showed that larger trucks will have little impact (compared with smaller trucks) at most urban intersections of the types tested, but some adverse operational effects should be expected at some intersections. Trailer length was determined to be a more critical element to smooth operations than trailer width for the trucks tested. Many site, driver, and equipment factors should be considered before the decision can be made to regulate truck traffic in a certain manner.

Humphrey, N.; "Access for Large Trucks," TR News, Transportation Research Board, Number 146, January-February 1990.

This paper summarizes the findings of a committee organized by the Transportation Research Board to study the establishment of a nationwide policy for the provision of reasonable access for large trucks authorized by the Surface Transportation Assistance Act (STAA) of 1982. Permitting larger trucks has improved the efficiency of freight transportation by truck. However, some state and local transportation officials believe that the highway system, particularly those highways built to lower standards than the Interstate system is at the limit of its ability to accommodate large trucks. Nine states (all in the west) allow STAA trucks on all primary roads. Another 18 states allow them on more than two-thirds of the mileage on their primary roads while 17 states, nearly all in the east, allow these trucks on fewer than one-third of the miles on their primary highways.

A national standard for determining access was deemed inappropriate by the committee because no single standard could take into account differences in local highway and traffic conditions. Instead, determination of appropriate highways for access should be based on safety-related differences between STAA vehicles and the vehicles they replace. In the absence of direct information on the accident experience of STAA relative to pre-STAA vehicles, making this determination requires judgments about the adequacy of specific highway design features. The modest increase in vehicle width was deemed to have only a minor effect on the safe operation of STAA vehicles, except on narrow lanes of 10 feet or less.

The committee recommended that the Federal Highway Administration require states to adopt and use procedures based on safety and engineering considerations to evaluate the adequacy of highways to accommodate STAA vehicles and review and certify these procedures. The report focused on measures to improve vehicle maneuverability. The committee recommended that states adopt a maximum kingpin-to-center-of-the-axle setting of 41 feet.

Guidelines for processing access requests were recommended: requests should be reviewed in 30 days or less, with automatic approval if applications were not reviewed in 90 days. It was concluded that it would not be necessary to evaluate all the short routes to provide access to service facilities, and a minimum distance of one mile from designated highways to provide access to service facilities should be provided. The recommended definition for terminal was any location where freight either originates, terminates, or is handled in the transportation process or where carriers maintain operating facilities.

Hutchinson, B. G.; "Large-Truck Properties and Highway Design Criteria," Journal of Transportation Engineering, Vol. 116, No. 1, January 1990.

Substantial increases in truck weights and dimensions have occurred over the past decade and these changes have important implications for the criteria used for the design of various components of highway infrastructure. This paper reviews the findings of a wide range of studies on truck characteristics and the ways in which these characteristics influence the design criteria. The truck properties examined include braking distances, rollover thresholds, traffic capacity impacts, speed profiles on grades, passing sight distances, low-speed offtracking at intersections, intersection capacity and signal timing, force effects in bridges, and pavement axle-load equivalencies. The paper concludes that the many design procedures used for infrastructure design should be revised to incorporate this new evidence.

Loaded trucks are capable of achieving a braking efficiency of 70 percent, but braking efficiency deteriorates substantially for the partially loaded and unloaded conditions. Trucks having worn tires will require stopping distances that are substantially longer than those recommended in AASHTO standards.

The rollover thresholds of some truck types are close to the centripetal accelerations implied in the design of horizontal curve elements, about 0.2 g. Side friction coefficients of about 0.08 rather than 0.13 should be used for curve design.

An analysis of passing sight distance on roads with 100 km/h design speeds suggests that the required distance would increase from about 300 m for a passenger car to 350 m for a standard tractor semitrailer to about 400 m for a double trailer.

Offtracking has important implications for intersection layout and traffic capacity. Draft Canadian regulations require that the ratio of effective trailer length to the effective wheelbase be limited to 1.35. If this requirement is combined with the maximum offtrack magnitude, then the maximum trailer lengths would be 38 feet for twin trailers and 53 feet for single trailers.

The size, acceleration, and deceleration capabilities of large trucks have impacts on signal timing decisions and intersection efficiency. Lower braking capabilities often result in trucks violating signal clearance times.

The lower acceleration capabilities of large trucks and their lengths suggest that current sight distance standards at stop-signed intersections should be increased.

Hutchinson, J. W.; Vaziri, M.; and Hopwood, T.; "Highway Factors in Truck Wrecks," American Society of Civil Engineers, Accommodation of Trucks on the Highway: Safety in Design, 1988.

An examination of highway factors as they interact with driver and vehicle factors in large truck accident causation is given. Examples of highway defects are presented along with some of the sources, consequences and needed preventive measures.

Most of the highway factors contributing to truck accidents appear to have resulted from avoidance or misapplication of safety design principles which were known long before large scale highway building programs in the 50's and 60's. Continued avoidance and misapplication of both those older principles and the new knowledge gained from subsequent research have increased the contribution of highway factors in large truck accidents. Increased size and weight allowances resulting from 1982 STAA legislation will even more grossly exceed the capabilities of this flawed highway infrastructure to provide safe accommodations for the general traffic profile comprised of increasingly smaller cars and larger trucks. The potential stability and control problems for larger trucks and the injury and death consequences for passenger car occupants are unacceptable.

These consequences are seen to have been generated by lack of an overall management strategy for the highway transport industry and the almost complete failure of present highway engineering routines. A continuing, cooperative, comprehensive planning and management process is needed for the highway transport industry. Present static highway engineering routines based upon tables and charts need to be supplemented by mandatory design dynamic acceleration end result specifications and measurements.

Jackson, L. E.; "Truck Accident Studies," Transportation Research Board Record 1052, 1986.

This paper is a compilation of the data on and analysis of many of the in-depth multidisciplinary, heavy-truck accident investigations that have been conducted by the National Transportation Safety Board (NTSB). Data from such investigations of the first event in an accident involving a combination truck showed that 72.1 percent involved another vehicle, 8.0 percent involved a pedestrian, 2.7 percent involved hitting a guardrail, and 5.4 percent resulted in an overturn. The percentage of fatal accidents on curves was 19.5 percent. Wet pavement was involved in 17 percent of the accidents with snow or ice involved in 5.3 percent.

Truck tires are designed for mileage and use hard material for the rubber compound so there is less adhesion for stopping. Truck tire traction is about 65 to 85 percent that for an automobile. Truck stopping is also hindered if brake adjustments are not made at regular intervals. Brake efficiency decreases if slack adjustment exceeds two inches. Front brakes are sometimes disconnected. In addition to creating longer stopping distances, deficient brakes create weight shift which reduces braking efficiency. A bobtail truck with no front brakes would have a coefficient of friction of 0.34 compared to 0.40 with front brakes. Vehicle inspections revealed truck brakes to be the greatest problem. One study revealed 37 percent of all violations were related to brakes and 18 percent of trucks were placed out of service as a result. Deficient brakes cause problems on steep downgrades and on wet pavement.

The center of gravity of trucks having high loads may approach 70 to 80 inches off the ground. These vehicles may overturn at 0.24 to 0.45 g's.

The acceleration of empty trucks may be as slow as two feet per second per second. Trucks have deceleration, acceleration, and turning problems at intersections. Longer acceleration lanes may be needed. Profiles of railroad crossings can be a problem for long trucks having low clearances. Problems with truck drivers hearing the warning horn early enough and sight distance limitations are problems at railroad crossings. There is a question concerning whether the 20-second advance warning at railroad crossings is adequate for trucks.

One issue is the significance of special wavelengths of road roughness to which trucks may be sensitive. Guardrails usually provide little protection for trucks. Concrete median barriers may have the tendency to dislodge the tractor's front axle. Different data bases give percentages from 5.4 to 8.7 percent for the percent of accidents with trailers involving an overturned vehicle. Truck drivers tend to turn curves sharper than the design for the curve.

