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This annotated bibliography summarizes selective research that is helpful in assessing the implications of longer and wider trucks. Both operational characteristics and geometric considerations are presented. The primary contents include pertinent literature on vehicle characteristics and performance, sight distance, horizontal and vertical alinement, cross section elements, capacity, safety, and truck regulation and enforcement. Each annotation is presented as a separate citation under a specific sub-topic heading for quick reference.

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ANNOTATED BIBLIOGRAPHY OF RESEARCH ON OPERATIONAL CHARACTERISTICS AND GEOMETRIC DESIGN IMPLICATIONS OF LONGER AND WIDER TRUCKS

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Research Report 397-1
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Sponsored by the

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February 1986

TEXAS TRANSPORTATION INSTITUTE
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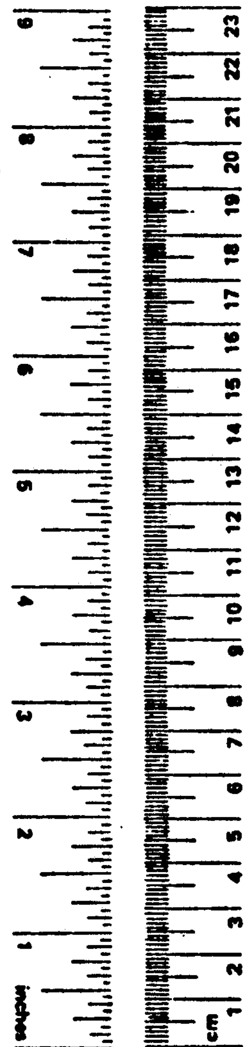
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

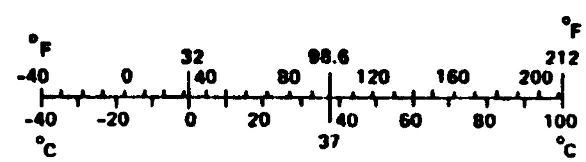
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABSTRACT

This annotated bibliography summarizes selective research that is helpful in assessing the implications of longer and wider trucks. Both operational characteristics and geometric considerations are presented. The primary contents include pertinent literature on vehicle characteristics and performance, sight distance, horizontal and vertical alinement, cross section elements, capacity, safety, and truck regulation and enforcement. Each annotation is presented as a separate citation under a specific sub-topic heading for quick reference.

SUMMARY

The Annotated Bibliography is arranged under seven (7) unique main topic headings:

1.0 Highway Functions
2.0 Design Controls and Criteria
3.0 Elements of Design
4.0 Cross Section Elements
5.0 Operational Design
6.0 Operational Safety / Truck Accidents
7.0 Regulations, Restrictions, and Enforcement

Each major heading is divided into unique sub-topics to clearly segregate pertinent sections of the cited literature. The user can quickly review the Table of Contents to identify an area of interest. Since each piece of research was reviewed following the outline of the Table of Contents, a particular reference (number in parenthesis) may appear under several sub-topic headings. Only the related portions of the cited reference are summarized under each category. The references under each sub-topic are arranged by publication date from most recent to oldest.

Several sub-sections do not have annotated references. It is anticipated that these citations can be added when pertinent information becomes available. Future research findings can be conveniently added to the references. This document is stored on IBM - PC microcomputer diskettes and can be easily retrieved and modified. The Texas Transportation Institute plans to add new research findings as they become available.

IMPLEMENTATION STATEMENT

The material presented in this document provides a ready reference to truck related research. This information has been assembled in topic heading format which can be quickly scanned to locate pertinent findings.

This bibliography attempts to establish a "status quo" on truck research regarding operational characteristics and geometric design implications of longer and wider trucks. Creation of this synthesis will improve the efficiency of future efforts that require a state-of-the-art literature assessment on the impacts of trucks on the highway system.

DISCLAIMER

The annotated bibliography was assembled as a specific task of the research project. The views and interpretations expressed or implied are those of the authors. They do not represent a standard, policy, or recommended practice established by the sponsors.

ANNOTATED BIBLIOGRAPHY OF RESEARCH ON OPERATIONAL CHARACTERISTICS AND GEOMETRIC DESIGN IMPLICATIONS OF LONGER AND WIDER TRUCKS

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2.1.2 TRUCK COMBINATIONS

This article describes the western double, the Rocky Mountain double, and the turnpike double. Since the 48-ft semitrailer experiences a significant increase in off-tracking compared to the 45-ft semitrailer, the typical western double has a maneuvering advantage over the typical tractor semitrailer. Although the relative safety of doubles has not been shown, doubles and singles differ little in safety, if at all.(43)

This article reports the results of a study of characteristics of double-trailer truck operations along a section of the New York State Thruway. Almost 90% of the vehicles observed were hauling two long trailers; i.e., trailers 40 ft or more long (double bottoms). No combinations were observed in which the first trailer was shorter than the second. Of all vehicles, 90% were owned by commercial transportation companies; however, UPS, Consolidated Freight, and Oneida Express accounted for 44% of the observed vehicles. Only nine vehicles were privately owned. Despite operation flexibility permitted on the New York State Thruway, double trailers are limited to a narrow spectrum of vehicle types and companies. It was noted that certain geometric features of highway sections (i.e., number of lanes, lane width, curve, grade, and sight distance) may substantially affect the operation of doubles and threaten safety. (58)

Truck combinations of the U.S. are classified as (1) truck and trailer, (2) Rocky Mountain doubles, (3) turnpike doubles combination, (4) triple trailer combination, (5) truck and two trailers, and (6) B train. Bridge Formula B is typically used to control the weight on interior axle groups. State and federal regulations require that the total side to side movement of the rear wheels of a truck combination operating at a steady speed on a smooth straight and level surface not deviate more than 6 in. total from the wheelpath of the tractor. A 1975 Illinois Institute of Technology study showed that none of the stability limits of the five classes of articulated vehicles differ appreciably from the standard tractor truck/40-ft (12.2-m) semitrailer combination when operated under identical conditions. (130)

This paper presents the findings of a study to assess the effect of increased truck size and weight on Texas highways. Four alternative scenarios characterized by forecasted truck ton-miles over 20 years, different highway classification, commodity flow, and truck configurations were studied to determine the effects of each on highway and bridge costs, truck operating costs, and fuel consumption over the same 20-year span. (154)

Ten truck combinations are identified in this report. Twin-trailer combinations are especially used for general freight in western states. In states which do not permit doubles, these trucks are often broken into two units. Twin 27-ft (65-ft overall length) combinations are compatible with existing geometrics on primary highways, as are triples and turnpike doubles on multilane, limited-access highways. (135)

This is a user's manual for the computer-based mathematical simulation program "Truck and Tractor-Trailer Dynamic Response Simulation - T3DRS:VI," developed by the Highway Safety Research Institute, University of Michigan in 1979. The program is written in a generalized manner to allow simulation of a large number of vehicle configurations. It can be highly versatile in representing commercial vehicle type and components in steering and braking maneuvers. This manual provides an introduction to the simulation program with a description of its external characteristics sufficient for a user to submit a run and interpret the output. (46)

This paper's objectives were to define car-truck interactions that produce unsafe changes in driver behavior and through experimentation, ascertain the magnitude and frequency of such changes. Remedial techniques to counter such changes and recommendations for maximum permissible truck sizes were to be provided. (127)

The size and weight of commercial motor vehicles have been effectively frozen since the adoption of the Federal Aid Highway Act of 1956, says this 1974 report. Liberalizing size and weight restrictions of commercial motor vehicles will help check inflation, while at the same time making potential fuel savings of up to 21% for intercity freight trucks. (70)

Triple trailers and/or double 40-ft trailers up to 110 ft are permitted on designated routes in six western states, and also on some toll roads in six midwestern and eastern states. Operation was discontinued in Washington and New York. In 1971, the California department of public works undertook a demonstration over almost 1800 miles on various types of roads to determine the feasibility of such trucks. The findings are inconclusive but generally favorable on stopping, backing, acceleration, off-tracking, environmental factors, operation on grades, operation on local roads, metropolitan area freeways, multilane rural highways, and operation at night. (142)

2.1.3 HEIGHT OF MOTOR VEHICLES

This 1981 report examines vehicle height for association with roadway design features and, hence, cost. Vehicle height was found to directly affect vertical clearances, including grade separations and interchanges. It indirectly affects right-of-way and utility adjustments, grading and drainage, and structures. (118)

This field study examined traffic operational effects associated with truck size and weight. Truck height was shown to impact traffic operations as an outgrowth of its effect on truck handling and stability characteristics. The Truck Trailer Manufacturer's

Association found in 1970 that the rollover speed of an empty semitrailer on a cloverleaf ramp with a 40-mph crosswind was reduced from 39 to 36 mph as the overall trailer height increased from 12.5 to 13.5 ft. A loaded truck's likelihood of rolling over is affected by its center of gravity. The author cites a 1974 study by Weir et al. who found that a 1.4 rise in the center of gravity significantly reduced a truck's performance on horizontal curves and increased its propensity to roll over. (57)

Since most states now restrict vehicles to a 13 ft. 6 in. (4.11 m) height, this 1979 NCHRP report recommends maintaining that height. Higher trucks with decreased stability in sway and rotation may threaten traffic safety. Furthermore, they may also damage overpass structures. (135)

This 1978 paper states that height and width regulations are the most uniform of the many size and weight limits. Height regulations are not expected to change due to the physical restrictions placed by structure heights passing over the highway. In approximately 87% of the states, maximum height is 13.5 ft (425 cm), and only the District of Columbia restricts vehicle heights to less than 13.5 ft (380 cm). (89)

In this 1973 NCHRP report, a methodology for estimating benefits and costs to highway systems of changes in legal commercial vehicle weights and dimensions is proposed. Truckers and manufacturers have expressed little interest in raising limits of vehicle heights above the common 13.5 feet because of existing loading dock dimensions, stacking limitations of most commodities, and vehicle instability on sharp curves in high wind situations. Trucks often block signs, particularly on multilane highways with more than one lane of travel in each direction. The severity of the consequences of sign blockage would depend on the relative value and importance of the highway communication being attempted, and could be an additional basis for warrants for overhead placement of signs and increasing the number of signs carrying the same message. (164)

This 1971 report is a theoretical mathematical analysis of the blockage of signs by trucks. A driver's vision will be blocked if a vehicle comes between him and the roadside sign. The shape and speed of this "shadow" is a function of the truck and other vehicle speed, truck size and position, and sign size. Lane widths, road length and geometry, and position of driver's line of sight also influence the "shadow". The solution to this problem appears to be very general because of the several random variables involved. Since the relationship between the probability of blockage, ADT, and percentage truck mix was not apparent in the study, more research was suggested. (1)

2.1.4 WIDTH OF MOTOR VEHICLES

This article on the safety of doubles reports that 102-in. wide trucks offer greater roll stability than the common 96-in. wide trucks, improving roll stability by about 16%. (43)

This 1981 report examines vehicle width for association with roadway design features and, hence, cost. There is a significant relationship between vehicle width and width of pavement and shoulders. Highway cost components associated with vehicle width are right-of-way and utility adjustments, grading and drainage, base and surface, and structures. (118)

This report recommends allowing the current 96-in. width be increased 6 in. for ease of loading certain kinds of shipments. (135)

This 1978 paper found that the maximum width in 80% of the states is 96 in. It is primarily limited by present roadway geometrics. The present manufacturing technology is capable of increasing axle widths up to 102 in. However, increases beyond 102 in. would require significant retooling. The authors state that increased vehicle widths would not impair operation on Interstates with their wider lanes as much as they would city streets or local roads with narrower lane widths. (89)

In this 1973 NCHRP report, a methodology for estimating benefits and costs to highway systems of changes in legal commercial vehicle weights and dimensions is proposed. Both truck and bus industries favor wider dimensions for limits. They state that the limit of 96 in. does not provide the necessary width over the rear drive axles for adequate design of differential, braking, and tire equipment. (164)

In August 1972, a tractor trailer with a width of 12 ft 9 in. went on a trial run over a variety of primary and secondary highways and city streets from northeastern to west central Florida. The entire run was monitored by accompanying vehicles and aerial photography. Observations were also made subsequently. Factors noted were adverse effects on pavements and shoulders, damage to signs and other roadside structures, effects on traffic flow and driver behavior, potential accident situations, and behavior in wind. Although there were no incidents during the run, and no damage observed, the potential of the wide load for damaging highway structures, causing accidents, and decreasing highway capacity led the study team to recommend to the Florida DOT that widths greater than 12 ft not be permitted on state highways. (72)

2.1.5 WEIGHT OF MOTOR VEHICLES

This article describes the new model big trucks that will be on the market in 1985. The revised overall truck-trailer lengths allowed by the Surface Transportation Assistance Act of 1982 are influencing size of sleeper cabs. (147)

As a result of the 1982 STAA, a procedure was needed to predict future gross vehicle weight and axle weight distributions and 18-kip equivalent single-axle load applications that result from changes in the legal size or weight limit. Various methodologies are reviewed and a new procedure is described--the Texas Shift. Although the main data set came from the Texas Interstate system, this shifting procedure can be used for other types of highway systems in other states to predict both gross vehicle weight and axle weight distributions. For a long term investment on existing federal and state highway systems, it is strongly recommended that truck weighing activities be intensified and operating efficiency be improved. (161)

The Surface Transportation Assistance Act of 1982 forced all states to allow bigger, heavier trucks on the Interstate highways. The deadline for states to implement the new rules was April 1983. The act set off an outcry in some states. This article discusses issues of politics, economics, and highway safety in the ongoing debate. (107)

This field study examined traffic operational effects associated with truck size and weight. Three analytical procedures determined operational differences between truck groupings (e.g., loaded versus empty, single versus double-trailer combination), correlations between truck characteristic and operational measures, and the predictive effect of truck weight on speed. Despite numerous operational differences associated with truck size and weight, the observed effects were weak. The correlative analysis demonstrated that higher gross weight was often found to be associated with lower truck speed, poor acceleration performance, and both delay and high closures with respect to following vehicles. (57)

This 1977 paper outlines the design approach and preliminary performance results of a highway freight transportation vehicle which maximizes the available payload space within existing regulatory limitations. It is a combination of a low profiled driver forward mid-engined tractor coupled to a freight box, and pulling a semi-trailer. Prototype testing of the two initial tractors with and without bodies and trailers have shown no handling, steering, or braking characteristics which differ from conventionally arranged tractor trailers. (176)

This report examines truck size and weight limits in Canada, Western Europe, Africa, Asia, Middle East and Oceanic, and South and Central America. High limits and other foreign limitations are noted. The relationship of road stress to vehicle weight limits is examined. Maximum single and tandem axle weights, maximum gross weight, and length permitted on tractor semitrailer and other combination vehicles are covered. A majority of the rest of the world permits the operation of vehicles which are heavier in both (single and tandem) axle and gross weight, and shorter than equipment used in the U.S. International container transport rules have influenced gross vehicle weights in Europe. Failure to provide for maximum gross weights in the 95,000- to 115,000-lb range to accommodate fully loaded 20- and 40-ft standard containers rated up to 67,200 lb gross weight could seriously hamper American foreign trade and cause domestic inefficiencies in container operations. (133)

This paper assesses the freight market and energy impacts of uniform truck size and weight limits. Impacts on competition among highway and rail carriers are estimated in terms of traffic diversion as a result of changing state limits prohibiting multiple trailer operations or having weight limits below current federal levels. Estimates of changes in revenues and profitability of carrier groups as well as freight rates are also under study. (94)

The first phase--a literature search and review of existing studies--is reported of a research project to assess the impacts of two proposed federal uniform truck size and/or weight (TSW) increases in tractor-trailer combinations on two groups: shippers or the users of transport services; and state transportation departments and legislatures. The first TSW alternative would be to increase the length of the trailer combinations without changing federally regulated gross vehicle weight (GVW) and axle loadings. The second proposed alternative would be to increase both the length and GVW of tractor trailer combinations without changing federally regulated axle loadings. The search revealed that research of TSW impacts, including the operation of 27-ft trailers, is inconclusive due to fragmented research efforts. The information base is very poor. (25)