Trucks are slightly overrepresented in accidents on wet pavements. A truck tire at 40 to 100 psi will hydroplane at 50 to 60 mph. Trucks tend to jackknife under many conditions (unbalanced braking, lack of brakes, or on low-friction surfaces) and can hydroplane when lightly loaded.

Jones, I. S. and Stein, H. S.; "Truck Operating Characteristics in Relation to Safety," American Society of Civil Engineers, Accommodation of Trucks on the Highway: Safety in Design, 1988.

For a two-year period, large truck crashes on the interstate system in Washington State were investigated using a case-control method. For each large truck involved in a crash, three trucks were randomly selected for inspection from the traffic stream at the same time and place as the crash but one week later. The effects of truck and driver characteristics on crashes were assessed by comparing their relative frequency among the crash-involved and comparison sample trucks. Truck configuration, truck equipment condition, and driving hours were the dominant factors associated with increased crash risk. Double trailer trucks were consistently overinvolved in crashes by a factor of three regardless of driver age, hours of driving, cargo weight, or type of fleet. Driving in excess of eight hours increased the risk of crash involvement by a factor of two; drivers with logbook violations, young drivers, and interstate drivers also had increased crash risks. Trucks with defective equipment were overinvolved in crashes. Trucks having brake defects had a crash risk one and one-half times that for trucks without brake defects. Trucks having steering defects had a risk that was at least twice that for trucks without defects.

Joshua, S. C.; "Traffic and Geometric Characteristics Affecting the Involvement of Large Trucks in Accidents; Vol. I: Accident Characteristics and Fault Tree Analysis," Virginia Transportation Research Council, VTRC 91-R17, January 1991.

Annual vehicle miles driven for large trucks in Virginia has been increasing at a rate higher than for all other vehicles. The fatal accident rate for tractor trailers is higher than other vehicle types and has been increasing.

The lower vehicle miles travelled on weekends means that countermeasures designed to reduce large-truck crashes resulting from driver-related causes will be more effective during the week than on weekends. No significant difference was observed in the monthly percentage distribution of truck accidents. Large-truck accidents tend to involve more than a single vehicle.

Driver-related factors appear to be the primary associated factors for truck accidents and occur predominantly on stretches of highways with vertical or horizontal curves and/or grades.

Most truck/other vehicle accidents are same-direction-sideswipe collisions whereas most large-truck/large-truck accidents and straight truck/other vehicle accidents are rear-end collisions.

Tractor trailer involvement in accidents has increased across all types of highways since 1982, with the highest increase on non-STAA primary routes. The next highest increase was on STAA primary routes, and the smallest increase was on interstate routes.

Preventive measures for driver-related failures, vehicle-related failures, and environmental-related failures are listed.

Jovanis, P. P.; Chang, H.; and Zabaneh, I.; "Comparison of Accident Rates for Two Truck Configurations", Transportation Research Board Record 1249, 1989.

Industry-supplied data allowed a structured statistical comparison of the safety performance of tractor-semitrailers (singles) and doubles by comparing their accident experience on the same routes for three years. This paired structure essentially controls for roadway, environmental and traffic conditions. Separate comparisons of vehicle safety performance were conducted for access- and non-access-controlled highways, local streets, and parking lots.

In general, doubles experienced lower accident rates than singles in 1983 and 1985, but higher accident rates in 1984, which was a year of greatly expanding doubles operation. Doubles' accident rates are significantly lower than singles' accident rates for all types of operating environments over the entire period from 1983 to 1985. For the types of carriers represented in the data and for the conditions characterized by the routes in the sample, the consistent evidence is that doubles had better safety performance than singles except for the transition year 1984. The generalization derived from the study is that doubles are generally as safe or safer than singles, even when specifically controlling for roadway, traffic, and environmental conditions. This study was conducted on routes that are approved for doubles' operation. It is, therefore, not appropriate to extrapolate these findings to any specific route.

Khasnabis, S.; "Operational and Safety Problems of Trucks in No-Passing Zones on Two-Lane Rural Highways," Transportation Research Board Record 1052, 1986.

The purpose of this paper was to discuss the interactive effects of geometric design elements and traffic composition (with particular emphasis on truck traffic) on traffic accidents and operational aspects on two-lane highways in mountains. Included in the analysis are passing-related accidents, human factors elements, and the impact of passing lanes and four-lane sections.

There is no information in the literature on the incidence of truck accidents in no-passing zones. Truck size (length and width) appears to be an intimidating factor in lateral placement of vehicles during passing, as well as longitudinal separation (gap) from the following vehicle. Also, increased traffic turbulences are associated with longer trucks. However, there is no evidence of increased hazard resulting from wider trucks.

The current MUTCD practice of marking passing zones designed for automobiles may not be adequate for trucks. The increased eye height of truckers does not compensate for increased truck passing distance.

Limited evidence from the literature suggests that both passing lanes and short four-lane sections are likely to provide significant operational benefits on two-lane highways.

"Large Truck Safety and Roadway Elements", Georgia Institute of Technology, November 1985.

The objectives of this study were to measure the relative safety of various types of large trucks, identify types of roadways and specific roadway and traffic characteristics most closely associated with large truck crashes, and develop a procedure that could be used to deny certain classes of truck transportation access to specified sections or classes of highways.

The study concluded that the truck safety problem on the Georgia state highway system largely concentrated in rural areas and predominantly involved tractor-semitrailers. The tractor-semitrailer accident rate for the lower functional classes of rural state highways exceeded that for rural Interstate and other principal arterials by a factor of about 6.5. This factor for urban highways was approximately 13.6. An engineering study of 200 truck crash sites failed to reveal any remarkable differences between the roadway and traffic characteristics of those sites and similar characteristics of a randomly selected group of Georgia roads. The design features of 200 truck crash sites were noticeably inferior to those of a 2,667-mile system of roads that had been designated in 1983 for larger truck use.

Lunenfeld, H.; "Accommodation of Large Trucks: Traffic Control Issues," American Society of Civil Engineers, Accommodation of Trucks on the Highway: Safety in Design, 1988.

This paper addressed the accommodation of large trucks in terms of traffic control. A systems approach identified driver attributes, driving task requirements, vehicle handling characteristics, and information needs for large trucks that are incompatible with similar passenger car factors and often result in problems. Traffic control issues were assessed for devices contained in the Manual on Uniform Traffic Control Devices (MUTCD). Problems were identified and suggestions for improvement presented. It was concluded that problems can often be ameliorated through engineering studies, optimum information displays, and trade-offs.

The effectiveness of retroreflective signs is diminished for truckers because of the vertical distance between eye height and headlight height, which is considerably smaller for passenger cars than for large trucks. The vertical distance affects the observation angle resulting in a higher observation angle for truck drivers which lowers the perceived specific intensity per unit area. Drivers of large trucks would have less lead time than passenger car drivers to read and respond to information from a fixed sign at night.

The truck eye height/headlight height vertical difference problem for signs applies to retroreflective pavement markings as well. Passing zones suitable for passenger cars may be too short for trucks.

There are disproportionately high numbers of truck-involved collisions at intersections. This may be the result of yellow signal phases that are too short.

Concerning islands, the primary issue, given proper island design to accommodate truck size and handling, is raised curb visibility. Proper marking and delineation to enable drivers of large trucks to see the islands is of paramount importance.

Truck handling and task performance demands are greater in construction and maintenance zones. One situation that is a recognized problem for truck accommodation is the median crossover. Unless properly dimmed, flashing warning arrow panels can temporarily blind a truck driver at night because their height is almost directly in the eyes of the driver of a large truck. Trucks often adversely affect traffic control at work zones by knocking down barriers and cones.