This report is the Department of Transportation's response to a directive by Congress to study the need for uniformity in maximum truck size and weight limits throughout the U.S. An analysis of truck vehicle miles of travel (VMT) by truck weight and highway system in 1977 shows: (1) about 75% of truck VMT is by trucks weighing under 50,000 lb; (2) on all highways except interstate or primary highways, nearly 85% of all truck VMT is from trucks weighing 50,000 lb or less; on Interstates, however, only 70% of truck VMT was from trucks in this category; (3) trucks weighing more than 73,000 lb are responsible for less than 10% of all VMT by trucks on any system and are especially low on non-Federal-aid roads; and (4) only a negligible percent of VMT on any highway system is attributed to trucks weighing more than 110,000 lb. (126)

This 1973 NCHRP report notes that the length of freight vehicles depends on intended type of service. Single units operating in loading/unloading operations in urban pickup and delivery are affected differently by length limits from those in line-haul operations. Additional length permits increase in the number of axles. Total gross weight can thereby be increased without exceeding axle-weight limits. Vehicle length also affects the longitudinal geometrics of highway design through restrictions on sight distance and passing opportunities. Highway costs due to increased length include extra roadway widths to accommodate the combination offtracking characteristics at curves and ramps and construction required to lengthen the sight distance on curves and crests. (164)

The purpose of this study was to determine the effects of factors such as geographical area, percentage of trucks, and average annual daily traffic on the variation in weights and number of trucks for each of eight truck types. The conclusion was that these variables had no significant effect on interstate truck weighing. (52)

2.1.6 TRENDS IN MOTOR VEHICLE SIZE

The authors of this paper review two major data bases which describe double and triple truck characteristics, the Truck Weight Study (TWS) and Truck Inventory and Use Survey (TIUS). The TWS emphasizes the dimension and weight of truck types. It has a large sample size but not a well-designed sampling program. The TIUS contains information on commodity carried, operator, engine type, vehicle length, and more. It has a well-designed sampling program, but a small sample of doubles and triples. (174)

Since January 30, 1980, general merchandise carriers have received permits to operate vehicles that exceed the maximum legal length (75 ft 5 in) on four-lane divided highways in Saskatchewan. This paper reviews the success of the program up to 1983. The vehicle configurations used are described. The original tests focused on triple trailers and Rocky Mountain doubles. One carrier also used twin 45-ft vans on an experimental basis. (18)

An Organisation for Economic Co-operation and Development road research group, the Co-ordinating Group on the Impact of Heavy Freight Vehicles, identified research of member countries on the effects of heavy freight vehicles. Their report states that these vehicles are significant in the traffic of the 16 member countries. In the United Kingdom and Italy, for example, only 4% of the truck fleet consisted of heavy freight vehicles, but 40% of the road ton-mileage and 30% of total ton-mileage was carried by heavy freight vehicles. (73)

This Organisation for Economic Co-operation and Development paper reports on the effects of heavy trucks on road traffic. The national truck fleet will continue to expand, with fleets becoming larger and heavier everywhere. Furthermore, the current trend is toward using tandem and tridem axles as well as wider tires. (61)

This 1981 report examines vehicle length for association with roadway design features and, hence, cost. Vehicle length affects intersections and therefore the right-of-way and utility adjustments, grading and drainage, and the base and surface. (118)

This 1979 report states that the trend has been toward longer tractor-semitrailer combinations and toward longer tractor-semitrailer combinations towing one or two trailers. The length of trailers has been steadily increasing, especially due to the influence of the cab-over type tractor. In the last 20 years, multiple-trailer combinations, doubles, and recently, triples have grown in use. (135)

This 1978 paper recognizes the possibility of new, higher size and weight regulations. The indications are that the vehicle of the future will be larger and heavier, and perhaps wider. Larger and heavier vehicles improve the efficiency of operation by reducing operating costs and increasing operating energy efficiency. However, increased gross vehicle weight may create damage to existing bridges and pavements unless vehicle lengths are increased sufficiently and more axles are added to retain lower axle loadings. The strongest recommendation of all was to correct the nonuniformity of regulations between states. (89)

This report focuses on limiting trailer or cargo-carrying length of heavy trucks in order to remove a major economic incentive that could jeopardize safety. The Department of Transportation should develop model length limit regulations that do not provide an economic incentive to increase cargo space at the expense of tractor length.

The DOT should recommend to State authorities that they specifically limit the length of trailers (or cargo-carrying portions) rather than merely setting an overall length limit on heavy trucks. A primary objective should be to reduce the possibility that non-cargo-carrying length will be decreased at the expense of safety. (152)

This article discusses Strick's proposed Cab-Under design for truck trailers. The Cab-Under has a height of 48 in., exactly that of the 1977 Corvette. In the Cab-Under rig, the box runs right to the front of the trailer, thus wasting no length at all on power plant or driver. Driver eye height, however, is drastically reduced, increasing necessary stopping sight distances. Other disadvantages are discussed. (10)

This report examines the possible effects of changes in commercial vehicle size and weight limits on the performance and operational characteristics of these vehicles. Appropriate controls to insure that increased limits do not cause performance and safety of heavy vehicles to degrade are suggested. Grade climbing ability and acceleration capability are considered most susceptible to an increase in vehicle limits. (170)

This report is a summary of Winfrey's 1968 study "Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights" and includes a sensitivity analysis of the key findings. The report concluded that the technical input data to the study are adequate and that benefit-cost analyses support increasing the single and tandem axle weight limitations to 26,000 and 44,000 lb, respectively. The report also supports the conclusion that gross loads may be increased to at least 120,000 lb, or no gross load need be specified and instead, axle weight and spacing may be used as the control. (132)

Determining desirable maximum limits of dimensions and weights of motor vehicles is approached on the basis of highway and operating costs. Axle weight, gross vehicle weight, and vehicle length are analyzed on six highway systems consisting of the rural and urban systems within the Interstate, primary, and secondary highway systems. The analysis is based on data from truck weight studies conducted in 46 states; operating cost data from truck fleet operators; and experimental data on pavements and bridges from the comprehensive AASHTO road test, as well as data from other studies. The desirable limits of dimensions and weights were found to be (1) vehicle height of 13.5 ft; (2) vehicle width of 102 in.; (3) maximum lengths on all highways of 40 ft for single-unit trucks and trailers, 55 ft for tractors and semitrailers, and 65 ft for any other combination of vehicles; (4) axle weight limits of 22,000 and 38,000 lb for single and tandem axles, respectively; (5) gross weight limit of at least 120,000 lb, or better yet, no gross weight limit at all with control of axle weight and spacing. (169)

2.1.7 VEHICLE PERFORMANCE

During the Annual Truck Weight Study conducted by state highway agencies in cooperation with the FHWA, all vehicles in the traffic stream are counted and classified. This report presents the results for the years 1975 through 1979. It includes the number of passenger cars, buses and trucks, from pickups to multitrailer combinations. For each truck type, the number of axles and the axle configurations are also recorded. A representative sample of trucks are surveyed for additional data, including axle and gross vehicle weights. (81)

This report presents eight computer simulation models that predict the movements of large trucks during steering and braking maneuvers. Four simulate steering behavior; two, braking behavior; and two, combined steering and braking behavior. The programs determine the pitch, roll or yaw, or combinations of these three movements. (38)

2.1.7.1 ENGINE PERFORMANCE

2.1.7.1.1 WEIGHT/HORSEPOWER RATIO

This paper illustrates the acceleration characteristics of loaded and unloaded trucks recorded as they crossed a two-lane bridge. Acceleration and speed curves for loaded and unloaded trucks for two distances were recorded on graphs. Although the sample size may be too small to give a good average acceleration and speed curve for general application, these truck acceleration curves for specific weights and horsepowers may be useful in other studies. (146)

So that combination trucks can climb at reasonable speeds, this report recommends setting minimum climbing speed capability under full load instead of power-to-weight ratio. (135)

In this 1973 report, a methodology for estimating benefits and costs to highway systems of changes in legal vehicle weights and dimensions is proposed. The report includes a figure showing cumulative frequency distributions of weight/horsepower ratios for loaded trucks. This ratio affects truck performance on positive grades, the cruise speed on level tangents, and acceleration limits on trucks passing other vehicles. (164)

2.1.7.1.2 ACCELERATION CHARACTERISTICS

The effects of increasing legal truck sizes and weights on highway geometric design was the focus of this report. Today's high torque rise engines and transmissions are superior to those of the AASHTO's representative truck of the 1950's, and therefore today's trucks have higher gradability and entrance speed on a grade. Increased entrance speeds and transmissions of today's longer trucks essentially offset the detrimental effects of increased weight, with a net result of gradability performance regressing to the approximate level of AASHTO'S representative 1950's truck, a 400:1 pounds to horsepower ratio. Thus trucks stay within the maximum allowable safe speed reduction of 10 or 15 mph on a grade. (156)

2.1.7.1.3 AVERAGE AND MAXIMUM SPEEDS

A simplified theory of the motion of heavy vehicles on grades is presented. A set of speed-distance curves computed from the theory, based on maximum sustained speeds observed in Arizona, is given as the basis for design of climbing lanes in Texas. Speed-distance curves representing the observed performance of a test vehicle on 11 grades agreed fairly well with the corresponding curves plotted directly from test data. This theory appears accurate for use in climbing lane design. (68)

2.1.7.1.4 FUEL EFFICIENCY

This article describes the new model big trucks that will be on the market in 1985. Details on engine performance and fuel efficiency are given for several truck makers, including Ford, Freightliner, International Harvester, Kenworth, Mack, Peterbilt, and Volvo White.(147)

Since January 30, 1980, general merchandise carriers have received permits to operate vehicles that exceed the maximum legal length (75 ft 5 in) on four-lane divided highways in Saskatachewan. This paper reviews the success of this program up to 1983. No accurate estimate of fuel consumption savings associated with all overlength vehicles can be made because of insufficient information. Fuel consumption depends on many variables such as engine, gear ratios, gross vehicle weight, trailer configuration, weather conditions, and drivers. However, based on the information provided by the carriers, an approximate fuel savings of 25% to 30% is associated with overlength vehicles. (18)

This 1983 FHWA report discusses technical and policy factors in the heavy vehicle size and weight issue. The author states that since the Department of Transportation has a substantial program on improving fuel efficiency of highway vehicles at the Transportation Systems Center in Cambridge, Mass., the FHWA has not felt the need to commit large portions of its limited research funding to this problem. Studies of liquid fuels derived from sources other than oil are also underway in this program and in Energy Administration programs. (123)

Optimization of the drive line in commercial vehicles has led to considerable savings in fuel consumption in recent years. This SAE paper describes the improvements to a 11.4 litre engine in three development stages occurring between 1976 and 1982. Both the combined turbocharged with charge-air cooling and the naturally aspirated version of the engine are considered. Optimization measures on the vehicle itself, such as the reduction of drag and the selection of optimized ratios in the drive line, showed fuel savings of more than 30% in measurements made by independent test drivers on the same routes and under comparable conditions between 1975 and 1981. (125)

The widespread use of turnpike double and western triple trucks limited to operate on the Interstates offers the potential not only to reduce U.S. diesel fuel consumption but also to increase truck productivity. This paper promotes the addition of "trailer parking lots" or corrals to the Interstate highway system. Implementing such a trucking system in the U.S. would save more than 100,000 bbl/day, which is equivalent to an investment of about $6 billion for synthetic fuel plants. Enhanced productivity for truck and better use of tractors means that truckers would see some or all of the cost of the system as being advantageous to them. The cost of the system can easily be raised by increasing the user charge. Any increase in the user charge will be more than offset by the reduction of costs per ton-mile that will occur with reduced labor (25%-40%) and equipment (20%-40%). One question which must be considered is whether the motorists' safety concerns can be overcome. (165)

An Organisation for Economic Co-operation and Development road research group, the Co-ordinating Group on the Impact of Heavy Freight vehicles, identified research of member countries on the effects of heavy freight vehicles. Their report notes that road transport is hard hit by the high and rising cost of crude oil, with heavy freight vehicles accounting for a significant share of the national oil consumption. For instance, in France and the Federal Republic of Germany, these vehicles accounted for some 4.5% of the national oil consumption, and some 5.5% in the United Kingdom. Determining heavy vehicle consumption was difficult due to many variables. Though member countries' approaches and material possibilities differed, their main conclusions were broadly consistent and some significant common trends emerged.(73)

This paper estimates the fuel saved by trucks operating under modern truck size and weight regulations since January 1, 1975, when the Federal Aid Highway Act of 1974 allowed weight limits of 20,000 lb for single axles, 34,000 lb for tandem axles, and a gross vehicle weight of 80,000 lb. The first part calculates the actual fuel conserved by twin-trailer combinations for the period 1975-1980 compared to the estimated savings potential for the same period. The second part estimates fuel conserved by five-axle trucks operating within states which allowed 80,000 lb gross vehicle weights on Interstates for the same year. The paper estimates a 700-million gallons savings for five-axle tractor semitrailer combinations operating in the 45 states which permit 80,000 lb gross vehicle weights. Moreover, above 75% of the 700-million gallon savings can be directly attributed to the 35 states which were able to increase their weight limits as a direct result of the 1974 Act. (84)

This paper estimates the potential fuel savings which would result from national standards permitting truck gross weight limit of 80,000 lb GVW and at least an overall length limit of 65 ft for twin-trailer combinations. Overall, if both limits were removed in states, more than 141 million gallons of fuel could be saved. The total savings reflects an adjustment made for double counting. If vehicles weighing 80,000 lb and 65-ft twin trailers were permitted on a nationwide basis, 31 million gallons of fuel could be saved. Thus, the total national diesel fuel conservation impact could be 178 million gallons annually. (85)

Both direct and indirect energy consequences of changes in truck size and weight limits have been analyzed in this study. Increasing limits will permit trucks to transport more freight with only a slight increase in fuel consumption. Total freight transported per gallon fuel will thus rise. However this will be offset somewhat by diversion of traffic to trucks from rail, since rail is more fuel-efficient. Higher weight limits may also cause increased energy in paving and maintaining the highway system and in increased bridge rehabilitation. (126)

In Texas, various size and weight combinations of trucks, including the 1980 limit, were studied for their effect on fuel efficiency, as well as truck operating costs and pavement and bridge impacts over a projected 20-year span. Only major highways and farm-to-market roads were included in the study. The most cost-efficient in fuel and operating costs was Scenario C in which truck units were increased to a maximum width of 102 in. and gross vehicle weight of 105,500 lb., and the bridge formula in 1980 was retained. (155)

Supervised by the Oregon State Highway Department, this 1968 study of triple trailer combinations was done by a freight company and supervised by the Oregon State Highway Department. An approximate 27% savings in fuel per payload ton-mile was made by triple-trailer combinations. (130)

This report shows fuel consumption per ton-mile to decrease as gross combination weight increases. Uniform truck regulations could save about 874 million gallons diesel fuel per year. (135)

This report covers Phase I of a study to determine whether increased size and weight vehicles would be energy efficient and cost effective and to investigate operational and environmental consequences resulting from their use. Although incremental fuel requirements for different size and weight trucks can be quantified, assessment of energy requirements for highway construction and maintenance needs further work. (88)

This paper outlines the design approach and preliminary performance results of a new highway freight transportation vehicle which maximizes the available payload space within existing regulatory limitations. It is a combination of a low profiled, driver forward, mid-engined tractor coupled to a freight box, and pulling a semitrailer. Fuel economy studies have shown this combination to perform better than the presently accepted industry norms. Specific road studies indicate fuel consumption ranges from 5.5 to 8.5 miles per gallon with gross combined weight of 30,000 to 68,000 lb. (176)

In this 1973 NCHRP report, a methodology for estimating benefits and costs to highway systems of changes in legal commercial vehicle weights and dimensions is proposed. Tests indicate that the principal factors affecting fuel consumption are gross weight and design top speed. The authors of this report developed an empirical equation for observed fuel mileage. Tests showed that fuel economy greatly increased with GVW. For example at 50,000 lb, one gallon was consumed for 40 ton-miles of payload. Doubling GVW to 100,000 lb resulted in 120 payload ton-miles per gallon. Reducing top design speed from 53.6 to 43.2 mph resulted in no change in fuel economy. Changing the rated engine output from 280 to 335 mph or to 380 hp did not result in any change in fuel economy for the same GVW. Fuel economy is also a function of driver characteristics, which were not included in the model. (164)