Several aspects of a railroad-highway grade crossing impact large truck safety. When the track bed is elevated from the roadway creating a "hump-back", large trucks can become hung on the hump. The length of the 20-second clearance interval from the onset of the train warning signal at the crossing to the arrival of the train may be inadequate for large trucks. The requirement that some trucks have to stop at railroad crossings may cause rear-end collisions as well as cause problems with having sufficient time for trucks with low accelerations capabilities to cross the tracks.

March, J. W.; "Findings of the Longer Combination Vehicle Study," Transportation Research Board Record 1052, 1986.

The paper presents the findings contained in the U. S. Department of Transportation's report to Congress entitled "The Feasibility of a Nationwide Network for Longer Combination Vehicles" that was mandated by the Surface Transportation Assistance Act of 1982. The purpose of this study was to examine the feasibility of establishing a network of highways for the operation of Rocky-Mountain doubles, turnpike doubles, and triple-trailer combinations.

Among the factors that were considered in assessing the feasibility of a network were:

1. safety,
2. vehicle performance and handling,
3. highway improvements needed to allow the safe operation of longer combinations,

4. increases in productivity that might be achieved by longer combinations, and
5. regulations imposed by states that currently allow longer combinations.

Among the findings of the study were that:

1. longer combinations are almost always operated under special permits issued by states or turnpike authorities,
2. longer combinations usually must meet certain performance standards and many states require special driver certification,
3. most Interstate interchanges would have to be modified to safely accommodate turnpike doubles,
4. it is unclear where and under what conditions various longer combinations could be operated safely, and
5. pavement condition, interchange spacing and geometrics, the availability of services, bridge characteristics, lane widths, curves and grades, and traffic levels would all have to be considered when assessing the suitability of a particular highway route for longer combinations.

Mason, J. M.; "Field Observations of Truck Operational Characteristics Related to Intersection Sight Distance," Transportation Research Board Annual Meeting, 1990.

Several pilot field studies were conducted to test a data collection methodology for the evaluation of AASHTO Case III-B and C sight distances for trucks at stop-controlled "T" intersections. The data collection plan used a combination of three traffic observation techniques: video recording, human observers, and portable traffic data collectors.

Specific findings include estimates for: the gaps (time and/or distance) that minor trucks accept during a turn maneuver onto a two-lane roadway; the average acceleration rate for a minor road truck turn maneuver; and the average deceleration rate of major road vehicles during a minor road truck's turn maneuver. Also observed were estimates of the speed reduction by a major road vehicle during the truck's turn maneuver and the minimum separation distance between the turning vehicle and an oncoming vehicle.

The median gaps accepted by truck drivers turning onto a major road range from 7.25 to 13.17 seconds, depending on the intersection, turning maneuver, and truck type considered. The range of time gaps accepted with 85 percent probability was 8.87 to 15.86 seconds.

The 50 percentile average acceleration rates range from 1.35 to 0.80 miles per hour per second and the 85 percentile average acceleration rates range from 1.74 to 1.20 miles per hour per second. The 50 and 85 percentile deceleration rates are 3.67 and 5.85 miles per hour per second.

Mason, J. M. and Briggs, R. C.; "Geometric Design of Exclusive Truck Facilities," Transportation Research Board Record 1026, 1985.

Past truck research was studied to determine the applicability of AASHTO geometric design policies to exclusive truck facilities (Efts). The following additions to current highway design policy was recommended to be considered in the development of criteria for the design of Efts:

1. Vehicle characteristics

a. A 105-foot double or triple combination design vehicle should be incorporated into design policy.
b. Ranges of truck driver eye heights for different truck classes are necessary.
c. Standardized brake testing of vehicles is needed to produce accurate braking distance requirements for different truck classes.

2. Sight distance

a. A design driver eye height representing a worst-case scenario should be considered in predicting sight distance requirements for cab-under-truck configurations.
b. Sight distance requirements on horizontal curves should be calculated and increased stopping distance requirements of heavy vehicles should be accounted for.

3. Horizontal alignment

a. The side friction factor may warrant modification in consideration of truck overturning moments.
b. Superelevation rates on turning roadways may need to be increased at low speeds to compensate for vehicle rollover.

4. Vertical alignment

a. Provisions for auxiliary truck climbing lanes should reflect the 10-mph speed reduction criterion recommended in the revised AASHTO policy.
b. Crest vertical curve length criteria should be examined for the stopping distance requirements of heavily loaded trucks.
c. Passing-zone design on Efts must consider truck performance limitations.

5. Cross-section elements

a. A design vehicle representing a heavily loaded vehicle having a high center of gravity is needed for designing barriers for Efts.
b. Little information is available to predict behavior of errant heavy vehicles on varying roadside slopes.

Mason, J. M.; Kitzpatrick, K.; and Harwood, D. W.; "Intersection Sight Distance Requirements for Large Truck," Transportation Research Board Record 1208, 1989.

This paper summarizes an analysis to determine the sight distance requirements of large trucks at intersections. AASHTO policy is reviewed and related vehicle characteristics are identified. Truck characteristics are updated based on permitted 1982 Surface Transportation Assistance Act design vehicles and published truck acceleration models. The results of sensitivity analyses are compared with current policy and are summarized for each of the intersection sight distance cases considered by AASHTO.

The findings imply that current intersection sight distance criteria may not be adequate for trucks when the current AASHTO models are exercised for the representative truck characteristics. The findings result in impractically long sight distance requirements. The development of alternative approaches for establishing realistic sight distance values is advocated. A truck driver gap-acceptance concept is proposed for further study. The gap lengths that truck drivers safely accept would be determined through field studies, and sight distance criteria would then be established to ensure that truck drivers on a side road approach would have sight distance at least equal to acceptable gap length.

McGee, H. W.; "Accident Data Needs for Truck Safety Issues," Transportation Research Board Record 1052, 1986.

A list of issues that are considered to be the highest priority truck safety issues are:

1. safety record versus truck type,
2. relationship of gross weight to truck safety,
3. relationship of truck length to truck safety,
4. relationship of type of highway to truck type,
5. where do truck accidents occur on various highway types and does this vary by truck type,
6. effect of critical geometric elements (lane width, shoulder width, degree of curvature, and grade) on trucks,
7. relationship of traffic volume to truck safety,
8. type of accident versus type of truck,
9. effect of truck restrictions by lane or time of day,
10. incidence of alcohol, drugs, or fatigue, and
11. effectiveness of barriers in truck accidents.

The key factors that influence truck safety and must be considered in the experimental design are:

1. truck type,
2. truck length,
3. truck trailer type,
4. truck weight,
5. driver type,
6. driver age, and
7. highway type.

Michie, J. D.; "Large Vehicles and Roadside Safety Considerations," Transportation Research Board Record 1052, 1986.

Because most highway traffic is composed of passenger vehicles, most current roadside hardware has been designed to interact with this vehicle type because of technical and economic restraints. Recent trends show that the percentage of vehicles larger than passenger cars is increasing and trucks are becoming longer and wider as a result of the Surface Transportation Assistance Act of 1982. This paper examines these trends with respect to roadside safety considerations, in particular to the roadside features and hardware that may need to be upgraded.

Relating to roadside design requirements, the following findings were presented.

1. Breakaway structures such as signs and luminaire supports do not pose a severe hazard to the large vehicle if the sign blank missile hazard is properly treated.
2. Crash cushions are not technically feasible for heavy trucks. However, designs to accommodate light trucks (up to 10,000 pounds) should be considered.
3. Longitudinal barriers such as bridge rails, guardrails, and median barriers are being designed to accommodate the largest vehicles but are relatively expensive and therefore sites must be carefully selected.
4. Shoulder side slope may need to be examined with regard to truck overturns and rollovers.

Miller, D. S. and Walton, C. M.; "Offtracking of the Larger Combination Commercial Vehicles," Transportation Research Board Record 1026, 1985.