The purpose of this study was to relate the loadometer and registration data of cargo vehicles operating in Texas to fuel consumption curves developed from secondary data and adapt these results to highway user taxation. Two objectives of this report were to (1) analyze the present system of motor fuel taxation in relation to highway use by weight classes of cargo vehicles, and (2) correlate total highway taxation (fuel imports plus licenses and fees) with highway use by weight classes of vehicles. (17)

Extensive data were collected on fuel consumption and travel time of heavier trucks at the University of Washington for two years in the early 1960's. A formula was developed to predict fuel consumption or travel time. The prediction of fuel consumption depends on gross vehicle weight and brake horsepower at wide-open throttle as well as on the length of downhill distance and the amount of rise in the highway profile. The prediction of travel time depends on these vehicle and road characteristics in the cases of relatively rolling or mountainous terrain. However, in relatively flat topography and free-moving traffic, the travel time is a function of the properly posted speed limit. The formulas will aid future highway planning and help truckers choose one route vs. another. (122)

2.1.7.1.5 PERFORMANCE ON GRADES (SEE ALSO SECTION 3.3.2.1)

This paper reports on a study of the effects of heavy trucks on urban freeway traffic flow as an operational measure of total capacity. Heavier, longer trucks on grades introduce speed differentials which were not expected when the highways were designed; these may cause impatient motorists to attempt to pass in unsafe situations. (30)

This NCHRP report found that only two states currently have minimum power requirements for trucks. AASHTO recommends that GVW should not exceed a ratio of 400 lb per engine net HP to the clutch. This report identified a preference by some people in the truck industry for a performance standard. A performance standard would require that a truck be able to maintain a specified minimum speed on a specified grade. (135)

This 1970 article is on the effect of trucks on the urban freeway. On rolling urban freeways, trucks tend to maintain a constant speed as long as they are not constrained by other vehicles. (69)

2.1.7.2 BRAKING PERFORMANCE (SEE ALSO SECTION 3.1.1.2)

This paper states that multiple trailer combinations now being operated in several states generally have an excess of brake force and thus an ability to dissipate kinetic energy faster than many conventional trucks and truck combinations because of their additional axles. The kinetic energy to be dissipated at each wheel is therefore less than the brake system is typically designed for and less than that produced by more heavily loaded wheels. (130)

2.1.7.3 TIRE WEAR CHARACTERISTICS

Because of the trend toward multiple trailer combinations, this research by the Western Highway Institute was done to study the tire wear characteristics of trucks and truck combinations. Tire wear and tire costs are compared for semitrailer, doubles, and triples powered by single drive, tandem drive, and four-wheel drive truck tractors. (140)

2.1.7.4 AERODYNAMIC EFFECTS AND SPLASH AND SPRAY

This report contains an inventory of urban freeways in the 20 most populous Standard Metropolitan Statistical Areas in the U.S. and a description of truck problems and management strategies along urban freeways. Aerodynamic disturbances caused by trucks could be minimized by better truck aerodynamic design and by reducing the relative speed of trucks with respect to the cars they pass. The latter would require better enforcement of speed regulations. Lane-use restrictions could prove beneficial. In addition, spray and splash are probably the two most studied truck problems. Solutions suggested in this report include the use of mud flaps, wheel protectors (side flaps), fenders, air deflectors, and "chined" tires. Constructing roads with greater cross-slopes and lateral grooving (instead of longitudinal) are also recommended. (128)

This paper describes the mechanisms involved in generating vision obscuring spray and relates them to vehicle design. It describes an assortment of vehicle design modifications and component additions which can be made to current truck design to materially reduce their spray generation properties. It also outlines points to consider as the next generation of more aerodynamically-shaped, fuel efficient trucks are being designed. (24)

This paper highlights the installation requirements and optimal spray control efficiency of textured spray control flaps fitted to heavy duty trucks. Tractor-trailer combinations operating on wet roads at highway speeds generate visibility impairing spray clouds. Special focus is placed on the practical flap fitment behind the tractor steered and drive axles and the rear trailer axle. Moreover, the need for stronger flap support systems to accommodate the greater snow accumulations characteristic with textured spray control truck flaps is addressed. (124)

This study was done to develop methods of minimizing three aerodynamic related phenomena: truck-induced aerodynamic disturbances, splash, and spray. An analytical methodology was developed and used to characterize aerodynamic flow, truck splash and spray generation and propagation, adjacent driver visibility factors, the performance of the disturbed adjacent driver/vehicle system, and benefit/cost comparisons. These factors were also studied in a series of driving simulator, wind tunnel, and full scale tests and experiments. Understanding the phenomena, as well as identifying and developing devices and techniques to minimize aerodynamic effects, was emphasized. Several truck mounted devices and prototype concepts were identified which could alleviate the adverse effects of splash and spray cost-effectively: collector flaps, simple fenders, and aerodynamic panels and devices near the tractor, under the truck, and around the wheels. Non-vehicle means of relief were also considered. (163)

2.1.7.5 STABILITY CHARACTERISTICS

This article reports on the safety of doubles. The amplification ratio, or the ratio of the lateral acceleration of the rear trailer to the lateral acceleration of the tractor in an emergency lane change maneuver, is 1.0, which means there is no amplification, for a tractor semitrailer. However the double has an amplification ratio of approximately 2.0, which means the trailer experiences twice the lateral acceleration of the tractor. The driver can make an evasive maneuver that feels safe, but that can cause the rear trailer to roll over. (43)

This paper describes the vehicle performance of multiple trailer truck combinations equipped with double drawbar dolly having a self-steering system. It describes double drawbar dolly types, factors in their design, and findings from tests of a specific dolly and computer simulation on a range of dolly concepts. Low and high speed offtracking, stability characteristics, and loads at the dolly hitch were studied. The results showed vehicle performance to be highly dependent upon friction and stiffness in the dolly self-steering system. (171)

This report contains an inventory of urban freeways in the 20 most populous Standard Metropolitan Statistical Areas in the U.S. and a description of truck problems and management strategies along urban freeways. Due to their relatively high center of gravity, trucks may overturn when negotiating sharp curves at fairly high speeds. Advance warning and provision of deceleration lanes may help where poorly designed exit ramps exist. (128)

Research in 1974 at the Transport and Road Research Laboratory on braking performance and braking stability of heavy vehicles has resulted in definite performance requirements for all classes of vehicles and in improved directional stability. The use of anti-locking brake systems on drive axles to prevent serious deviations (in particular jack-knifing of articulated vehicles) is standard in a number of heavy vehicle fleets. However the performance and stability of heavy vehicles is still not compatible with that of a car. (29)

2.1.8 ENVIRONMENTAL CONSIDERATIONS

This report is the Department of Transportation's response to Congress' direction to study the need for uniformity in maximum truck size and weight limits throughout the U.S. Where roads on which trucks make up more than 2% or 3% of the traffic volume, truck noise usually dominates the noise from all other vehicles. The effect of increased truck size and weight limits may increase truck traffic and therefore noise and air pollution, or reduce truck traffic and therefore decrease truck noise and emissions. Rail transport may be shown to be less polluting. Changes in truck size and weight limits would change community exposure to noise in four ways: (1) Changes in the distribution weights and axle configuration types would change the noise levels generated by a given number of trucks on the road. (2) Larger loads might increase the time trucks spend accelerating if new and larger engines are not used. (3) Diversion of freight traffic from rail to truck (or vice versa), together with changes in the average load per truck, would change the number of trucks generating noise. (4) Diverting freight traffic to or from rail will have some effect on noise from railroads, by changing the average length or frequency of trains. (126)

This Organisation for Economic Co-operation and Development paper reports on the environmental effects of heavy trucks. These trucks are generally twice as loud as cars. Noise and speed are independent of each other up to 18 mph, after which noise increases by 3 to 9 dB(A) for each doubling of speed. As much as 70% to 90% of exhaust emitted by heavy trucks could be removed by using appropriate elements in the exhaust system. (61)

This is a report on the environmental effects of heavy freight vehicles. These effects are often associated with traffic noise and vibration, smoke and fumes, visual intrusion, and dust and dirt. A fear of goods vehicles felt by pedestrians in narrow streets is another factor. Noise alone can be most reliably measured and predicted. Goods vehicles cause the peaks in noise level. A frequently used index is L_{10} measured in dB(A). Increasing the percentage of goods vehicles over 1.5 tons GVW from 5% to 10% of the flow increases L_{10} by 0.5 to 1.0 dB(A), depending on the total flow. A further increase from 10% to 20% would increase L_{10} by another 1-2 dB(A). (96)

This paper summarizes the findings of a study of the social and economic impacts on urban communities of increased heavy load haulage along a route ranging in size from a major highway to a narrow residential street. Where minor routes are used, truck traffic often has a common origin or destination, and frequently involves the movement of a particular commodity or group of commodities. Road damage, accidents, noise, traffic congestion, engine emissions, vibration, and dust and spillage were studied. The greatest costs of impacts were from road damage, accidents, and value depreciation. The study confirmed that the impact of heavy vehicles on residents, road users, and the community is relatively much greater than their numbers might at first indicate. For example, in comparison with an average car, a typical (32.8 ton) truck has at least twice the effect on traffic congestion, contributes at least 10 times as much to noise levels, and wields 2,000 times the damaging power to roadways. Therefore it is in the public interest to confine heavy truck traffic to main roads and prevent it from filtering through the local road system. (78)

2.1.9 TRUCK EXPOSURE

This paper is a summary of the Symposium on Commercial Truck Exposure Estimation held in 1979. It was identified that a large number of state and federal agencies were compiling truck exposure data in a non-uniform fashion. Developing a national exposure data gathering system for commercial truck accident rates (accident exposure) which would have multiple uses to be used by all federal agencies collecting truck exposure information was recommended. (114)

These are the proceedings of the 1979 National Symposium on Commercial Truck Exposure Estimation. The 22 formal presentations dealt with (1) background (what exposure data is, why it is needed, and what it looks like); (2) general needs (at the national level, for accident analysis); (3) measures of truck exposure; (4) techniques for exposure estimation; (5) vehicular observation techniques; and (6) uses of exposure data. (115)

2.2 DRIVER PERFORMANCE

An Organisation for Economic Co-operation and Development road research group, the Co-ordinating Group on the Impact of Heavy Freight Vehicles, identified research of member countries on the effects of heavy freight vehicles. Their report found that in France accident risks varied strongly with the length of the driving sessions, the types of transport (long vs. short hauls), and the hour of the day. In Australia, accident risks doubled for drivers with an excess of 55 hours weekly driving time compared to drivers with less than 45 hours weekly driving time. A 1968 United Kingdom review of available literature showed almost no evidence of any positive correlation between duration of driving and accident involvement or changes in driving behavior of a risk increasing nature. (73)

This paper states that although it is difficult to back a truck combination of two or three trailers very far, tests have shown that drivers can back them to circumvent obstacles and prevent them from blocking traffic. (130)

This report credits the good safety record of multiple trailer combinations to their well-trained, experienced drivers. (135)

This report found the following information about drivers of large trucks involved in accidents: (1) the typical driver is male between 26 and 55 years old and was the sole occupant of the vehicle at the time of the crash; (2) drivers of large trucks were more likely than drivers of other vehicles to use seat belts, but belt usage was not high for any group; and (3) alcohol was not as prominent a factor for large trucks as for small trucks, nor were other physical conditions a major factor. (92)

2.3 TRAFFIC CHARACTERISTICS

2.3.1 VOLUME

2.3.2 DIRECTIONAL DISTRIBUTION

2.3.3 COMPOSITION OF TRAFFIC

This paper reports the effect of trucks on Australian two-lane highway traffic. An observational study was done to investigate the ability of drivers to overtake trucks under particular conditions and their behavior while overtaking. The distribution of accepted gaps was found to be independent of the length of the overtaken vehicle, and it was concluded that drivers were unable to descriminate between trucks of various lengths. If drivers cannot discriminate between trucks of various lengths, then the introduction of longer vehicles in the traffic stream is expected to result in more risky overtakings. Road designers need to insure that long vehicles can be overtaken safely. To this end, the minimum gap required by the driver before he should be able to overtake vehicles of various lengths was calculated from observed overtaking times. A figure illustrates the effect of speed and length of the overtaken vehicle on the distribution of overtaking times. (145)

This visual impact analysis shows that the average combination vehicle creates almost 5 million visual impressions annually based on the typical "mix" of travel by road system and U.S. yearly average travel of 49,125 miles. Of this total, 81% of the viewers see the front and one or both sides, 11% see only the sides, and 7% see the rear. Overall, 94% of all visual impressions originate with the drivers and occupants of other motor vehicles, while 6% originate from roadside pedestrians. (134)

2.3.4 SPEED

2.3.4.1 DESIGN SPEED

This study supplements others in finding that the geometric design of the highway is an important factor in determining vehicular speed. Percent grade, in particular, has a minimal effect on car speeds, but a larger effect on limiting truck speeds. On level downgrade sections, trucks are capable of traveling faster than the posted limit. (56)

2.3.4.2 RUNNING SPEED

This study found that trucks, on the average, passed more and were passed less than automobiles. This seems to indicate that a large proportion of automobiles are traveling slower than the desired speed of the heavy vehicles for this test section. (86)

This study found that the actual speed differential between trucks and passenger cars was less than the 10-mph posted differential, except on upgrades. Posting a speed differential was not found to be related to truck accidents. Although models suggested that lower truck accident rates can be expected with higher truck speeds; vehicle defects, weight, or roadway design may also have an effect. The limit should be temporarily increased on a test section. (56)

2.4 HIGHWAY CAPACITY

2.4.1. VOLUMES AND CAPACITY

This paper presents the results of a study of the effects of the presence of heavy trucks on urban freeway traffic flow as an operational measure of total through-put capacity. The variable of time headway, the time in seconds for the front bumper of two successive vehicles in the same lane to pass a single datum point, was used to evaluate truck impacts. After each headway had been classified by type of vehicle involved, variations in headway due to headway type, lane width, and traffic volume were analyzed. Headway type was shown to be the major determinant in length of the headway, with those headways involving trucks of the greatest magnitude. (30)

A model for estimating passenger car equivalencies (PCE's) for two-lane rural highways based on passing, speed, occupancy, and capacity is presented. A set of PCE values is developed for various vehicle types, and six-axle trucks are included. From PCE values, truck adjustment factors for rural highways are computed. Service volume adjustment factors are also developed from PCE values. Specific ways are proposed to update the parameter values used to determine PCE values in the 1965 Highway Capacity Manual. (31)

This study found that the larger the space that trucks occupy in the traffic stream, the more reduced is the capacity of the highway. There is a strong interrelation between the percentage of trucks, the rate and length of grades, and the service volume for all levels of service. (110)

Trucks further reduce traffic volume because of the difference between the average running speed of cars and trucks and because they occupy more space. A. Werner and J. F. Marshall suggest that speed difference is the only criterion for calculating passenger car equivalency for trucks on grades, while the space they occupy influences only the equivalent factor for trucks operating on flat surfaces. (156)

2.4.2 EQUIVALENCY FACTORS

This report discusses the effects of trucks on speed and highway capacity on grades, on delay to other vehicles, and the use of climbing lanes and truck escape ramps on the safety of trucks and other vehicles. Passenger car equivalents for trucks and truck correction factors are given for various road conditions. Examples showing the method used to compute the capacity of the facility are also presented. (177)

The authors describe specific effects of heavy freight truck traffic in countries in the Organisation for Economic Co-operation and Development. Data on trucks' share of the traffic flow, passenger car equivalents of trucks in different road conditions, and the effects of trucks on the traffic stream are included. Truck equivalency factors change not only with terrain and number of lanes, but also with level of service. On terrains with a slope up to 1% and a 400-m upgrade length, a PCE of 2 is used. As the percentage of trucks increase, their effect pn the traffic stream decreases. This is because trucks tend to form platoons in the righthand lanes, reducing the effect that a single truck has on the traffic stream. (36)

This report proposes a model for estimating passenger-car equivalent (PCE) values for vehicles in free-flowing, multilane conditions. The PCE of a truck represents the number of passenger cars displaced by each truck in the traffic stream under specific conditions of flow. Some measure of impedance (level of service) as a function of traffic flow is used to relate two traffic streams or categories--one that mixes trucks with passenger cars and the other that has only passenger cars. In reality an analysis of PCE values should be based on a model that considers three or more vehicle categories simultaneously. (67)

An Organisation for Economic Co-operation and Development road research group, the Co-ordination Group on the Impact of Heavy Freight Vehicles, identified member countries' research on the effects of heavy freight vehicles. Their report suggests a truck be defined in terms of "the number of passenger cars whose addition to the traffic stream would cause the same reduction to the speed of other traffic as would the addition of a truck." The report includes recent standards for passenger car equivalents used in various countries and notes ongoing research. (73)

This report deals with the development of a method to determine passenger car equivalencies. The PCE was evaluated by the ratio of the average delay caused by one truck to the average delay caused by one passenger car. (109)

This report includes an annotated bibliography of all literature relevant to the passenger car equivalencies of trucks. New methods are described for developing the PCE of trucks on multilane rural highways and urban freeways and on rural two-lane highways. These differ from other methods reported to date by both providing equivalencies of trucks as they act and interact as components in the traffic stream, and providing these equivalencies over lengths of highways involving several gradients of different percentages and lengths. A new method which requires only data in general street inventories is also described for developing PCE's at signalized intersections on two- or four-lane arterial streets. (66)

This Organisation for Economic Co-operation and Development paper reports on the effects of heavy trucks on road traffic. Trucks are generally the equivalent of 2 to 5 passenger cars, depending on a number of factors, and up to 20 PCEs in certain circumstances. These PCEs suggest that the values used in the 1965 Highway Capacity Manual are no longer true and are overestimates. (61)

This paper assembles truck populations for high type rural highways and selects four representative truck types to determine passenger car equivalencies on multilane and two-lane rural highways. Since few differences exist between representative trucks for the two highway types, one representative set with weight/NHP ratios of 295, 200, 135, and 75 is suggested. The lowest performance trucks have the most pronounced effect on traffic characteristics. The number of trucks with weight/NHP ratios greater than 295 lb/NHP is 3.5% on rural multilane and 2.6% on rural two-lane highways. The number of trucks with weight/NHP ratios greater than 400 lb/NHP are 0.27% on rural multilane and 0.26% on rural two-lane highways. (120)

This article describes a procedure for calculating automobile equivalents for any percentage of trucks on any severity of sustained grade. The truck equivalents are generated based on keeping a constant value for the v/c ratio. The resulting truck equivalents will convert a service volume in automobiles per hour to a volume in mixed vehicles per hour that will consume the same percentage of roadway capacity. In addition, a procedure is given to determine the truck equivalents for trucks on grades shorter than the critical length. (91)

Studies have been done to determine truck equivalencies. Midwestern Research Institute's work has shown that truck equivalencies are non-linear with respect to type of vehicle. (32)

This 1973 NCHRP report found that values of car equivalents for trucks vary with type of highway and level of service. On flat sections of two-lane highways and where speed differences between trucks and cars are small, trucks usually are considered equivalent to two or three passenger cars. On multilane highways, research indicates that this equivalence can vary from 0.8 to 2.0 on upgrades. There is a wide variation in car equivalents, depending on degree and length of grade, and on the speed differences on grades between passenger cars and trucks. Published tables give a wt/hp ratio of 400 for trucks on various grades, with no means to compensate for higher performance trucks. Without a data collection program, no means of relating truck equivalence factor to truck variables such as wt/hp ratio, dimensions, and configurations seems to exist. (164)

A two-lane, dual-dual, 50 mph, level, tangent roadway having a 1967 AADT of 68,000 vehicles with a high percentage of trucks was studied under uninterrupted flow conditions. A relationship between mixed volume and equivalent passenger car volume was determined for 20%, 40%, 60%, and 80% truck groups. The passenger car equivalent of trucks was found to approach a value of 2 as the percent of trucks in the stream approached 100%. The approximate truck equivalent factors, as computed for the speed range of 35 to 43 mph, are as follows: 1.60 for 20%, 1.65 for 40%, 1.75 for 60%, and 1.95 for 80%. (113)

2.4.3 LANE DISTRIBUTION

2.4.3.1 URBAN

2.4.3.2 RURAL

2.4.3.3 CLIMBING LANE USAGE (SEE SECTION 3.3.3)

2.4.4 RAMP CAPACITY

This article discusses the results of an effort made by the FHWA to update and revise freeway related elements of the Highway Capacity Manual. Existing procedures for freeway-ramp junctions are modified. The use of 5% trucks as a base vehicle population in the HCM complicates computations and is inconsistent with other freeway related parts of the manual. (117)

This 1970 article is on the effect of trucks on the urban freeway. Poorly designed ramps and acceleration lanes, particularly those located just prior to an upgrade, present special geometric problems. Slowly accelerating vehicles often cause undesirable operations, possibly resulting in a breakdown of the stream flow. (69)

2.4.5 DELAY

This chapter describes specific effects of heavy freight truck traffic on road traffic in member countries of the Organisation for Economic Co-operation and Development. Delays are caused by either unequal operating speeds (trucks and passenger cars) or maneuvering, parking or unloading. Some studies on delay from the United Kingdom, France, and the U.S. are summarized. (36)

This Organisation for Economic Co-operation and Development paper reports on the effects of heavy trucks on road traffic and safety. The paper concludes that, on the average, any parked truck inflicted a penalty of 4 to 5 minutes on other traffic for each minute that the truck is parked. (61)

This paper on the effects of heavy freight vehicles calculates the delay they cause to other traffic traveling on various types of roads. This delay depends on factors such as quality of the road, traffic flow, power/weight ratio, and vehicle load. On urban roads in the United Kingdom, the delay is 0.2-1.0 min/vehicle km; on rural roads it is 0.15-0.3 min/vehicle km; and on motorways or other dual carriageways, the delay is small or zero. These coefficients can be used to make approximate estimates of the delay which can be converted to a cost. The total cost of delays caused by goods vehicles is very small compared, for instance, with the total expenditure on roads. The delay goods vehicles cause other vehicles while delivering in urban streets has been measured in other studies. Total delay depends on street width, traffic flow, and the degree of parking control. (96)

This article on the effect of trucks on a graded multilane section of road states that as long as trucks stay in the right lane, their effect is minor on traffic operations. Automobiles are able to pass trucks in the left lane. Capacity is only slightly reduced as the truck percentage increases. However once trucks start using the left lane to pass slower moving trucks, the delay for the automobiles will increase greatly. For example, if the amount of trucks double, the delay on cars due to passing maneuvers will increase by four. (106)

This paper reports on a study of the effects of commercial vehicles on intersection delay. The objectives were to determine the delay commercial vehicles cause to through traffic at signalized intersections and to determine the effect of intersection corner radii on right-turn speeds of commercial vehicles. At intersections in 5 cities in Indiana, 23 intersection approaches were studied for commercial vehicle delay. It was found that the average travel time of a passenger car through a signalized intersection was increased from 39.9 to 49.4 s when one or more commercial vehicles were traveling ahead of it in the same platoon of vehicles. From a delay viewpoint, a 30-ft radius was found to be optimum for a single-unit truck, and a 60-ft radius was found optimum for a truck combination. (175)

2.5 ACCESS CONTROL

3.0 ELEMENTS OF DESIGN

3.1 SIGHT DISTANCE

3.1.1 STOPPING SIGHT DISTANCE

This paper reports that a variety of geometric conditions can negate the advantages of greater eye height for truck drivers. A complete functional analysis reveals significant inconsistencies in AASHTO stopping sight distance design policy. Horizontal sight obstructions (e.g., retaining walls or tree lines) restrict the view ahead from trucks and passenger cars equally, for example. Trucks greater braking distances, loss of eye-height advantage, and friction demands for cornering all contribute to much greater stopping sight distance requirements than indicated by AASHTO design policy. (104)

This paper discusses the effects on highway geometric design elements of increasing legal truck limits and the cost implications should various segments of the Texas highway system require redesign and modification to facilitate safe and efficient operation of larger trucks. Any change from the current policy on stopping sight distance is not foreseen due to the ability of the 2-S1-2-2 and 3-S2-4 vehicle combinations to stop with the FHWA braking distances. (45)

3.1.1.1 BRAKE REACTION TIME

This 1973 NCHRP report on benefits and costs from proposed changes in legal vehicle weights and dimensions found that perception and brake reaction time varies with skill and attentiveness of drivers. the usual average value for this combined time is 2.5 sec., a conservative figure from results of limited experimental data. (164)

3.1.1.2 BRAKING DISTANCE

This article reports on the ability to control doubles. Although they are larger and sometimes heavier than singles, there is no perceptible difference in their braking ability since their braking systems are designed to provide the required torque for the loads carried. However, brake condition, weather, and other variables may cause large variances in braking ability. (43)

This paper reviews current truck brake standards in both the U.S. and Europe in relation to the brake performance of heavy trucks in use today. Overall truck accident experience is examined, and an assessment is made of the effect that improved braking could have on reducing accidents. Current brake technology is discussed. The stopping distances that can be expected from trucks are theoretically and experimentally evaluated. The effect that out-of-adjustment brakes have on these stopping distances is also assessed. (80)

This report contains: (1) an inventory of urban freeways in the 20 most populous Standard Metropolitan Statistical Areas in the U.S.; (2) truck problems and management strategies relating to urban freeways; and (3) empirically derived distributions of urban freeway traffic characteristics. Since vehicle braking characteristics are dependent upon variables like tire type and condition, weight of vehicle, road surface condition, number of axles, and tires per axle; the only way to improve truck braking characteristics is by developing brake systems designed to operate under these conditions. Strict enforcement of minimum braking standards and proper maintenance are a must. (128)

This paper states that multiple trailer combinations now being operated in several states generally have an excess of brake force and thus an ability to dissipate kinetic energy faster than many conventional trucks and truck combinations because of their additional axles. The kinetic energy to be dissipated at each wheel is therefore less than the brake system is typically designed for and less than that produced by more heavily loaded wheels. (130)

Four vehicle scenarios A through D based on truck combination types were studied for the effects of increased legal limits on geometric design elements. From calculation, the authors concluded that if Scenarios B, C, and D are implemented, no change in desirable perception/reaction distance or braking distance is expected. Therefore desirable stopping sight distances as recommended by AASHTO should remain the same. (156)

This report summarizes a computer program for simulating the braking and directional response of heavy vehicles developed for the Federal Highway Administration to investigate the effects of increased truck size and weight. This Truck and Tractor-Trailer Dynamic Response Simulation - T3DRS:VI program consolidated all combinations of trucks, tractor-semitrailers, doubles, and triples into one program. Modeling was adapted from earlier simulations produced under the sponsorship of the Motor Vehicle Manufacturers Association. The program has been operatonal on FHWA computers. (47)

This report is concerned with problems of truck eye-height and braking distances. The analysis indicates that the inferior braking of trucks on vertical curves is compensated for by increased visibility due to raised eye-height. However, this is not true for the long stopping distances required in the case of heavily loaded trucks. In particular, the cab-under truck design, with eye-height barely above 2.98 ft does not have the visibility advantage of conventional trucks and consequently does not have any compensation for inferior braking ability. AASHTO policy for passenger cars prescribes that vertical curves be designed to permit the driver, whose eye height is 3.75 ft, to brake to a halt in time to avoid hitting a 6-in. high road object. The visibility advantages of tall trucks over passenger cars are calculated to range between 32% and 49%. (51)

Six typical articulated vehicle configurations were analyzed in order to define their basic stability and handling, determine the hitch point forces, and evaluate relative braking performance. A standard truck tractor with a 40-ft semitrailer was used as a baseline for comparison with all other configurations. Six maneuvers were performed under various road and influencing conditions, with and without antilock brake control, to determine the effect of increased sizes and weights. The safety qualities of interest were vehicle dynamic stability and forces transmitted at the coupling points between vehicles. Scaling techniques and computer simulations were used in the analyses. The stability, cornering, and braking capacity with conventional brakes of the five basic classes of articulated vehicles in this study compare favorably with the 40-ft semitrailer. (37)

This 1973 NCHRP report on the effects of legal vehicle weight and dimension changes contains a figure comparing braking distance of truck combinations from actual road tests of controlled trucks with the braking distance in the AASHO Policy. The data shown probably represent optimum values, since they are based on tests conducted on trucks in excellent condition, with skilled mechanics constantly checking and adjusting brakes. Tires and equipment were relatively new, and drivers were carefully picked. However, in normal operations, deterioration in any of these factors is known to occur. Therefore, some reconsideration of these stopping distances is in order. This report also includes tables showing the maximum deceleration capability of baseline vehicles, the performance of trucks and buses under failure conditions, and the minimum stopping distance. (164)

3.1.1.3 EFFECT OF GRADE ON STOPPING

3.1.2 DECISION SIGHT DISTANCE

3.1.3 PASSING SIGHT DISTANCE FOR TWO-LANE HIGHWAYS

This 1981 paper concludes that although the longer and wider trucks will necessitate additional sight distance, the current pavement marking policy should remain unaffected and require no upgrading costs. This applies only to two-lane, two-way operations. However if the current pavement marking practice is maintained, an adverse effect on safety can be expected, since passing sight distance will increase with an increase in vehicle length. The increase in abortive passing maneuvers, then, must adveresly affect safety. (45)

This report states that while an increase in vehicle weight and width will not affect passing sight distance, an increase in vehicle length will have a pronounced effect. This was confirmed by tests in Utah and Alberta, Canada. AASHTO and Texas SDHPT design values are based on requirements for passenger cars passing passenger cars. (156)

In passing tests conducted by the Nevada Highway Department on two-lane highways in 1968, it was found that actual passing times and distances were practically the same for passenger cars passing a straight truck, a tractor-semi, a set of doubles, or a longer multiple trailer combination. Passenger cars accelerated to higher passing speeds as the drivers became aware of the length of the unit being passed. (130)

This report is concerned with problems of truck eye-height. Passing zones designed for passenger cars are not adequate for trucks. The 17% to 27% sight distance advantage of trucks in passing on crest vertical curves does not fully compensate for the 50% increased truck passing distance found in two studies cited by the authors of this report. The inferior ability of trucks to overtake and pass poses a problem of how to sign and mark truck passing zones. (51)

This report deals with the effect of increasing the height of a long overtaken vehicle, the use of a sign advising of a long load, and vehicle configuration on overtaking times and distances. An articulated vehicle and a double trailer combination (articulated vehicle hauling one articulated trailer) were used to test the effect of changing the vehicle configuration. Tests as to whether the means and standard deviations of overtaking behavior parameters change as a result of the overtaken vehicle being higher (4 m instead of 2.5 m), displaying a "long load" sign on the rear, or being of a different configuration were discussed. Changes in overtaking behavior of drivers cannot be attributed to changes in the physical characteristics of the overtaken vehicle. A Swedish study of overtaking has supported these results. (143)

Overtaking data were used to determine drivers' overtaking behavior changes due to the overtaken vehicle's length and speed. Three overtaking types were considered: accelerative overtakings by cars, flying overtakings by cars, and accelerative overtakings by commercial vehicles. Results showed that increasing the overtaken vehicle's length from 5 to 16 meters increased overtaking time by about 18%. Overtaking time also increased by about 14% for each 10 km/hr increase in the overtaken vehicle's speed. If trucks travel 16 to 20 km/hr slower than cars, the same time will elapse, while 85% of drivers overtake both vehicle types. It is recommended that regulatory bodies in Australia carefully study the findings with respect to truck speed and length. (144)

This 1973 NCHRP report on proposed increases in vehicle weight and size includes several figures concerned with passing sight distance. The first shows the elements of the passing maneuver and the total passing sight distance for a two-lane highway as a function of passing vehicle speed. Another figure shows the result of acceleration tests of trucks having weight/horsepower ratios of 100 to 400 lb/ghp by graphing passing time and distance. These vary depending on vehicle condition, environmental conditions, and driver performance. From acceleration performance data, the passing distance vs. weight/horsepower ratios were plotted in another figure. (164)

3.1.4 CRITERIA FOR MEASURING SIGHT DISTANCES

3.1.4.1 HEIGHT OF DRIVER'S EYE

AASHTO states that although trucks require a longer stopping distance for a given speed, the additional braking distance is balanced by a higher truck operator eye height. AASHTO assumes a driver eye height of 3.50 ft when calculating stopping sight distance. (156)