This paper describes a project which had the objective of producing offtracking templates that could be used to aid in the design or evaluation of roadway geometrics. The result was a set of 18 templates covering 14 vehicles with combinations of vehicle type and turn type that total 74.

The trend toward excessive, and in some cases unacceptable, offtracking for large twin-trailer vehicles is evident. Poor offtracking characteristics will detract from whatever benefits are offered by those vehicles. Alternatively, triple-trailer vehicles, although offering many of the same advantages as large doubles of similar overall length, do so without the detrimental excessive offtracking.

Mingo, R. D.; Esterlitz, J. R.; and Mingo, B. L.; "Accident Rates of Multi-Unit Combination Vehicles Derived from Large-Scale Databases," Transportation Research Board Annual Meeting, January 1991.

This study used large national data sources to calculate overall involvement rates of various vehicle configurations. When the fatal accident rate of all current multi-trailer operations was compared to the fatal accident rates of other trucks, multi-trailers were shown to be much more dangerous than either single-unit trucks or single-trailer combinations. The best available sources showed multi-trailers to be more than one-and-one-half times as dangerous as single-trailer combinations and more than three times as dangerous as straight trucks. The much higher rates for multi-trailers would be expected in similar operations because of their inferior operating characteristics.

Moon, S. A.; "Keeping Up with Big Trucks: Experiences in Washington State," Transportation Research Board Record 1052, 1986.

Changes in Washington State trucking regulations necessitated by the Surface Transportation Assistance Act (STAA) of 1982 and attempts to standardize regulations among states are discussed. Because the large trucks permitted by the STAA had been allowed by permit on the system before passage of the 1982 STAA, it was determined that they would not be restricted from any part of the system as a result of the STAA.

The large trucks were using mostly the major corridors that were designed to reasonably high geometric standards. On minor corridors having at least 11-foot lanes, there are isolated areas where tight curves would require encroachment on the adjacent lane to keep the vehicle on the roadway surface. The current Interstate system could not handle the legal vehicle within the designated lanes at every access point because of the offtracking characteristics of the vehicles. In rural areas the primary problem is the ramp terminal area at the crossroad. In suburban and urban areas, ramp curvature becomes a problem.

On the non-Interstate system on both major and minor corridors, intersection geometrics are the biggest problem area. Bigger trucks have also created challenges for cities and towns in providing local access to terminals. Intersection widening and increased curb radii are the majority of modifications.

The 48-foot box presented the worst case for offtracking. Offtracking curves developed by California have been used. Sight distance requirements for negotiating intersections and for stopping and passing are of concern.

Inconsistent laws in adjacent states work a hardship on the trucking industry. Meetings between adjoining states have been conducted to discuss the standardization of regulations.

The collection and monitoring of traffic and accident data for the entire system are continuing to provide information to identify areas needing attention and what countermeasures can be taken to relieve problems that are identified.

Navin, F.; "Estimating a Truck's Critical Cornering Speed and Factor of Safety," Transportation Research Board Annual Meeting, 1990.

This paper outlines the relative precision of equations of varying complexity used to estimate a truck's critical rollover speed based on tire marks. An error analysis is compared with a limited tachometer data base to evaluate the accuracy of the speed estimating equations.

The study shows that for most situations with fully ladened trucks, the simple lumped parameter model given an acceptable estimate of the rollover speed. Also, a review of the lateral acceleration generated by a vehicle negotiating a minimum radius curve found that the acceleration is very close to the level needed to tip over a truck. A method for developing a reasonable estimate of level of safety is presented.

Data show that fully ladened heavy trucks, if involved in an accident on a curve, will most likely have rolled over. The formulation to estimate a heavy loaded vehicle's rollover lateral acceleration threshold need only include the height to the center of mass, the lateral position of the center of mass corrected for tire stiffness, and the road's superelevation. The average loaded tractor trailer's rollover lateral acceleration threshold is 0.46 to 0.47 g and the standard deviation is between 0.06 to 0.08 g.

"New Trucks for Greater Productivity and Less Road Wear-An Evaluation of the Turner Proposal," Transportation Research Board, Special Report 227, 1990.

The Turner Proposal calls for the use of trucks having lower axle weights but higher gross weights than currently, to reduce pavement wear while increasing productivity. Use of the new trucks would be voluntary and the new trucks would be required as a fleet to be as safe or safer than the existing fleet of trucks and to be compatible with roadway design on most major roads in all parts of the country.

Four prototype truck configurations are described. The prototypes include: 1) a 7-axle tractor-semitrailer combination with a maximum weight of 91,000 pounds and a length of 60 feet, 2) a 9-axle double trailer combination with two 33-foot trailers, 114,000-pound maximum weight, and 81-foot overall length, 3) a 9-axle B-train double, with dimensions similar to the previous double but with a different coupling arrangement between the two trailers, and 4) an 11-axle double trailer that would weigh up to 141,000 pounds.

If no special measures were taken to improve its safety, the Turner double-trailer prototype having a single-drawbar dolly would have an accident rate slightly worse than that of the five-axle tractor-semitrailer it would replace and equal to or slightly better than that of the five-axle twin trailers replaced when operated under identical conditions. There would be no significant difference in accident rates for the Turner tractor-semitrailer prototype compared with existing tractor-semitrailers. If Turner trucks had hill-climbing speed and acceleration capabilities less than those of existing trucks, traffic conflicts would increase, on a per-vehicle basis. Operation of Turner trucks that are longer than existing trucks may degrade traffic operations in extreme urban congestion, again on a per-vehicle basis. Other than these effects, the prototype nine-axle double, seven-axle tractor-trailer, and B-train double would not have significantly different impacts on traffic operations than those of existing trucks.

The major source of a systemwide impact on accident losses and on traffic flow would be changes in the volume and distribution of total truck traffic resulting from introduction of Turner trucks. Because of normal growth, travel by large trucks will increase whether or not Turner trucks are introduced. However, compared with the level that would occur if they were not used, the impact of adopting Turner trucks would be a small decline in truck accidents and a small reduction in truck interference with traffic flow, because total annual miles of combination-truck travel would decline through use of Turner trucks compared with the travel that would occur without Turner trucks.

Several measures would improve the intrinsic safety of Turner trucks and reduce accident losses. An antilock brake system on the tractor would improve control and braking performance. A standard for minimum speed on grades would reduce adverse impacts on traffic flow. Use of the B-train configuration for double-tanker combinations would help maintain safety in their operation.

Turner trucks should be able to operate on all roads except routes blocked by bridges that fail the state's loading criteria and routes that fail established state procedures for assessing adequacy to accommodate large combination trucks. States allowing Turner trucks should adopt consistent procedures based on safety and engineering considerations for assessing the adequacy of roads to accommodate these trucks. Allowing Turner trucks on the existing road network designated in a state for operation of double-trailer trucks and 48-foot single trailers together with access routes selected in accordance with existing federal regulations would be consistent with these recommendations.

Ogden, K. W. and Tan, H. W.; "Truck Involvement in Urban Accidents in Australia," Monash University, Department of Civil Engineering, January 1988.

An overview of the truck accident is presented in terms of accident types, causal factors, and accident rates. Detailed analysis of truck accidents in urban areas is presented. Truck accident countermeasures are discussed.

In urban areas, accidents involving trucks represented around 13 percent of fatal accidents. Urban truck accidents mostly involved rigid trucks, with articulated trucks being not as important. When expressed in terms of exposure measured in terms of vehicle-km of travel, articulated trucks had a comparable fatal accident rate to rigid trucks in urban areas, and a worse injury rate. Urban truck accidents mostly involved more than one vehicle, and tended to be associated with intersections or rear-end collisions.