This report is concerned with problems of truck eye-height. Official AASHTO policy has maintained that truck performance disabilities are compensated for by the advantage of elevated eye-height position. This report investigates (1) the stopping performance of trucks and (2) the visibility advantage of the increased truck eye height in order to evaluate how it compensates for reduced braking performance. Trucks' inferior braking performance on vertical curves is compensated for, on the average, by increased visibility from raised eye-height. However, this is not true of the long stopping distances of loaded trucks. A procedure for determining the geometric design eye-height standard is described and includes photographing unaware drivers. (51)

3.1.4.2 HEIGHT OF OBJECT

3.1.5 SIGHT DISTANCE AT AT-GRADE INTERSECTIONS

If it is assumed that the acceleration ability of the 3-S2-4 and 2-S1-2-2 vehicles will be at least the same as that of the WB-50, then longer sight distance will be needed due to the increase in vehicle length. (156)

In this 1973 NCHRP report, a methodology for estimating the effects of changes in legal vehicle weights and dimensions is proposed. Trucks often block signs, particularly on multilane highways with more than one lane of travel in each direction. The severity of the consequences of sign blockage would depend on the relative value and importance of the highway communication being attempted, and could be an additional basis for warrants for overhead placement of signs and increasing the number of signs carrying the same message. (164)

This 1971 report is a theoretical mathematical analysis of the blockage of signs by trucks. A driver's vision will be blocked if a vehicle comes between him and the roadside sign. The shape and speed of this "shadow" is a function of the truck and other vehicle speed, truck size and position, and sign size. Lane widths, road length and geometry, and position of driver's line of sight also influence the "shadow". The solution to this problem appears to be very general because of the several random variables involved. Since the relationship between the probability of blockage, ADT, and percentage truck mix was not apparent in the study, more research was suggested. (1)

3.2 HORIZONTAL ALINEMENT

3.2.1 GENERAL CONSIDERATIONS

3.2.2 DESIGN CONSIDERATIONS

Research at the Transport and Road Research Laboratory dismisses the theory that commercial vehicle rollover may occur because vehicles are driven too slowly through S bend maneuvers or on roundabouts. Dynamic tests at the Laboratory in which a skid is used to prevent rollover do not support the theory and indicate that rollover will occur only when the speed is too high for the radius of turn. A table shows that the lateral acceleration at which an articulated vehicle with a high load can roll over can be as low as 0.20 g's representing speeds of around 25 km/h (15 mph) on a small roundabout. There is little difference between single bend and S bend maneuvers. (29)

3.2.3 DESIGN FOR ALL RURAL HIGHWAYS AND HIGH-SPEED URBAN STREETS

3.2.4 DESIGN FOR LOW-SPEED URBAN STREETS

3.2.5 CURVATURE OF TURNING ROADWAYS AND CURVATURE AT INTERSECTIONS

This paper shows the offtracking of longer combination commercial vehicles (more than 118 ft) as well as the offtracking of less extreme vehicles. A mathematical equation was used to estimate the maximum offtracking of the vehicles, and adjustable scale models were used to produce curves showing the shape of the vehicles' paths. It was found that as the length of a vehicle increases, the length of the tractor becomes less significant. As the turning radius increases, the relative effect of tractor length decreases. (102)

This paper describes the vehicle performance of multiple trailer truck combinations equipped with a double drawbar dolly having a self-steering system. It describes double drawbar dolly types, factors in their design, and findings from tests of a specific dolly and computer simulation on a range of dolly concepts. Low and high speed offtracking, stability characteristics, and loads at the dolly hitch were studied. The results showed vehicle performance to be highly dependent upon friction and stiffness in the dolly self-steering system. (171)

This article describes a method of using a microcomputer to calculate the layout of a circular arc or bend 15 m outside radius to facilitate the longer and heavier delivery vehicles on access roads such as those to urban shopping areas. A circular arc connecting two straights is shown to be a feasible design for the outside edge of a bend on a two-way access road. The maximum widths of the two lanes occur close to opposite ends of bend. For an outside radius of 15 m, the inside radius is approximately 15 m opposite the midpoint of the circular arc and increases gradually on either side. (23)

This paper notes that additional pavement width will be needed in turning roadways because of the increased off-tracking characteristics and decreased turning ability of longer and wider vehicles, especially the 3-S2-4. (45)

Due to the increased offtracking particularly of the 3-S2-4 vehicle, additional pavement width will be needed to negotiate the turning path with minimum radius. Various templates for different configurations on varying degree turns are included in this report. (156)

The most important reason to control unit length of truck combinations is offtracking, which can cause encroaching in other lanes and difficulty in negotiating interchanges. This NCHRP report states that, generally, the shorter the unit, the better a multiple trailer vehicle articulates. With the degree of curve on most Interstates, offtracking should not be a problem. (135)

This paper reports on a study of the effects of commercial vehicles on intersection delay. The objectives were to determine the delay to through traffic caused by commercial vehicles and the effect of intersection corner radii on right-turn speeds of commercial vehicles. At intersections in 5 cities in Indiana, 19 varying intersection corner radii were studied for right-turn speeds of single-unit trucks, truck combinations, and passenger cars. The maximum right-turn speed for a truck combination at a signalized intersection is approximately 22.4 km/h (14 mph) and approximately 23 km/h (15 mph) for a single-unit truck. (175)

This report discusses how road width required by a vehicle to negotiate a bend or corner varies with the design of the vehicle. Measurements were obtained for a sample of commercial vehicles, and then compared with other results obtained using the models and the calculation. (16)

In this 1973 NCHRP report, a methodology for estimating benefits and costs to highway systems of changes in legal commercial vehicle weights and dimensions is proposed. A figure shows the equivalence of five various definitions of offtracking. The magnitude of combination offtracking is affected in combinations by the number and location of articulation points, by the length of the arc and the type of curve, and by the speed and turnability of the wheels. This report describes two approaches for determining offtracking. It also provides several versions of a mathematical equation for determining offtracking. A table shows AASHO basic design policy for pavement widths of turning roadways. Three traffic conditions and three cases of traffic operation are cited. Pavement widths for both long curves and for turning roadways are discussed using AASHO Policy figures, which may or may not conform to a specific state's design standard. Differences may occur when the critical design vehicle of the state differs from that used in developing the AASHO Policy. (164)

3.2.6 PAVEMENT WIDENING ON CURVES (MINIMUM TURNING PATHS OF DESIGN VEHICLES)

This report contains: (1) an inventory of urban freeways in the 20 most populous Standard Metropolitan Statistical Areas in the United States; (2) truck problems and management strategies relating to urban freeways; (3) empirically derived distributions of urban freeway traffic characteristics. Since offtracking is mainly related to the radius of the curve and the length of trucks, new facilities should be built using minimum design standards for curves. The offtracking problem must be considered when setting size, particularly length and wheelbase, limitations. (128)

This paper notes that because of the increased offtracking characteristics of the 3-S2-4 vehicle, additional pavement width on curves will be needed if legislation for longer and wider trucks is passed. (45)

This report shows several tables which detail the pavement widening necessary for either pavement construction or reconstruction. Formulas are given to calculate maximum offtracking values, width to compensate for the difficulty of driving on curves, and width of the overhang. (156)

This paper shows that triples can negotiate sharper turns than many of the common tractor-semitrailer combinations which operate more or less unrestricted on all streets and highways. Truck combinations can be restricted to those roads having the geometric capability to accommodate them. (130)

This paper discusses turning requirements for large vehicles. A table lists values obtained for a large vehicle in each of three categories. The largest articulated vehicle and some rigid public service vehicles with a large body overhang forward of the front will have trouble meeting a proposed minimum 5.3-m inside radius of turn and a 12-m outside radius of turn. Generally, the articulated vehicle requires a greater lane width to negotiate a given radius than comparable rigid and drawbar trailer vehicles. (29)

This NCHRP report on the effects of proposed changes in legal vehicle weights and dimensions includes a table of calculated and design values for pavement widening of one- or two-way, two-lane pavements on open highway curves. On earlier highways with narrow pavements and sharp curves, it was common practice to consider widening the pavements so that operating conditions on curves approached those on tangents. AASHO Policy on pavement widening at curves on rural highways suggests a mininimum widening of 2 ft be used on restrictive curves. (164)

3.2.7 SIGHT DISTANCE ON HORIZONTAL CURVES

3.3 VERTICAL ALINEMENT

3.3.1 TERRAIN

3.3.2 GRADES

3.3.2.1 VEHICLE OPERATING CHARACTERISTICS ON GRADES

This paper reports on a study of the effects of heavy trucks on urban freeway traffic flow as an operational measure of total capacity. Heavier, longer trucks on grades introduce speed differentials which were not expected when the highways were designed; these may cause impatient motorists to attempt to pass in unsafe situations. (30)

Charts in this paper show the average deceleration speeds for trucks operating on grades of +2% to +7% and the average acceleraton speeds of trucks operating on grades of -7% to +7% from California 1977 and 1978 data. The charts may to used to prepare speed profiles for typical slower trucks and average trucks for upgrades along proposed highways. The charts are for 15% two-axle trucks with six tires, 5% three-axle trucks, 5% four-axle trucks, and 75% five axle trucks. (177)

This report examines vehicle performance (weight/horsepower ratio) associated with roadway design features and, thus cost. The design vehicle's climbing ability determines the vertical alinement and affects highway cost components through charges for grading and drainage. (118)

Multiple trailer combinations have truck engines with adequate power to climb limited grades of 5% or under found on most Interstates. In severe conditions, traction aids are available. (130)

This report was prepared by measuring speeds of a large sample of trucks, recreational vehicles, pickup trucks, vans, and other vehicles on grades along California rural freeways and expressways. The truck speed measurements included sustained speeds on grades, speeds while decelerating on grades, and speeds while accelerating on a -0.14 % grade. The truck speed information was used to prepare calculated deceleration curves for trucks on grades. The sustained speeds were used for the calculations, and the measured deceleration speeds were used to determine that the calculated speeds were similar to the measured speeds. (22)

This report deals with the power requirements for trucks and truck combinations, their performance on grades, and with what is needed to meet minimum speed requirements on various highway grades. Part One reviews the performance capability of various trucks, including an assessment of possible future horsepower requirements for these vehicles. Although weight is the principal factor determining horsepower requirements, other external factors, such as air-resistance and rolling resistance, and internal factors, such as friction, accessories, and gear ratio, affect horsepower availability. Part Two describes the operational test conducted by state highway departments in several western states along with experience data compiled by those turnpike authorities which permit sizes and weights in excess of federal and state requirements. (63)

This manual provides charts and procedures for calculating operating speeds and performance capabilities of trucks in the traffic mix. Special attention is given to the situation where a third lane is added and then dropped to maintain service on an extended upgrade, and design procedures are provided for short upgrades and for downgrades where trucks may crawl to maintain speed control. The possibility of short periods of depressed service during hours of otherwise acceptable service is also addressed, with quantitative procedures given. (41)

This book is a comprehensive treatment of intercity highway truck drive traction. It emphasizes how steep a grade a truck combination can climb without spinning out on packed snow or wet pavement. Requiring two or more driven axles for combinations above a certain weight is not recommended, since more driven axles do not necessarily insure better performance. It might be that no rule is the best rule, also since the driver will want to keep his truck operating without interruption for safety and economic reasons. (34)

This 1975 research report presents data characterizing trucks (and combinations) and recreational vehicles on grades. Field data collected at locations in central and east Texas were analyzed, and speed-distance curves developed for a range of grade profiles. (158)

This 1973 NCHRP report is on the effects proposed changes in vehicle weights and dimensions would have on highway systems. It showed that the external existing forces any vehicle must overcome with a specific load to travel at a steady speed on level pavement are rolling resistance and air resistance. In an accelerating mode for any vehicle, inertial resistance is introduced. In negotiating a grade, the "grade resistance" to overcome gravity is encountered. Equations are provided to calculate the rolling resistance factor, air resistance, grade resistance, gradability, inertial resistance, and grade climbing under adverse conditions. (164)

This 1970 article is on the effect of trucks on the urban freeway. On rolling urban freeways, trucks tend to maintain a constant speed as long as they are not constrained by other vehicles. (69)

On a 6% grade snow-packed roadway, demonstrations were made to show that chained-up 6x4, 4x2, and 4x4 truck-tractors could stop and restart pulling both empty and loaded trailers to present legal load limits.

Further, it was demonstrated that 6x4 and 4x4 truck-tractors with chains could stop and restart on this grade pulling triples loaded to the higher gross weight levels in accordance with Bridge Formula "B" values. (141)

The Western Highway Institute researched the performance levels of the various highway vehicles traveling the various highway systems. This report contains the results of July 1969 field acceleration tests on commercial truck combinations engaged in regular highway operation.(62)

This 1969 study was conducted in response to an increasing concern by highway design engineers about the validity of geometric design criteria for the safe operation of slow-moving vehicles on highway grades. Major findings were: (1) The AASHTO truck speed-distance curves appear to be adequate for design, since they were developed for a design vehicle with a weight/horsepower ratio of 400:1; this represents a reasonable lower boundary for trucks presently on the highway. (2) Based on a comparison of truck accident involvement rates, the speed reduction criterion for initiating truck climbing lanes should be lowered from 15 mph to 10 mph. (50)

This report presents a method for calculating the speed vs. distance history of large trucks traversing various types of vertical highway curves at wide-open throttle. Charts were developed using ranges of values of both vehicle and highway properties to relate vehicle speed to distance along the vertical highway curve. Assumptions concerning ranges of vehicle properties were used to reduce the complexity of the equations to be considered. The limitations mentioned did not appear serious because the majority of large transport trucks were included except when empty or very lightly loaded. (39)

This article reports on a study of truck congestion on uphill grades. Under ideal conditions on a 6% grade, a 1000 ft passing bay should allow 14 vehicles to pass a truck moving at crawl speed. Actually, only nine can expect to clear a truck. A 1000 ft bay properly signed should handle a total daily traffic volume of 3000 vehicles, with 20% trucks. (167)

A simplified theory of the motion of heavy vehicles on grades is presented. A set of speed-distance curves computed from the theory, based on maximum sustained speeds observed in Arizona, is given as the basis for design of climbing lanes in Texas. Speed-distance curves representing the observed performance of a test vehicle on 11 grades agreed fairly well with the corresponding curves plotted directly from test data. This theory appears accurate for use in climbing lane design. (68)

This article analyzes truck performance data on length of grade and speed on the grade. The effect of truck load on speed is very small when the grade is short and the approach speed is high. As the truck's payload increases, it is more advantageous to enter the grade at a higher speed. As the load is increased, its relative effect on the truck's speed is reduced. (137)

Four tests were used to determine a truck's hill climbing ability: actual grade test, theoretical test based on engine-torgue and power curves, acceleration test, and drawbar dynamometer test. Grade test is the most laborious and expensive but offers the most accurate results. The theoretical test is quick and inexpensive as well as reasonably accurate. The acceleration test is quick to perform in the field but requires time to process the data in the office. The procedure is by far cheaper than the grade test and reasonably accurate. The drawbar test has a high initial cost but offers good results. (119)

3.3.2.2 CONTROL GRADES FOR DESIGN

3.3.2.3 CRITICAL LENGTH OF GRADES FOR DESIGN

This paper predicts no adverse effect on the climbing ability of trucks should legislation for longer and wider trucks be implemented. The authors wonder whether there may be a shift back toward the 400:1 ratio if larger trucks are legalized. (45)

Truck Gradability curves from the Highway Capacity Manual, studies at Penn State, Midwest Research Institute, and Texas A & M, and from Firey and Peterson's research are presented. The curves seem to agree on the crawl speeds attained but not on the intermediate rate of deceleration. (32)

The size, power, gradability, and entrance speed of trucks contribute to the performance of trucks on grades. Their combined effect will lead to the maximum allowable speed reduction of 10 or 15 mph. (156)