Rear-end truck collisions in urban areas involved both collisions with parked vehicles, and collisions in the traffic stream. The former mostly involved another vehicle running into the rear of a parked truck, while in the latter case cars ran into the rear of trucks to about the same extent as trucks ran into the rear of cars.

The only significant single vehicle urban truck accidents were those involving pedestrians. Most of these involved a pedestrian stepping onto the roadway ahead of the truck, or emerging from behind a parked car. Very few of these accidents involved an articulated truck.

In urban areas, the most common fatal accident type for rigid trucks was striking a pedestrian on the roadway (28 percent of such accidents), although this involvement rate was much less than that for the fleet as a whole in this type of accident (45 percent). ~~In almost all cases, the pedestrian was listed as being at fault. For articulated trucks,~~ pedestrian accidents were much less common than with other vehicle types. Pedestrian fatal accidents were much less likely to involve trucks than cars.

Olson, P. L.; Cleveland, D. E.; Fancher, P. S.; Kostyniuk, L. P.; and Schneider, L. W.; "Parameters Affecting Stopping Sight Distance," National Cooperative Highway Research Program Report 270, 1984.

This report presented results of research conducted to evaluate existing stopping sight distance criteria in relation to the current vehicle fleet and driver population. Various parameters affecting stopping sight distance were studied. The stopping sight distance for cars was compared to that of heavy trucks.

Unloaded heavy trucks have much lower braking efficiencies than those achieved by passenger-car braking systems. Experimental data show that the frictional capabilities of truck tires have approximately 0.7 times the frictional capabilities of passenger-car tires. Consequently, heavy trucks require greater braking distances than passenger cars.

For locked wheel stops on a poor wet road, trucks require stopping distances that are approximately 1.2 times those attained by passenger cars. For controlled stops (in which the driver modulates the brakes to prevent the vehicle from spinning around and to maintain steering control), trucks require stopping distances that are approximately 1.4 times those required for passenger cars. However, because of the differences between the eye-heights of truck and car drivers, truck drivers have stopping sight distances on crest vertical curves that are approximately 1.35 times longer than those achieved by drivers of passenger cars. Hence, for locked wheel stops, the sight distances provided for passenger cars are adequate for trucks, although increases in sight distance of about 10 percent over those required to allow cars to make controlled stops would be needed to allow heavy trucks to make controlled stops.

Perera, H. S.; Ross, H. E.,Jr.; and Humes, G. T.; "A Methodology for Estimating Safe Operating Speeds for Heavy Trucks and Combination Vehicles on Interchange Ramps," Transportation Research Board Annual Meeting, 1990.

This paper describes an analysis procedure that provides a method to determine the critical speeds of interchange ramps for heavy vehicles (trucks and combination vehicles). The Phase-4 computer model was utilized to simulate the dynamic behavior of the vehicle for a specified ramp geometry. The complete procedure is computerized with a user-friendly interface for specifying ramp parameters and built-in data sets of vehicle-parameters. A method to convert the critical speed determined by the analysis to a safe operating speed for the ramp is presented.

Two types of hazardous situations are considered in computing the critical speed of a given ramp for a given tractor-trailer type. These are:

1. rollover and
2. wheels running off the ramp.

The critical speed for rollover is defined as the lowest speed at which a wheel would lift off the ramp surface. In the latter case, it is the lowest speed at which a wheel runs off the ramp. The overall critical speed is the lowest speed at which a wheel runs off the ramp.

"Providing Access for Large Trucks," Transportation Research Board Special Report 223, 1989.

The Surface Transportation Assistance Act (STAA) of 1982 liberalized truck size regulations. It authorized the designation of a National Network of interstate and other major highways on which the wider (102 inch) and longer tractor-semitrailers (minimum trailer length 48 feet) and twin trailer (minimum trailer length 28 feet) trucks approved by the act (STAA vehicles) could travel without restriction. The act also required states to provide "reasonable access" from this network to terminals and service facilities. The states provided regulations to determine where such access could safely be provided. This study concerns a nationwide policy for provision of reasonable access.

It was determined that local highway and traffic conditions differ from state to state and from route to route making a single national standard for determining access inappropriate. The proportion of mileage open to STAA vehicles for through travel and access varies widely among states. Decisions to limit or not limit access should be based on safety-related differences between STAA vehicles and the vehicles they replace. It was recommended that FHWA should require states to adopt and use procedures based on safety and engineering considerations to assess the adequacy of highways to accommodate STAA vehicles.

Safety should be the primary criterion for access determination. However, little information is available about the accident experience of STAA vehicles to that of the vehicles they replace. Comparisons of the accident record of twin trailer trucks with tractor-semitrailers reveal little difference in accident rates. No comparisons were noted in the accident record of STAA tractor-semitrailers with that of tractor-semitrailers of pre-STAA dimensions. Accident rates of trucks are most affected by the type of road on which they travel with lowest rates on roads designed to the highest standards. It was recommended that governments should open the maximum practical number of miles of roads to STAA traffic.

Offtracking is the performance characteristic that is the most different for STAA and pre-STAA vehicles. Inward offtracking occurs during turning maneuvers (at speeds below 35 to 40 mph) on curves and at intersections. At low speeds, twin trailer trucks offtrack less than pre-STAA tractor-semitrailers. The amount of inward offtracking of semitrailers is affected by the dimensions of the vehicle with the dominant dimension being the distance from the kingpin to the center of the rear trailer axle or axles. It was recommended that all states be encouraged to adopt a maximum kingpin setting of 41 feet (measured from the kingpin to the center of the rear trailer axle or group of axles) on National Network highways and access routes. Such a setting would make the maneuverability of the longer STAA semitrailers equivalent to the 48-foot pre-STAA semitrailer.

It was determined that STAA vehicle (particularly the fully loaded twin trailer truck) reduces pavement life.

The recommendation was that states should provide a distance-based access limit of one mile to service facilities. Access to service facilities could be denied because of safety and engineering considerations.

As used in the 1982 STAA, terminal should be defined as any location where freight either originates, terminates, or is handled in the transportation process or where carriers maintain operating facilities.

Roads open to STAA vehicles are either part of the National Network, highways independently designated by the state, or access routes. Nationwide, more than 70 percent of FAP mileage is open to STAA vehicles, but there are sharp regional differences. Fifteen states allow STAA vehicles to travel unrestricted on all public roads. The other states have adopted a wide range of access policies. Procedures for providing access can be grouped in two broad categories. One procedure involves distance-based policies that allow STAA vehicles to travel within a specified number of miles from the National Network or state-designated highways to access terminals and service facilities. Such policies are used in 15 states. The second procedure involves route-designation policies where the adequacy of individual roads to accommodate STAA vehicles is evaluated. These types of policies have been adopted by 19 states. Access policies should have the following characteristics: a through-travel network composed of the major highways connecting urban centers, explicit policies for providing access that are applied in a consistent and timely manner, access policies that can be simply communicated and enforced, and mechanisms for industry and government to resolve access problems.

All new van trailers sold since passage of the STAA in 1982 have been of the dimensions permitted by the act. The 48-foot semitrailer is replacing the 45-foot trailer as the truckload (TL) industry standard. The use of twin trailer trucks has been concentrated within the less-than-truckload (LTL) segment of the industry. LTL carriers account for 10 to 15 percent of combination truck traffic. Access regulations have not adversely affected the majority of shipments by carriers using STAA equipment. The problems associated with access regulations relate to inability to access some terminals, circuitous routing and hours-of-service limitations, time and administrative cost of applying for access, and uncertainty about access regulations and enforcement.

Combination vehicles, as a class, are involved in a relatively small share of all motor vehicle accidents but in a higher share of all fatal accidents. Fatal and total accident involvement rates are higher for combination vehicles traveling on major undivided four-lane and two-lane highways, which are most similar to truck access roads.

A review of safety studies did not identify any research that has directly compared the accident experience of STAA with non-STAA vehicles. Studies comparing accident involvement rates between twin trailers and tractor-semitrailers have revealed that only a small difference in the accident involvement rates. Undivided highways are less safe for combination vehicle travel than are divided highways and major undivided rural highways have the highest total accident and fatal accident involvement rates for combination vehicles. Extending access on urban roads for STAA vehicles would likely increase injury accidents but not fatal accidents. Narrow lane widths and narrow and unstabilized shoulders could pose a safety problem for STAA vehicles. Narrow bridges may pose a greater problem for large trucks than cars with width and offtracking a problem on curved bridge approaches. Because combination vehicles are more likely to be involved in single-vehicle accidents, roadside slope and clear zone width is important. Longer wheelbase trucks are susceptible to edge drops on the inside of horizontal curves because of inward offtracking. Offtracking on curves could also lead to rollover. Longer wheelbase vehicles have a problem negotiating turns at intersections but accidents caused by offtracking is unknown.

The key geometric features that may pose problems for STAA vehicles are grouped into three categories. These are alignment features (sight distance for passing and stopping, slope and length of vertical grades, and horizontal curvature), cross-sectional features (lane widths, shoulder widths, and roadside design features), and intersection, interchange, and ramp design elements (turns and sight distance at intersections, sight distance at railroad-highway grade crossings, and interchange and ramp design).

Vehicle length is a more critical factor than vehicle width. The offtracking problems of the longer-wheelbase tractor-semitrailers make it difficult to negotiate sharp horizontal curves on narrow two-lane roads without encroaching into the oncoming traffic lane or running off the road. The distance required to pass a STAA vehicle is longer than provided by current practices for signing and marking no-passing zones. STAA vehicle length may also affect the adequacy of sight distance at intersections and railroad-highway grade crossings. Intersections with restrictive roadway geometry (short radii and narrow lanes) cause a problem for STAA tractor-semitrailers which would affect capacity and traffic flow. The stability and control characteristics of STAA vehicles are likely to adversely affect their performance on many interchanges and ramps.

The two characteristics of STAA vehicles which are likely to adversely affect highway capacity and traffic flow are higher average vehicle weight and added vehicle length. The greater size of STAA vehicles increases the difficulty of passing on two-lane roads and causes delays at intersections, particularly as trucks make turning maneuvers. Because the introduction of larger STAA vehicles has resulted in a smaller increase in truck traffic than would have been experienced with equipment of pre-STAA dimensions, the net adverse impact on traffic operations of the slightly heavier and larger STAA vehicles is likely to be small.

STAA vehicles cause greater pavement damage than do the 45-foot tractor-semitrailer they replace. The twin trailer truck is the most damaging of the STAA vehicles because of its axle spacings and more uneven loading. Fifty-three foot tractor-semitrailers are more damaging than are 48-foot tractor-semitrailers. The incremental cost of increased pavement damage caused by STAA vehicles depends on the mix and volume of STAA vehicle traffic. The introduction of STAA vehicles is unlikely to have a serious adverse effect on the serviceability of properly designed bridges and culverts on access roads. The greater width of STAA vehicles and the offtracking problems caused by increased semitrailer wheelbase length may result in more frequent encroachment onto highway shoulders which would increase the deterioration of shoulders and create edge drops.

Rogers, E.; "California Design Practice for Large Trucks," Transportation Research Board Record 1052, 1986.

Following the passage of the 1982 Surface Transportation Assistance Act (STAA), the California State Legislature changed state laws to comply with federal truck regulations on the designated system. This law prescribes access to the system. Service access is permitted for fuel, food, lodging, and repairs provided those services are within 1/2 mile of an interchange and is handled by the California Department of Transportation. Terminal access places no limits on the distance between terminal and interchange and is handled on a case-by-case basis by local agencies. Interstate truck service access and truck terminal access signs are provided.

California has adopted an Interstate design vehicle based on dimensions given in the 1982 STAA. A computer program is used for generating offtracking plots. A set of truck-turn templates has been prepared as a tool for highway design engineers. Current practice requires highway designers to use the Interstate truck-turn templates on all new or upgraded interchange projects.

On the assumption that a large truck should not cross a lane line, especially a centerline, when travelling around a curve, and allowing for some margin of error, a 400-foot minimum curve radius was established for the designated system. This assumes a 12-foot traffic lane.

Safwat, K. N. and Walton, C. M.; "Expected Performance of Longer Combination Vehicles on Highway Grades," Transportation Research Board Record 1052, 1986.

This paper described the investigation of the expected performance of longer combination vehicles (LCV) such as the double 48-foot and triple 28-foot combinations on highway grades and possible impacts on the current AASHTO design criteria. The analysis involved the application of a modified simulation model under alternative hypotheses about gross vehicle weight-to-net horsepower (GVW/NHP) ratios, rolling resistance, and aerodynamic drag for LCVs operating on different percentage upgrades (1-9 percent grade). The research also included a limited collection of data on GVW and NHP values of actual LCVs.

It was determined that for LCVs, a GVW/NHP ratio between 300 and 400 would be considered normal, and a ratio above 400 could, occasionally, be observed. It was also determined that critical lengths of grades up to 6 percent could be significantly less than

AASHTO-recommended values depending on the percentage grade and the LCV's characteristics such as GVW/NHP ratio, rolling resistance, and aerodynamic drag. The expected difference in critical lengths could be as large as 1,060 feet on a two percent grade; that is, 44 percent less than the AASHTO-recommended value of 2,400 feet. In order to make specific recommendations with respect to changes in current AASHTO design criteria, actual field data for the operation of LCVs on grades have to be collected and analyzed.

Sayers, M. W.; "Vehicle Offtracking Models", Transportation Research Board Record 1052, 1986.

The methods that have been used by designers to estimate the offtracking of heavy trucks (when the rear wheels track inside the path traced by the front wheels in a turn) are reviewed. A computer method for graphing the complete swept path of an arbitrary vehicle making any type of turn at low speed is described. The method is valid for nearly all truck configurations in use on the highways, including double and triple combinations. The paper includes several example plots, and a computer program that uses this method, developed for the Apple II computer, is described.

The review of methods used by designers to estimate the offtracking of heavy trucks shows that analytical methods are not available for predicting low-speed offtracking for transient paths. Two graphic methods are used instead: the tractrix integrator (a drafting device) and transparent overlay templates, usually generated with the tractrix integrator. A computer-based method for graphing the complete swept path of an arbitrary vehicle making any type of turn at low speed is described and demonstrated. The computer method is essentially a numerical version of the tractrix integrator.

Schorr, D. J.; "Traffic Control Device Problems Associated with Large Trucks," Transportation Research Board Record 1052, 1986.

The problem of the blockage of road signs due to increased truck volumes and sizes is discussed. The inability of drivers to see advisory and warning signs will result in an increasing number of accidents leading to a growing number of law suits with the states as defendants. There are some guidelines that engineers can use, but a general solution is not available. View obstructions relating to passing and following trucks are discussed.

The following guidelines were given:

1. Repeat signs whenever practical and if possible use them in combination, roadside and overhead.
2. Educate the driving public placing emphasis on the need to maintain a suitable spacing not just for stopping but also for observing and reacting to signing.
3. Increased effort to enforce good driving with legal criteria for vehicle spacing.
4. Document all design and sign placement with a permanent record to show that a study was conducted and the installed system was the best suitable.

5. Conduct a site inspection and check for any unusual condition that did not show up on paper such as the need for added height for a traffic signal to be seen when installed just beyond the crest of a grade or moving a sign so it precedes a driveway that is used by trucks that would block it while waiting to enter the traffic stream.

Seguin, E. L.; Crowley, K. W.; Harrison, P. C., Jr.; and Perchonok, K.; "The Effects of Truck Size on Driver Behavior," Federal Highway Administration, Report No. FHWA/RD-81/170, March 1982.