3.3.3 CLIMBING LANES

Although this report states that there are no absolute criteria for the construction of climbing lanes and passing lanes, there are several factors to consider. These include the environment, typical trip distances, corridor design continuity, present and probable future traffic volumes and volume to capacity ratios, present and probable future truck and recreational vehicle volumes, numbers of vehicles delayed by slow vehicles, congestion, costs and benefit to cost ratios including vehicle operating costs, delay and safety. The most cost effective location for constructing one climbing lane or passing lane along a road where the grades, traffic volumes, number of passing opportunity locations, and construction costs for a climbing or passing lane do not vary much is at the halfway point. The best locations for two climbing or passing lanes are at the one-third and two-thirds distances along the grade. For three passing lanes the best locations are at the one-quarter, halfway, and three-quarter distances. Although no absolute criteria can be used to determine the minimum distance between diverge and merge tapers, generally the minimum distance along low-volume roads with AADT's of approximately 1000 should be adequate for at least one fast sedan to pass another fast sedan. (177)

An Organisation for Economic Co-operation and Development road research group, the Co-ordinating Group on the Impact of Heavy Freight Vehicles, identified member countries' research on the effects of heavy freight vehicles. Several factors commonly considered to determine the need for climbing lanes were listed in the report: truck speed on the grade, total volume-capacity, length of grade, percentage of trucks in the traffic flow, and the terrain. A thorough international review of design criteria of crawler lanes on two-lane roads was made, including the effects and an economic evaluation of climbing lanes. (73)

This paper is concerned with a level-of-service concept for introducing climbing lanes on two-lane rural highways, for both upgrade and downgrade directions. A set of criteria is devised for each direction, and extensive use is made of a previously developed model for truck equivalency factors for upgrades and downgrades. Where there are no restricting conditions to cause low approach speed, the full-width extra lane may be introduced on the grade at a point defined by a reduction of 20 km/hr from the average running speed on a level section. The climbing lane should end when trucks again reach the average running speed. (110)

This paper reviews existing methods and models used to evaluate climbing lanes. Because it can most accurately evaluate the nonsteady state in the vicinity of a climbing lane, the simulation model is the most suitable. Six candidate simulation models are described. (12)

The objective of this working paper is to report upon a preliminary evaluation of the existing climbing lane models regarding their suitability for employment in a future study. The study will create a model to evaluate the performance of climbing lanes. The primary model chosen is MIDWEST by St. John et al. at the Midwest Research Institute, and the alternate model SIMTOL was developed by Stock at the University of California at Berkeley. Travel time, accident potential, and queue dissipation are the most important measures of performance of a climbing lane. (13)

After evaluating the SIMTOL and MIDWEST models, this paper recommends that the MIDWEST model be modified and used for their study of a climbing lane project. The paper also presents the methodology to be used in modeling the climbing lane and collecting the data. (11)

This report presents a procedure for determining the most cost-effective climbing lane design. Five different length climbing lanes corresponding approximately to AASHTO standards (1978) were studied. The 1500-ft lane was found to be the most cost-effective. Constructing one 1500-ft climbing lane on several upgrades rather than on one upgrade was also found to be more efficient. Upgrades with severe gradients would benefit most from climbing lanes. The best location for the construction of a climbing lane is near the upgrade midpoint. (14)

The general relationships between impact of gradient, length of grade, and traffic volume on climbing lane performance observed in the first study still hold. Simulation of a 1000-ft. lane showed no cost-effective improvement over the 1500-ft lane. Changes and additions are proposed to the model to evaluate longer sections of road in discovering a safe climbing lane design. (15)

AASHTO uses two criteria to justify the use of a climbing lane for trucks: primarily, when a 10-mph speed reduction is observed, but also when the level of service of a roadway indicates a need for a climbing lane. Also, the lane would be terminated only when truck speeds reach 30 mph. States basically adopt AASHTO policy. (32)

This study obtained new field data about motor-vehicle operating characteristics on selected grades and related these data to current and future geometric design standards for highway grades and the related capacity and safety aspects of vehicle climbing lanes. The report recommended that some composite critical-length-of-grade speed versus distance curves that were developed in the paper should be applied to the evaluation of the need for and the design of climbing lanes for trucks. It also recommended that 55 mph should be used for the evaluation and design of climbing lanes. (157)

This manual provides charts and procedures for calculating operating speeds and performance capabilities of trucks in the traffic mix. Special attention is given to the situation where a third lane is added and then dropped to maintain service on an extended upgrade. Design procedures are provided for short upgrades and for downgrades where trucks may crawl to maintain speed control. The possibility of short periods of depressed service during hours of otherwise acceptable service is also addressed, with quantitative procedures given. (41)

This report validates the gradability curves adopted by AASHO in 1965. It criticizes using the 15-mph criteria for climbing lane installation, and suggests using a 10-mph cutoff point to reduce the number of accidents. (49)

This study is based on a small survey conducted to statistically prove that on a given grade, with a known entrance speed, a truck will decelerate to a crawl speed in x number of feet. The researchers had trouble locating study sites in the area which met the requirements. After the sampling was done, some samples were determined to be statistically unsound. The data collected at the most successful location supported the conjecture that truck speeds, on the average, have greatly increased since the deceleration rate curve for a +5% grade in the Connecticut Geometric Design Manual was compiled. (168)

This paper develops equations based on the operational characteristics of the truck, the physical environment, and the roadway geometry to calculate the speed and acceleraton properties of large trucks on various grades and acceleration lanes. The results of the calculations were presented as charts relating vehicle speed to distance along the vertical highway curve. The weight/horsepower ratio is varied from 200 lb/hp to 400 lb/hp. (39)

This article reports on a study of how truck congestion on uphill grades is reduced by adding 1000-ft passing bays on the right. All delays to each car were computed separately. Three bays were located at the bottom, middle, and near the top of the hill. Congestion was measured before and after the bays were built; 65% to 70% relief from congestion was found. Construction costs were high with a final benefit ratio of less than one. However public approval was great and accident reduction, as well as less driver irritation, were the benefits. Building three bays also cost only 20% of what a full uphill lane would have cost. (167)

A simplified theory of the motion of heavy vehicles on grades is presented. A set of speed-distance curves computed from the theory, based on maximum sustained speeds observed in Arizona, is given as the basis for design of climbing lanes in Texas. Speed-distance curves representing the observed performance of a test vehicle on 11 grades agreed fairly well with the corresponding curves plotted directly from test data. This theory appears accurate for use in climbing lane design. (68)

3.3.4 EMERGENCY ESCAPE RAMPS

This 1985 California report recommends an emergency escape ramp be constructed whenever the maximum safe speed for trucks is equal to or less than 55 mph on a highway. When determining the location of emergency escape ramps, factors to be included are traffic volumes; truck volumes, especially three-, four-, and five-axle trucks; the number of lanes downgrade, whether so many curves exist that most runaway trucks would run off the road prior to one or more escape ramps; and whether a safe area such as a tangent freeway exists for runaway trucks to decelerate beyond the downgrade provided that the trucks did not run off the road or hit other vehicles. (177)

The purposes of this 1982 report, which represented the "state of the art" in heavy vehicle escape ramps, were to (1) review current truck escape ramp literature; (2) document all acceptable designs; (3) determine any and all shortcomings in current methods of arresting heavy vehicles and recommend specific research needs to eliminate these deficiencies; and (4) develop a framework of information, criteria, and specifications to serve as interim guidelines and a basis for setting national design standards for truck escape ramps in the future. Six types of truck escape ramps were studied. Future research needs to be done on several design elements of each type of escape ramp. (8)

A questionnaire was used to determine truck drivers' perceptions of mountain driving problems and truck escape ramps. The main opinions of truck drivers were: (1) Better signing would facilitate their descent down a steep mountain grade. (2) Recommended speed signs on downgrades had little effect on truck driver's gear selection. (3) Escape ramps would damage their vehicles and cause injury to themselves. Most truck drivers are reluctant to use them and will try to ride out the grade. (4) An escape ramp should be located between halfway down and the bottom of the grade. (5) Truck drivers would use left-handed escape ramps only when there was sufficient sight distance to check opposing traffic. (35)

This article describes a truck-arrester system tested in New York state. The system consisted of a 528-ft long bed of 2-ft deep screened gravel, backed up by an array of 88 sand-filled plastic barrels. The depth of gravel increases from 0 to 2 ft in the first 50 ft, remains constant, and then tapers back to 0 at the other end. At the entrance and at the end of the gravel bed, conventional impact attenuators are placed to stop any automobiles or light trucks that may enter the gravel bed. Heavy guiderail extends the entire length to prevent the vehicle from jackknifing and insure that both rows of sand barrels are struck simultaneously. Three tests were conducted with a 37,000-lb dump truck traveling at 21, 41, and 56 mph. The truck entered the arrester bed with the transmission in neutral, the clutch engaged, and using no brakes. In each test, the truck came to a safe, complete stop at a distance of 81, 177, and 300 ft, respectively. From these tests and other studies, it appears that articulated vehicles would also be safely stopped by this truck-arrester system. The decelerations experienced in these tests were also similar to those experienced in panic stops on dry pavement. (6)

This report explains the need for emergency escape ramps to minimize the hazards of steep grades. The techniques and designs used in the development and operation of existing and planned emergency ramps in the U. S. are summarized. The desirable conditions for constructing an escape ramp and types of ramps are outlined. (166)

3.3.5 VERTICAL CURVES

3.3.5.1 CREST CURVES

This report evaluates the potential for hazard to trucks operating on crest vertical curves designed to AASHTO standards. A truck performance simulation model (TPSIM) was developed to calculate sight distance and stopping distance associated with each point along the path of a vehicle traversing a specified crest vertical curve. The total stopping distance is compared to the sight distance at a sequence of truck positions along the curve. A range of truck braking characteristics and cab types operating over a complete range of crest vertical curves were analyzed. For selected curve and truck combinations, there are potential hazards for trucks. (101)

3.3.5.2 SAG CURVES

3.4 OTHER ELEMENTS AFFECTING GEOMETRIC DESIGN

Longer and wider trucks will probably most effect the geometric design features of highways. Substantial costs will be incurred to widen lanes, improve shoulders, and adjust turning radii, for example. These costs need to be calculated before the efficacy of large vehicles can be judged. (155)

In a WASHTO meeting, this presentation points out that not all WASHTO states agreed as to specification of signs for oversize loads, or long loads. (27)

4.0 CROSS SECTION ELEMENTS

4.1 PAVEMENT

This article analyzed the impacts of changes of federal truck length and weight on truck productivity, modal diversion, freight costs, safety, energy, air quality, and noise. Also estimated was the present value of the forecast cumulative changes in transportation and highway system costs. Increases in truck length and weight limits within a substantial range provide sufficient transportation cost savings to pay for damage done to the highway system. But if limits are increased without a corresponding increase in highway system expenditures, then the condition of pavements and bridges in the U.S. would deteriorate; thus affecting vehicle operating costs, travel speeds, and circuitry experienced by drivers. (136)

This report is the Department of Transportation's response to a directive by Congress to study the need for uniformity in maximum truck size and weight limits throughout the U.S. The impacts on pavement costs from changes in truck size and weight limits will occur in (1) changes in maintenance costs required for the Nation's highway pavements; (2) changes in the cost of overlays due both to the timing of the required overlays and the cost of the overlays necessary to support the anticipated traffic; (3) changes in the cost of major pavement reconstruction as may occur because of substandard highway geometry, inadequate vehicular capacity, or other types of functional obsolescence; (4) changes in the costs of pavements for new highways built in a new location; (5) changes in the operating costs of motor vehicles, both for fuel and repairs, due to changes in pavement condition. High or low axle and gross vehicle weight limits correlate with reported changes in highway condition to only a limited extent. Thus, high weight limits have not posed an insurmountable barrier to maintaining highways, although highway costs may have been higher in states with high weight limits. (126)

Lighter axle and gross weights distributed on more axles and longer wheelbases have less effect on highways, thus saving on maintenance, repair and construction costs. Tandem axles on flexible pavements have an advantage over single axles. Longer multiple trailer combinations show less effect on pavement and also show significant reductions in live-load moments imposed on a 50-ft bridge span. Similar reductions apply to shorter span bridges. (130)

This report states that tandem axle loads operate as if they are single axles and produce less equivalents than twice the single axle loads represented in the pair. If axle load repetitions are increased beyond the designed axle load, pavement life will be shortened. The costs of both overlay and reconstruction directly due to uniform truck size and weight would be the major expenses of truck uniformity. (135)

4.2 LANE WIDTHS

This paper states that although no change in the Texas lane width policy is expected if truck limits increase, a 6-in. vehicle width increase will necessitate strict adherence to the current desirable standards. The cost estimates from adopting longer and wider trucks as design vehicles should not be considered as "over and above," since the same costs will be necessary in upgrading the Texas road network to current policy. (45)

This paper states that only vehicle width will have an impact on lane width. The AASHTO design vehicles SU, WB40, WB50, WB60, and the BUS are all 8.5 ft wide. If the 102-in. truck keeps within the 55-mph speed limit on a two-lane 22-ft wide highway, it will disturb oncoming traffic and create driver strain and tension. Therefore lane width should be gradually modified to 12 ft if 102-in. wide vehicles are allowed on these highways. (156)

This paper reports on a study of vehicle encroachment on bituminous shoulders and of vehicle lateral placement within the outside driving lane of 4-lane divided pavements. Vehicles observed were only trucks with dual tires on the back axle, tractor-trailer combinations, and buses. Lateral placement data were obtained on 4 Minnesota standard design highways, each rural, 4-lane divided, with 24-ft wide Portland cement concrete surface roadways and bituminous shoulders. Additional data were collected on two wider pavements which had a 15-ft outside lane and bituminous shoulder. Some of the findings are: (1) wider pavements seem to attract more excursions of heavy vehicles outside the edge stripe; (2) wider rigid pavements have decidedly fewer edge loadings than 12-ft outside lanes; and (3) the average vehicle travels closer to the edge stripe on wider pavements. (19)

In this 1973 NCHRP report of the effects of proposed increases in truck weight and size, lane widths are discussed. Studies have shown that from ideal standards of driver convenience, operational ease, and safety, constructing all highways with 12-ft wide lane widths and usable shoulders of 6 to 10 ft is desirable. This report, however, finds that marginal lane widths less than 12 ft can be operationally acceptable if traffic volumes are low, if only moderate truck volumes are in the traffic stream, and if relatively low design speeds are feasible. Research shows that body and edge clearances for meeting or passing vehicles are critical factors in judging the adequacy of pavement width. Drivers of commercial vehicles traveled closer to the centerline when meeting other commercial vehicles on 18-ft pavements than on 20-ft pavements. On 24-ft pavements drivers were apparently satisfied with both edge and center clearance, as indicated by their choice of a placement near the center of their lanes. On 4-lane divided highways, AASHTO Policy recommends a 12-ft lane, with 13-ft lanes considered for highways that accommodate many large combinations. However, with a lane wider than 12 ft, drivers tend to use it as two effective lanes in some situations. A tendency of accident rates to increase on 13-ft lanes, as compared to 12-ft lanes, is an indication of this practice. (168)

4.3 SHOULDERS

4.3.1 WIDTH OF SHOULDERS

This report contains: (1) an inventory of urban freeways in the 20 most populous Standard Metropolitan Statistical Areas in the U.S.; (2) truck problems and management strategies relating to urban freeways; and (3) empirically derived distributions of urban freeway traffic characteristics. A common problem for trucks operating on urban freeways is inadequate left shoulder widths for emergency stops. These do not permit trucks to completely clear the lane unless they run onto the median. Sometimes inadequate left shoulder widths are coupled with narrow medians which may prohibit widening the left shoulder. Also, a significant number of shoulders in each urbanized area are not surfaced and therefore may be structurally inadequate for trucks. (128)

This paper states that although no change in the Texas policy on shoulder width is expected if limits increase, a 6-in. vehicle width increase will necessitate strict adherence to the current desirable standards. Therefore lane width should be gradually modified to 12 ft if 102-in. wide vehicles are allowed on these highways. (45)

Since AASHTO standard vehicles vary from 7.0 ft to 8.5 ft, AASHTO recommends for heavily traveled and high-speed highways the usable shoulder width should be at least 10 ft but preferably 12 ft wide.(156)

This 1973 NCHRP report on the effects of proposed larger truck limits on highways finds that trucks tend to use shoulders as the traveled way when meeting other vehicles on narrow-lane roadways. Adequate shoulders give the driver a sense of security and thereby enhance traffic flow. On highways with 12-ft lanes, however, the relationship of shoulder width to truck dimensions appears to be governed by the width required for truck emergency stops clear of traffic. Wide trucks on adequate shoulders aggravate the situation. (164)