This report discusses the effects of truck size on the behavior of drivers who interact with trucks in selected roadway situations. Truck length and configuration was addressed in freeway entrance merge, mainline lane change, and narrow bridge situations while truck width was studied in a rural two-lane, two-way passing situation. Field work involved the collection of microscopic traffic measures using the Traffic Evaluator System in addition to observations of erratic maneuvers and truck type for the length/configuration studies.

Length/configuration had little or no effect on interacting drivers as judged from the data available. The truck width-passing study employed an impedance factor to induce passing of an experimentally widened vehicle. Increasing truck width was found to be related to increased prepass headways, reduced lateral distance between passers (overtaking and oncoming) and the truck, and reduced lateral distance between oncomers and the road edge. However, no increases in shoulder encroachments by passers or acceptances of small gaps were found.

Skinner, R. E.; Morris, J.; and Godwin, S.; "TRB's Study of Twin-Trailer Trucks," Transportation Research Board Record 1052, 1986.

The Surface Transportation Assistance Act (STAA) of 1982 legalized the nationwide use of twin-trailer trucks on Interstate highways and other designated primary routes. This paper reviews the effect this legislation has had on the trucking industry relative to who is using these vehicles, where, and for what purposes.

The review of the pre-1983 use of twins and post-1983 experience, as observed through preliminary trailer sales statistics, trailer manufacturer interviews, and less-than-truckload (LTL) motor carrier interviews, resulted in the following findings:

1. Pre-1983 use of twins was concentrated in western states. LTL common carriers were the most frequent users of twins. LTL common carriers can take advantage of the added cubic capacity of twins and the added routing flexibility that is provided by separating freight into two units that can be easily divided.
2. The 1982 STAA has had significant effects on the motor carrier industry's equipment decisions. These effects include the increased use of twins and the shift in new trailer purchases to 102-inch wide and 48-feet long semitrailers.

3. Large LTL common carriers are the primary new users of twins. By 1990 twins carrying LTL freight may account for eight percent of all combination-truck traffic.
4. There are scattered instances of other (non-LTL) carriers that have begun using twins. This is usually associated with industries that move low-density cargoes to numerous distribution or outlet points.
5. Among new users of twins, the primary motivation has been added cubic capacity.
6. Common carriers in the Midwest and Southeast are quickly adopting the use of twins, but carriers in the Northeast are not.

Smith, B. L.; "Existing Design Standards," Transportation Research Board Record 1052, 1986.

The paper presents an overview of existing design standards with concerns about the subtleties of designing for trucks. The features and adequacy of present standards are reviewed and areas in which reinforcement or inclusion of additional standards or concerns are needed are highlighted.

The subtleties of designing for trucks relating to the areas of rollover, guardrails, dished wheel tracks, washboard pavement, pavement warp, truck brakes, and pavement edge dropoffs and surface discontinuities are discussed. Simple curves without spirals, compound curves, and areas of high crossover crown values are potential locations for truck rollovers at modest speeds. Large trucks are more sensitive to surface discontinuities than passenger cars.

Stout, M. L.; "Big Trucks in New Jersey: From Crisis Management to Strategy", Transportation Research Board Record 1052, 1986.

The response of the New Jersey Department of Transportation to the Surface Transportation Assistance Act (STAA) of 1982 is discussed. The main issues that are being worked on are:

1. Development of settled truck size and weight standards in conformity with the needs of the highway system. Combinations with 48-foot semitrailers are accepted universally under New Jersey law. Doubles are permitted to travel on an integrated network of Interstates, freeways, and toll roads. Reasonable access is granted for services within one mile of the system, but access to terminals is restricted to a written permit. The 102-inch wide truck is permitted only on the STAA network.
2. Integration of new truck requirements into design and operations standards. A study of the need to correct deficiencies on the designated system has been initiated.
3. Recognition of the needs of truck movements and truck access in the planning and project selection processes.
4. Requiring trucks to pay their fair share of highway costs.
5. Development of an adequate data base on trucks.
6. Better enforcement of truck size and weight laws.

7. Better liaison with motor carriers and shippers.
8. Rationalization of truck policy and regulatory responsibilities within the department and with other state agencies.

"Truck Size and Weight Issues," AASHTO Ad Hoc Group on Truck Size and Weight Research and Policy, April 1990.

This report offers a summary of proposals considered by the AASHTO Ad Hoc Task Group relating to establishing a set of national truck size and weight and related policy recommendations. In order to allow increased motor carrier productivity benefits for vehicles of over 80,000 pounds, the Task Group examined three proposals: Turner trucks, a special permitting program, and an alternative truck of 88,000-pounds gross vehicle weight, with six axles, including a rear tridem. For vehicles of 80,000-pounds gross vehicle weight or under, the Task Group examined two proposals, both based on adopting a more liberal bridge formula, the TTI HS-20, for Interstate highways.

Various safety enhancements to the vehicle were considered. These included: anti-lock brakes, vehicle activity recorders (mechanical tachographs or electronic recorders), underride protection (particularly rear underride and lower bumpers), air suspension systems, tires (tire pressure monitors, doubles versus super singles, and low profile tires), vehicle proximity alerts, and on-board weigh scales.

The Task Group identified two priority areas for future research and policy development. The objectives of these two areas would be to establish an electronic infrastructure (including both highway and vehicle) and improve communications and enhance coordination of research efforts between government and industry.

"Truck Characteristics for Use in Highway Design and Operations," Federal Highway Administration, FHWA-RD-89-226 and FHWA-RD-89-227, August 1990.

The purpose of the study was to determine the truck characteristics that should be considered in highway design and operation and to evaluate the need for changes in current highway design and operational criteria to accommodate trucks. The 16 highway design and traffic operational criteria evaluated in the study were:

1. stopping sight distance,
2. passing and no-passing zones on two-lane highways,
3. decision sight distance,
4. intersection sight distance,
5. intersection and channelization geometrics,
6. railroad-highway grade crossing sight distance,
7. crest vertical curve length,
8. sag vertical curve length,
9. critical length of grade,
10. lane width,
11. horizontal curve radius and superelevation,

12. pavement widening on horizontal curves,
13. cross-slope breaks,
14. roadside slopes,
15. vehicle change interval, and
16. sign placement.

A sensitivity analysis was conducted for each highway design and traffic operational criterion to determine how it varies over a range of truck characteristics. Revisions to the current highway design and traffic operational criteria were considered where necessary to accommodate trucks. Specific conclusions concerning the need to revise each of the highway design and operational criteria to accommodate trucks were presented.

Following is a summary of the conclusions and recommendations made in the report relative to the various highway design and traffic operational criterion.

1. Design Vehicle - The WB-50 design vehicle should use the 45-foot semitrailer. The STAA single with either a 48-foot or 53-foot semitrailer and the STAA double with two 28-foot trailers should be added to the AASHTO Green Book.
2. Stopping Sight Distance - Current AASHTO stopping sight distance criteria are adequate for trucks with antilock brakes. Criteria are adequate at vertical sight restrictions for trucks with conventional brake systems and the best performance driver, but, at horizontal sight restrictions, a truck with the best performance driver needs about 50 feet additional stopping sight distance. Current criteria are not adequate to accommodate trucks with conventional braking systems and poor performance drivers. Stopping sight distance criteria are given.
3. Passing and No-Passing Zones on Two-Lane Highways - Passing sight criteria are given for passing by passenger cars and trucks.
4. Decision Sight Distance - Trucks may require 100 to 400 feet more decision sight distance than passenger cars at a design speed of 70 mph and lesser additional amounts at lower design speeds.
5. Intersection Sight Distance - For intersections with no control, trucks may require up to 69 percent more sight distance than passenger cars. For intersections with yield control, the intersection sight distance requirements for trucks are the same as the stopping sight distance requirements. The larger trucks require up to 17.5 percent more sight distance for an intersection crossing maneuver than the current AASHTO criteria based on a WB-50 truck. For left- and right-turn maneuvers at intersections, use of truck characteristics can require sight distances up to 139 percent greater than a passenger car.
6. Intersection and Channelization Geometrics - This should be based on low-speed offtracking characteristics of the larger design vehicles.
7. Railroad-Highway Grade Crossing Sight Distance - Current criteria for the sight distance along the highway ahead to a railroad crossing should be increased by up to 54 percent for trucks with conventional brake systems with no changes for trucks with an antilock brake system. Criteria for sight distance along the tracks for a moving vehicle should be increased by up to 49 percent for trucks with conventional brake systems. Criteria along with tracks for a stopped vehicle are adequate.