4.3.2 SHOULDER CROSS SECTIONS

4.3.3 SHOULDER STABILITY

4.3.4 SHOULDER CONTRAST

4.4 HORIZONTAL CLEARANCE TO OBSTRUCTIONS

This 1983 report discusses some technical and policy factors in the heavy vehicle size and weight issue. Some recent work is discussed on the development of traffic barriers--guardrail and bridge rail--which cannot be penetrated by heavy vehicles but which retain a desirable level of energy absorption and redirection capability for passenger autos. (123)

This paper states that since guardrails are designed according to passenger car characteristics, no change because of longer and wider trucks is expected. (156)

4.5 CURBS

4.6 DRAINAGE CHANNELS AND SIDESLOPES

4.7 ILLUSTRATIVE OUTER CROSS SECTIONS

4.8 TRAFFIC BARRIERS

In this study, a standard Texas traffic rail type C202 barrier was modified by increasing its height and strengthened to restrain and redirect an 80,000 lb van type truck or tractor-trailer. In a crash test at 49.1 mph and a 15 degree angle, a truck was restrained and smoothly directed. Damage to the truck and rail was moderate. The upper rail would have probably performed better had it been lower;

therefore the lower standard T4 is recommended. Also, since the post anchorage cast steel washers had shattered, hardened steel washers should be used at the post anchorages. (2)

4.9 OTHER ELEMENTS AFFECTING CROSS SECTION

5.0 OPERATIONAL DESIGN

5.1 TRAFFIC CONTROL DEVICES

5.1.1 OVERSIZE LOAD DETECTORS

5.1.2 INNOVATIVE SIGNING

5.2 FLOW RESTRICTIONS

5.2.1 LANE AND SPECIAL ROUTE RESTRICTIONS

This report analyzed the feasibility of exclusive truck facilities (ETFs). In the first phase, the physical problems associated with placing ETFs in the existing right-of-way were studied. The second phase was a review of current geometric design policy to determine applicability to ETFs. Vehicle characteristics, sight distance, horizontal alinement, vertical alinement, and cross-section elements were examined. Areas where additional design criteria are necessary were identified. (97)

This report concluded that the contraflow lane had more than adequate capacity for truck use, but few truckers would use the facility because of its limited access. It was recommended that trucks not be considered as potential users of the contraflow lane. (60)

This project identified 15 links on a national freight network as representative of heavy truck volume and heavy traffic problems. The report analyzed the cost-effectiveness of several types of improvements designed to better accommodate commercial traffic. Improvements or modifications included: (1) addition of lanes in each direction of travel, with or without lane reservation full time or during specific hours; and (2) lane reservations only, where practicable. It was concluded that physical modifications to improve intercity truck operations would be cost-effective, while lane reservations were generally non-productive. (75)

This critique states that the commodity flow network of NCHRP Report 198 has two drawbacks: (1) it does not include intrastate traffic which would move under new, higher limits, and thus gives an inaccurate forecast of the initial investment needed to maintain present pavement life; and (2) the network provides a limited view of individual states'commodity flows which makes the analysis too broad for any useful guidance to states on policy choices. Missing are the major costs of providing drayage and marshalling yards along limited access routes, which should be added to transport costs. (28)

This report includes a commodity flow network which (1) identifies regional truck mileage of 14 commodities and (2) calculates the average payload by commodity. In regions permitting twin trailers, they are not used much for heavy commodities. (135)

5.2.2 SPEED RESTRICTIONS

This Organisation for Economic Co-operation and Development paper reports on the impacts of heavy trucks on road safety and traffic. Data from 7 member countries showed that 12% to 90% of trucks exceeded posted speed limits, depending on the type of road, local conditions, and the speed limit. (61)

6.0 OPERATIONAL SAFETY / TRUCK ACCIDENTS

6.1 OPERATIONAL SAFETY

The direct safety effects of increasing the number of large trucks in urban areas are explored in this article. A simple theoretical model of mixing trucks with cars is presented which is supported by recent detailed data from national in-depth accident investigation programs. The model shows that the physical difference of mass between large trucks and cars necessarily leads to a larger number of fatalities unless the probability of such collisions is reduced. (108)

This article reports that the actual effect of one double on traffic safety during hill climbing is minimal, but large numbers of doubles could cause significant operational problems on grades. Generally, doubles and singles have not been shown to differ in accident experience. Therefore, it is unlikely that allowing doubles to operate nationwide will result in any observable differences in highway safety. (43)

This study of the probable effects of the 102-in. truck widths and 48-ft trailers and twin trailers probable effects on Georgia state routes provides (1) a statistical analysis of accident and roadway characteristics data to identify roadway features closely associated with truck safety; and (2) an evaluation of the benefits and costs of allowing more liberal access of large trucks to two-lane roads. The report developed various models and tables to estimate the safety benefits of alternative roadway improvements. It also provides examples of approaches that could be used to estimate the benefits of (1) allowing 102-in. wide trailers more liberal access to two-lane roads, and (2) allowing the tractor-twin-trailer configuration greater access to two-lane roads. (172)

This paper reviews the problems associated with heavy truck air brakes. Overall truck accident experience is examined, and an assessment made of the effect that improved braking might have on reducing accidents. The controversial Federal Motor Vehicle Safety Standard 121 brake standard is reviewed, together with the maintenance and reliability problems that led to its repeal. Improvements that can be expected from new brake technology are reviewed, and the feasibility and practicality of a new brake safety standard discussed in relation to European brake regulations. (80)

This report evaluates the potential for hazard to trucks operating on crest vertical curves designed to AASHTO standards. A truck performance simulation model (TPSIM) was developed to calculate sight distance and stopping distance associated with each point along the path of a vehicle traversing a specified crest vertical curve. The total stopping distance is compared to the sight distance at a sequence of truck positions along the curve. A range of truck braking characteristics and cab types operating over a complete range of crest vertical curves were analyzed. For selected curve and truck combinations, there are potential hazards for trucks. (101)

This report provides safety advantages of bigger trucks in braking and stability. The accident frequency ratio for interstate trucks operated by large motor carriers (big trucks and truck and truck combinations) is only 2.5, while all motor vehicles combined have an accident ratio of 14 per 1 million vehicle miles. Triples have advantages over lighter and shorter vehicles in braking and stability. They are progressively lighter from front to rear due to required and accepted loading practice. Large trucks with their high pressure tires never hydroplane at normal traffic speeds and have a higher average coefficient of friction during a wet stop. Bigger trucks can maneuver and offtrack as well as some conventional tractor-semitrailer combinations. When properly operated under regulated conditions, they can help improve highway safety as well as many problems of congestion, smoke, and noise. (129)

This report examines several truck studies on larger and wider vehicles and their safety problems. It points out several flaws in the analysis procedures of these studies. This report concludes that although larger trucks do have real safety problems, they can be operated safely under certain conditions. (42)

This article discusses the issue of insurance related to the safety of big trucks. The American Trucking Association sees the dispute over the twin trailers as a matter of politics that has little to do with safety. The ATA maintains that truck safety studies which point to the dangers of twin trailers are "flawed and biased." The article includes a reference by the Insurance Institute of Highway Safety to studies showing that: large trucks account for 6% of the nation's highway crashes and 12% of all fatal crashes. On a per mile basis, trucks are involved in crashes less frequently than cars, but trucks are involved in twice as many fatal crashes. (107)

An Organisation for Economic Co-operation and Development road research group, the Co-ordinating Group on the Impact of Heavy Freight Vehicles, identified research in member countries on the effects of heavy freight vehicles. Their report notes a renewed interest in safety improvements in a wide array of heavy freight vehicle design and operational features. (73)

This field study examined traffic operational effects associated with truck size and weight. Matched weight and operational data were gathered on nearly 6,000 trucks ranging in gross weight from 20,000 to 160,000 lb. Three analytical procedures determined operational differences between truck groupings, correlations between truck characteristic and operational measures, and the predictive effect of truck weight on speed. Adverse safety effects were most pronounced on upgrades; certain safer behavior was noted for heavier trucks on downgrades. A maximum of only 37% of truck operational effects were explainable by truck size and weight. (57)

This report is the Department of Transportation's response to a directive by Congress to study the need for uniformity in maximum truck size and weight limits throughout the U.S. If truck payloads are increased, a given volume of freight can be moved with fewer trips, thus decreasing exposure to accidents. However, the improvement in productivity may cause diversion from other modes and additional traffic, which will increase accident exposure. Although trucks have higher accident involvement rates than autos, the evidence with respect to larger and heavier trucks, including doubles, is not conclusive. The safety implications of changes in truck size and weight limits should be seriously considered. (126)

Numerous state and federal reports and hundreds of motor carriers attest to the operational safety of multiple trailer combinations. Better data and record keeping on their safety will delineate areas of superiority and areas where improvements can be made. (130)

Of 23,838 motor carriers inspected in 1980, 41% were found to have at least one mechanical defect serious enough to put the vehicles out-of-service. The largest number of out-of-service defects were found in the vehicles' brake systems. (116)

In this Texas study, costs of larger, wider, and heavier trucks associated with public safety have not been included and need to be calculated. These include passing maneuvers, splash and spray, braking and stopping characteristics, and vehicle maneuverability. In addition, the effect of larger and wider trucks on accidents must be estimated. (155)

This report states that a truck contraflow lane is operationally safe if there is enough flow rate to keep at least one vehicle in sight of oncoming traffic at all times. However, this is only possible if all trucks use the contraflow lane. (60)

Tests of double and triple trucks' stopping ability have shown it to be superior to that of single semitrailer trucks. The amount of sway can be eliminated by proper loading. Because of passing hazards, triples should not be operated on two-lane highways. Not much data is available on how accident rates vary as a function of truck weight and size. This report suggests better followup investigations of truck accidents. (135)

This critique of NCHRP Report 198 maintains that increasing truck weights and sizes affects public roadside safety more than Hansen concedes by (1) threatening the highway safety of other vehicles and (2) increasing, rather than decreasing as Hansen assumed, the number of trucks in the traffic stream. Accident and user costs will increase as the number of trucks in the traffic mix increases. (28)

This report used Bureau of Motor Carrier Safety data to study the severity of accidents between cars and articulated trucks. A statistical analysis revealed that such an accident is most likely to be severe (as measured by a fatality to a car occupant) only if it occurs on a rural, two-lane road. Except at this type of location, accident severity is not greater for longer and heavier trucks (ie., double bottoms over 70,000 lb). (59)

This 1974 paper reviews research at the Transport and Road Research Laboratory in London on heavy commercial road vehicles. Although no breakdown of traffic data is available for the higher weights, the number of accidents and accident rates per vehicle population both suggest a trend toward more serious injuries with heavier vehicles. The vulnerability of the pedestrian, the pedacyclist, or a car impacting a more massive vehicle are the main problems. Because of the underrunning of cars into heavy vehicle rears, remedial measures of identifying and redesigning the rear of heavy vehicles are being considered. (35)

This report describes two major studies conducted to determine the effect of truck size and weight on accident experience and traffic operations. The first study involved a field evaluation of the effect of truck size and weight on traffic operations. The second study addressed the effect of truck size and weight on accident experience. (150)

This report describes present lighting and marking regulations of large vehicles and proposes they be increased to prevent accidents. Developing an improved lighting and marking system would involve (1) increasing conspicuity, (2) developing methods to implement the stop, turn, and presence functions of trucks, and (3) adding distinctive lights or markings to those vehicles which create potentially hazardous traffic conflicts. (74)

6.2 ROADSIDE SAFETY

6.3 HAZARDOUS MATERIAL CARRIERS

These amendments in the Federal Register establish routing and driver training requirements for highway carriers of large quantity packages of radioactive materials. Such carriers must follow highway routes designated by the appropriate state agencies. If no specific routes have been assigned, the carriers must use the Interstate System of highways. Under the Hazardous Material Transportation Act and as interpreted by the Department of Transportation, state officials should have the key role in designating hazardous material routes, with local and federal authorities providing inputs. A Departmental policy statement which addresses the appropriate role of Federal, state, and local governments in the regulating radioactive material transportation is contained in this document. (112)

A method for selecting a route for safely transporting large quantities of radioactive material is presented. The steps include: (1) determine all available routes; (2) develop a list of route comparison factors; (3) evaluate route comparison factors of each alternative; (4)

select the best alternative route; and (5) document your routing analysis to serve as a basis for the routing decision. A hypothetical case was constructed. (55)

A method of choosing hazardous materials truck routes is outlined: (1) define issues and responsibilities, (2) analyze mandatory factors (i.e., physical and legal constraints), (3) determine risks, (4) analyze subjective factors (optional), (5) compare alternatives, and (6) select route. A hypothetical example of route analysis is shown. Sample worksheets for each step are in the appendix. (9)

This report was published to make a number of corrections and clarifications to the final rules in the May 22, 1980 Federal Register. The corrections and clarifications included: (1) a numerical identification system for hazardous materials transported in commerce; (2) regulations on the transportation of hazardous wastes; (3) regulations on the identification of, and discharge notifications for, hazardous substances; (4) identification of certain forbidden materials; (5) proper shipping names for organic peroxides; and (6) a requirement to enter on shipping papers the technical names of certain hazardous components of some materials. (71)

6.4 ACCIDENT RATES

A simple theoretical model to measure the safety effects of increasing the number of large trucks in urban areas or the consequences of mixing trucks with cars is presented in this article. Comparing urban and rural truck accident experience shows that the most severe urban accidents occur on urban interstate roads. Therefore, traffic engineers will be challenged by the problems associated with an increased truck population and will need to continue developing ways of reducing contact between the two types of vehicles in the traffic flow. (108)

This paper reviews a recent study on truck impact on roadway safety done in Israel. Some of the conclusions are: (1) certain attributes of combination trucks might create a high accident risk, especially when traveling empty; (2) passenger cars and buses are involved in more accidents than are trucks; (3) a decreasing trend in accident rate exists with increasing gross vehicle weight; (4) heavier truck accidents are more often fatal; and (5) trucks are involved in more rear-end, side-to-side, and single-vehicle accidents than passenger cars. (111)

This paper is a critical review of the study "The Effect of Truck Size and Weight on Accident Experience and Traffic Operations--Vol III," by G.R. Vallette et al. The study's conclusion that twin trailer combinations have a significantly higher accident rate than single tractor-trailer combinations is not supported by the data bases, according to W.D. Glauz and D.W. Harwood. Lack of site uniformity, missing data, and other problems make the two data bases totally inaccurate and thus negate the results derived from them. Only the accident data base may be useful to other researchers, if used with care. (48)

This report contains computerized data from the University of Michigan Transportation Research Institute (UMTRI) data file of Trucks Involved in Fatal Accidents in the contiguous 48 states during 1980. The UMTRI file combines data from the Fatal Accident Reporting System (FARS) and the Bureau of Motor Carrier Safety with information from telephone and mail surveys on ownership, trip type, cargo, vehicle configuration, weights, and lengths. Overall, 81.4% of the FARS medium and heavy trucks were correctly classified. The 5,058 vehicles were divided into 1,350 straight trucks and 3,634 tractors, 3,495 of which were combination trucks. (20)

Since January 30, 1980, general merchandise carriers have received permits to operate vehicles that exceed the maximum legal length (75 ft 5 in) to operate on four-lane divided highways in Saskatchewan. This paper reviews the success of the program up to 1983. Overlength vehicles logged approximately 700,000 miles in Saskatchewan without serious accidents. The only incident involved a Rocky Mountain double caught in an unexpected spring blizzard. The driver ran the power unit and lead trailer into the ditch because of poor visibility. The unit did not incur any damage. (18)

This 1983 report discusses some technical and policy factors in the heavy vehicles size and weight issue. The safety of heavy vehicles received some attention in the FHWA "economics of size and weight" study. In this study no statistically significant trends toward higher accident incidence or severity among the legal maximums tested was found. Studies on the safety performance of heavy vehicles are represented by the Bureau of Motor Carrier Safety study on the effects of preventative maintenance, by the National Highway Traffic Safety Administration study on the evaluation of Braking Standard No. 121; and by the FHWA study on off-tracking behavior of articulated units. (123)