8. Sag Vertical Curve Length - Trucks with antilock brake systems require shorter sag vertical curve lengths than current criteria while trucks with conventional brake systems may require lengths up to 670 feet longer than current criteria.
9. Critical Length of Grade - The criterion for truck weight-to-power ratio used to define the critical length of grade should be reduced from 300 to 250 lb/hp.
10. Lane Width - The current lane width criteria are adequate to accommodate trucks.
11. Horizontal Curve Radius and Superelevation - Current criteria for horizontal curve radius, superelevation, and superelevation transition methods are adequate to accommodate trucks.
12. Pavement Widening on Horizontal Curves - Revised criteria for pavement widening on horizontal curves to accommodate an STAA single 48-foot semitrailer truck are given.
13. Cross-Slope Breaks - No data are available to determine the adequacy for trucks of criteria for pavement/shoulder cross-slope breaks but breaks at the centerline crown should be kept to a minimum to maintain safe truck operations in passing maneuvers.
14. Roadside Slopes - No data are available concerning the adequacy for trucks of current roadside slope design criteria.
15. Vehicle Change Interval - Trucks require vehicle change intervals between 40 and 110 percent longer than passenger cars, but current guidelines should not be revised without an analysis to assess the operational and safety problems that would be created by the resulting reduced levels of service.
16. Sign Placement - Advance warning sign placement criteria for trucks with conventional brake systems should be longer than the current criteria which are based on consideration of passenger cars.

Twin Trailer Trucks, Transportation Research Board, Special Report 211, 1986.

The Twin Trailer Truck Monitoring Study examined the potential safety effects of the new federal truck size rules. Other effects studied were the trucking industry use of twins, safety consequences of using twins, pavement wear and other highway features affected by twins, and safety and pavement wear affected by 48-feet long semitrailers and 102-inch wide trucks.

The use of twin trailer trucks will be concentrated within certain segments of the trucking industry. In particular, general freight common carriers which specialize in shipments that are less than a full truckload will use twins. By 1990, twins will account for about 11 percent of nationwide combination-truck miles. As a result of increased capacity and greater flexibility in operations, general freight common carriers adopting twins will achieve, on the average, a 9 percent reduction in combination-truck miles of travel in the portion of their freight hauling that is switched from tractor-semitrailers to twins.

The increased use of twins will have little overall affect on highway safety because a reduction in miles of truck travel will approximately offset the small possible increase in accident involvements per mile traveled. Twins probably have slightly more accident involvements per mile traveled than tractor-semitrailers operated under identical conditions at highway speeds. Compared to tractor-semitrailers, twins are prone to experiencing rear-trailer rollover in response to abrupt steering maneuvers, provide less sensory feedback to the driver about trailer stability, tend slightly more to encroach on outside lanes or shoulders on curves at highway speeds, and undergo greater rear-end sway during routine operations. At low speeds, twins are more maneuverable than tractor-semitrailers. Professional truck drivers generally prefer to drive tractor-semitrailers rather than twins.

Compared with the tractor-semitrailers they replace, twins accelerate pavement wear and will increase pavement rehabilitation costs. This is because twins typically weigh more than the tractor-semitrailers they replace, loads on twins are usually distributed less uniformly among their axles, and twins transfer their loads to the pavement through an axle arrangement different than that of tractor-semitrailers.

Widespread use of 48-foot semitrailers will accelerate deterioration of highway shoulders and roadside signing and guardrails to some extent in some locations and will probably require changes in highway design standards. The safety consequences of the 48-foot long and 102-inch wide semitrailers have not been demonstrated. Although wider trucks may be more hazardous on roads having narrow lanes, the added width increases stability and reduces the possibility of overturn.

Waller, P. F.; Council, F. W.; and Hall, W. L.; "Potential Safety Aspects of the Use of Larger Trucks on North Carolina Highways," University of North Carolina, Highway Safety Research Center, HSRC-A110, December 1984.

This project examined potential problems that may arise in the use of twin trailers, 48-foot trailers, or 102-inch wide trailers and how such problems could be minimized or avoided. Input was received from motor carriers and drivers.

Based on the figures supplied by motor carriers, twins will eventually represent 36 percent of the total trucks placed on the road and 48-foot trailers will eventually represent about 14 percent. The ages of drivers operating the larger rigs do not appear to be a major consideration. While the motor carriers appeared satisfied with their training procedures, the drivers did not. While all companies investigate crashes, very few keep computerized records.

Companies anticipate a productivity increase of approximately 10 percent with the use of the larger trucks and fuel savings between 5 and 10 percent.

Companies expressed a great deal of concern about the lack of uniformity in state practices (considerable variation in the designated route system).

Several concerns were mentioned by both drivers and motor carriers. These included the stability of the vehicle, with particular concern about sway in the last trailer; operation of the larger rigs in bad weather; and operation of these rigs on narrow roads. The condition of roads was also mentioned by both groups in that pavement edge drops and rough surfaces apparently cause more problems for twins than for other configurations.

Drivers frequently mentioned problems with swaying of the trailers. They were also concerned about the adequacy of mechanics' training for maintaining and servicing twins, especially in regard to the brakes. Drivers had fewer concerns about 48-foot trailers, and most of these related to the greater width and its incompatibility with the current mirror placement on many tractors.

If larger trucks are to use our highways as safely as possible, there is a need to have coordinated attention directed to some of the underlying issues. Different states and companies must apply the same guidelines. There must be an effort to ensure that the qualifications of the drivers and the conditions of the vehicles are adequate and that the highways have had adequate attention to ensure that lane widths, shoulder heights and widths, pavement conditions, and signing are sufficient to enable safe operation.

Zegeer, C. V.; Hummer, J.; and Hanscom, F.; "Operational Effects of Larger Trucks on Rural Roadways," Transportation Research Board, January 1990.

The purpose of this study was to determine the ability of various truck configurations to negotiate rural roads with restrictive geometry and to determine the effects of such trucks on traffic operations and safety. The truck sizes of concern included truck tractor semi-trailers with trailer lengths of 40, 45, and 48 feet and twin trailer combinations with 28 foot trailers. Test sites consisted of approximately 60 miles of rural, two-lane roads in New Jersey and California with a variety of lane widths, shoulder widths, and horizontal and vertical alignment.

The field testing involved following control trucks of each truck type along the routes with professional drivers. Photographic and radar equipment were used in a data collection caravan to measure the effects of the trucks on speed changes and lateral placement changes of oncoming vehicles. Statistical testing was used to compare operational differences between various truck types for specific geometric conditions.

The results indicated that the semi 48 and twins resulted in some changes in operations of oncoming vehicles, particularly on narrow roadways. However, careful driving of the larger trucks may have partially compensated for operational differences in oncoming vehicles between truck types. Overall, driving behavior and site differences had more of an influence on vehicle operations than the effects of the different truck types. However, potential safety problems were evidenced by extreme maneuvers by a few oncoming motorists in reaction to the twins and longer tractor semi-trailers.

APPENDIX C

LIST OF REFERENCES

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