This report examines several truck studies on larger and wider trucks and their safety problems. Some findings on accident rates were: (1) Doubles have a significantly higher ton-mile accident involvement rate than singles on urban freeways and rural nonfreeways, but there is no significant difference on other road types. (2) There is no significant difference in accident rate of tractor-trailer combinations with conventional tractors from those with cab-over-engine tractors. (3) There is no significant difference between the accident rates of tractor-trailer combinations with 40-ft trailers and those with 45-ft trailers. (4) Truck drivers under age 20 have the highest accident rate, followed by drivers 20 to 29 years of age, and drivers 60 years and older. (42)

This Organisation for Economic Co-operation and Development paper reports on the impacts of heavy trucks on road safety. From countries in which accident data identifies the vehicle at fault, trucks caused between 13% and 26% of all fatal accidents. (61)

This report covers accident data on rural accidents from 1976 to 1979 in Texas involving combination and single unit trucks as well as small, midsize, and large cars. From a combination of a need for fuel economy and lower operating speeds on highways, a principal design change in trucks has been reduced engine horsepower. Many states have compensated by increasing the maximum gross vehicular weight limit for trucks. This results in a higher average weight to horsepower ratio, causing reduced acceleration ability and reduced performance on grades. Less than 5% of all accidents involved a fatality. However from 1976 to 1979, the total number of large truck accidents increased over 50% and fatal accidents increased over 150%. Car/truck accidents only accounted for 5% of all accidents while 93% involved only cars and 3% only trucks. The majority of all accidents occurred on U.S. and State highways. For accidents in which a combination truck was involved, there was a higher risk of a fatality or injury, especially in collisions with small cars. However, accidents between combination trucks and small cars resulted in the least number of fatalities or injuries per accident. Collisions between large and midsize cars were the most frequent and resulted in the highest number of persons killed or injured per accident. (121)

This report compares the operational characteristics and occupant injury experience of trucks and tractors of two cab styles--conventional (with the engine forward of the driver compartment) and cabover (with the engine below the driver compartment). City and state accident data are analyzed. Federal accident data and national exposure information are compared for national accident, injury, and fatality rates. Injury and fatality rates from the Bureau of Motor Carrier Safety do not differ for the two cab styles, but fatality rates from a combination of the Fatal Accident Reporting System and the Truck Inventory and Use Survey show the occupants of cabovers to be at a somewhat greater risk. (87)

In 1979, motor carriers longer than 65 feet accounted for 2,080 accidents of which 7.45% were fatalities and property damage per accident was $11,106. Trucks less than 65 ft had 33,227 accidents with a fatality rate of 8.68% and $9,676 worth of property per accident. Trucks over 50,000 lb but under 80,000 lb were involved in 15,092 accidents resulting in 9.45% fatalities and costing $12,286 per accident for property damage. (5)

In 1978, motor carriers longer than 65 ft accounted for 2,125 accidents resulting in a 7.81% fatality rate and $10,400 in property damage per accident. Vehicles less than 65 ft had 31,635 accidents with a fatality rate of 8.86% and $8,743 property damage per accident. Trucks weighing between 50,000 and 80,000 lb were involved in 15,866 accidents resulting in a 9.78% fatality rate and costing $11,276 in property damage per accident. (4)

This 1978 report compares the relative safety of single and double truck combinations. The 1974 accident data for California, the state having closest to a 50-50 split between the two truck classifications, was combined with estimates of truck exposure to arrive at accident and injury rates based on vehicle miles of travel. Also, estimates of average cargo weights were determined to evaluate the safety of the two vehicles on the basis of cargo ton-miles of travel. The analysis showed that doubles resulted in more fatalities per million vehicle miles of travel, but that singles had higher accident rates on the basis of cargo ton-miles of travel. (173)

Road accident data in this paper on the effects of heavy goods vehicles show the involvement of these vehicles to be low in Britain in 1975, compared to other vehicles. However the fatal accident involvement rate is somewhat higher, indicating that when heavy goods vehicles are in accidents they tend to be serious ones, but it is still well below that for public service vehicles and motor cycles. (96)

In 1977, trucks longer than 65 ft were involved in 1,802 accidents. These accidents resulted in a 8.77% fatality rate and $9,378 property damage per accident. Accidents involving motor carriers less than 65 ft long produced a 10% fatality rate and an average of $8,086 per accident. Trucks with a gross weight of 50,000 lb but less than 80,000 lb had 13,970 accidents with a 11% fatality rate and $10,281 property damage per accident. (3)

One of the important findings of this study on main rural highway accidents is that the greater the differential in speed of a vehicle from the average speed of all traffic, the greater the chance of that vehicle being involved in an accident. During the day, for passenger cars and trucks, only small differences existed in involvement rates. However at night, passenger car involvement rates were nearly three times as great as those for trucks having six or more tires. (131)

6.5 ACCIDENT CAUSES

This report describes two major studies conducted to determine the effect of truck size and weight on accident experience and traffic operations. The first study involved a field evaluation of the effect of truck size and weight on traffic operations. the second study addressed the effect of truck size and weight on accident experience. (150)

This report determines the effect the size and weight of large trucks have on accidents and traffic operations. The effect on accidents was determined by comparing the accident rates for a variety of truck types defined in terms of configuration, size, and weight. The accident rate is obtained by dividing the number of accidents of a specific truck type, size, and weight by the exposure mileage (opportunity to have an accident) for that same truck type, size, and weight. This volume documents the methodology used to obtain the accident and VMT exposure data. Tables of accident distributions and accident rate calculations are presented for all large truck accidents occurring on 78 roadway segments in 6 states. A total of 2112 accidents were investigated in-depth over 1 1/2 years in 1976-1977. (151)

This report consists of tables describing truck accidents in Texas. Truck accidents predominately occur in urban areas. However, approximately 30% of all accidents involving articulated vehicles (trucks and trailers, tractors and semitrailers) occur in rural areas. The primary contributing factor to truck accidents is speeding. Articulated vehicles were involved in a higher percentage of single vehicle accidents than are straight trucks. The percentage of non-injury accidents was highest for trucks and trailers (78%), followed by straight trucks (75%), and then tractors and semitrailers (71.79%); while tractors and semitrailers had the highest proportion of fatal accidents (2.45%). Truck accidents involving injury are more prevalent late at night or early in the morning. Tractors and semitrailers experienced the highest percentage of accidents after dark on unlighted roads. Accidents involving articulated vehicles were more likely to occur on or beyond the shoulder of the roadway than were accidents involving straight trucks. (54)

This report states that for trucks on grades, greater speed reduction is associated with a higher accident involvement rate. (156)

This 1979 report lists statistics on causes of truck accidents including the driver, the highway environment, and mechanical failures. (5)

This 1977 report lists statistics on causes of truck accidents, including the driver, the highway environment, and mechanical failures. (3)

This report contains a statistical analysis of the factors present in California commercial vehicle accidents: accident factors, involved commercial vehicle factors, noncommercial vehicle factors, and human factors. Commercial vehicle dimensions were a factor in 0.7% and 3.1% respectively, of the accidents reported. (40)

This report found that large trucks were more likely to be involved in single vehicle crashes. Going straight ahead was associated with the majority of the crashes of all vehicle types. However turning was associated with a large number of crashes, especially with multi-vehicle crashes. Right turns may pose special problems for drivers of large trucks. (92)

This study found that the actual speed differential between trucks and passenger cars was less than the 10-mph posted differential, except on upgrades. Posting a speed differential was not found to be related to truck accidents. Although models suggested that lower truck accident rates can be expected with higher truck speeds; vehicle defects, weight, or roadway design may also have an effect. The limit should be temporarily increased on a test section. (56)

7.0 REGULATIONS, RESTRICTIONS, AND ENFORCEMENT

7.1 TRUCKING REGULATIONS

This study investigated one aspect of the Texas Highway Cost Allocation Study--the tracking of revenues generated by different motor vehicle classes. The revenue tracking procedures are described and the calculations for the 1980 baseline are summarized in two tables. Of the vehicles registered in Texas, combination trucks over 72,000 lb accounted for 0.6% of the vehicles, 3.6% of the vehicle miles of travel, and 11% of the fuel consumed. Trucks were identified by their axle configuration as well as by their gross vehicle weight. Even if registration records classify trucks by weight only, reasonable breakdowns into different axle configurations can be accomplished by working closely with the data from the Truck Inventory and Use Survey. (21)

This study examines six general classes of truck regulations in terms of their impacts on urban freeway safety and traffic operations: (1) lane restrictions, (2) time-of-day restrictions, (3) speed restrictions, (4) route restrictions, (5) driver licensing and certification programs, and (6) increased enforcement of existing regulations. Reduced speed limits, either for all vehicles or trucks only, should be enacted on a trial basis. Over the long term, driver licensing/training, and incident management techniques should be emphasized. (98)

This booklet, written in 1981 by the Texas Department of Public Safety, contains regulations governing the size and weight of commercial vehicles. (138)

This report is Volume 3 of several reports prepared by the Secretary of Transportation for Congress on the Truck Size and Weight Study mandated by Section 161 of the 1978 Surface Transportation Assistance Act. This volume documents the effects of truck size and weight limit changes on intercity freight unit vehicle truck and rail fuel intensiveness. Probable changes in direct or indirect fuel consumption for new truck size and weight limits are estimated. This method includes linehaul and access fuel and allows for the system fuel requirements of empty backhaul and circuitry. Single unit and multiple unit combination trucks as well as the competitive carload boxcar and TOFC rail services are covered. Truck service and competitive rail services are separated into their component parts. (82)

This is Volume 2 of several reports prepared by the Department of Transportation for Congress on the Truck Size and Weight Study mandated by Section 161 of the 1978 Surface Transportation Assistance Act. This volume presents reported truck and rail operating data and analytical methods developed to estimate changes in transportation prices due to specific sets of truck size and weight limits. A system of cost based "rates" (average shipment charges) is developed for differentiating among specific truck and rail transport services by allocating full economic cost to appropriate vehicle payloads. The effects of various truck size and weight limits are studied in terms of changes in the competitive relationships among various highway and rail carrier services. (83)

This is Volume 1 of several reports prepared by the Department of Transportation for Congress on the Truck Size and Weight Study mandated by the 1978 Surface Transportation Assistance Act. This volume documents the investigation and results of the effects of truck size and weight limit changes on individual vehicle capacity and average truck payloads. Design payload approximates the actual payload of fully loaded trucks, and design density is an important determinant of the loaded character of trucks. A relationship between the average load carried on full trucks and the average load carried on partially loaded trucks, and the relative mix of full and partially loaded trucks was developed. (99)

This document, subtitled "Appendices," is one volume of a two-volume set containing the report of the Secretary of Transportation to Congress on the Truck Size and Weight Study mandated by the 1978

Surface Transportation Assistance Act. The "Final Report" describes the most important impacts that can be expected from changes in truck size and weight limits. This volume presents supporting material to the "Final Report." (76)

This is Volume 4 of several reports prepared by the Department of Transportation for Congress on the Truck Size and Weight Study mandated by the 1978 Surface Transportation Assistance Act. This report documents the development of VMT data files. It describes the development of the 1985 base case truck traffic projection, and changes from this base that occur as a result of various postulated changes to existing limits. Each data file consists of a series of 15 x 15 matrices of truck VMT by gross combined weight group and truck axle configuration, including a separate matrix for each of four highway types within each of the states. These files account for changes in VMT by each type of truck due to changes in truck payload, changes in the choice of equipment type, and changes in the route selected. (100)

Part I of Volume 7 expands upon the summary results in the Secretary of Transportation's response to Congress on the Truck Size and Weight Study and provides a more comprehensive treatment of the productivity and fuel tradeoffs among the categories of truck size, weight, and configuration limits. Disaggregations of impacts among freight service user groups are reported to provide information to the interest groups most affected by alternative limit changes. This volume also presents an analysis of the sensitivity of the reported transport cost and fuel impacts to alternative limits and to the possible inaccuracies in the analytical methods and data used in the study. (95)

Part II of Volume 7 is a technical letter report prepared by the Department of Transportation for Congress on the Truck Size and Weight Study mandated by the Surface Transportation Assistance Act of 1978. This appendix contains a comprehensive description of the use of Western Doubles in carrier operation, as well as the general commodity less than truck load markets and rate data pertinent to the overall Truck Size and Weight Study. The areas studied included: (1) which corridors were actually using multiple trailer combinations; (2) how and why they were used in corridor operations; (3) what kinds of markets benefit from their use; (4) what is the character and magnitude of these benefits; and (5) what is the apparent effect on competitive services and rates. (77)

This NCHRP report summarizes the major differences among states in truck size and weight enforcement and permit operations and makes recommendations for coordinating these operations. The current legal limits for all states including length, width, height, axle weight, and gross weight are in a table. Two additional tables deal with the tolerance level and legal limit exceptions. (79)

The Federal Motor Carrier Safety Regulations program is designed to identify and remove buses that have defects serious enough to be hazardous to the public. Any vehicle fitting this description and/or any driver who violates the Federal Hours of Service limitation will be declared out-of-service. Any driver found to violate the June 18, 1979 law requiring drivers keep a log of their hours' work will be out-of-service for a minimum of 8 hours. Regardless of whether a driver or vehicle defect is found, the motor carrier is to certify within 15 days to the Bureau of Motor Carrier Safety that the defects have been corrected. This report gives 1980 driver and vehicle violations. (103)

Since January 30, 1980, general merchandise carriers have received permits to operate vehicles that exceed the maximum legal length (75 ft 5 in) on four-lane divided highways in Saskatchewan. This paper describes the vehicle configurations used, the conditions of the permit, and the efficiencies that are associated with the overlength vehicles relative to legal units. (18)

An Organisation for Economic Co-operation and Development road research group, the Co-ordinating Group on the Impact of Heavy Freight Vehicles, identified research of member countries on the effects of heavy freight vehicles. Their report contains tables of maximum permissible loads, weights, and sizes for heavy freight vehicles of the 16 member countries. (73)

This 1979 report summarizes present trucking regulations. Limit increases are available by permit in all states and tolerances in 18 states. Greater weights and/or widths than the limits are allowed on Interstates under a grandfather clause in the Federal Aid Highway Act. Lack of uniform regulation in all states causes extra cost to truckers and the public. This report lists specific ultimate and minimal size and weight provisions which should be legalized in all states. (135)

Fifteen links on a national freight network were identified as representative of heavy truck volume and heavy traffic problems. The report analyzes the cost-effectiveness of several types of improvements to better accommodate commercial traffic. Where appropriate, the effects of change to more liberal size and weight limits, such as are in effect in some western states, were also evaluated both in conjunction with and without the modifications. (75)

This paper includes an October 1975 statement of the American Trucking Association on commercial vehicle goals. Carrying more weight on a truck, generally speaking, is a fuel efficient and productive way to transport freight. ATA asks the Department of Transportation to encourage the use of truck combinations which allow greater cubic capacity. DOT needs to encourage continued state adoption of modernized truck weight and length limitations. (90)

The Federal-Aid Highway Amendments of 1974, effective January 4, 1975, allowed the states to authorize single axle loads of 20,000 lb, tandem axle weights of 34,000 lb, and gross weights of 80,000 lb for trucks and combinations on Interstate highways. The distribution of these weights is controlled by Formula B. This report demonstrates the application of Formula B through the use of representative examples. Charts of tractor-semitrailer combinations are developed which show the minimum axle spacing and maximum vehicle gross weight when the front axle load is known. (65)

7.2 WEIGHT RESTRICTIONS

This report documents state legislation on truck size and weight and summarizes the current status of truck size and weight and highway cost allocation studies. Laws on the operation of doubles or triples, overall vehicle length, width, axle weight, and gross vehicle weight were emphasized. Six states conducted studies to see if the weight limit should be raised to the federal weight limits of 1974. Three were opposed. Tennessee recommended making the decision after highway cost allocation study findings are released. Iowa was in favor, and Indiana did not develop a policy statement. (162)

This NCHRP report summarizes states' weight restrictions. Although they vary, the trend is toward the 80,000 lb gross weight on federal interstates. Most states (42) provide enforcement agencies empowered to require unloading. Permit operations and types are also described. (33)

This booklet, written in 1981 by the Texas Department of Public Safety, contains regulations governing the size and weight of commercial vehicles. (138)

This report is the Department of Transportation's response to a directive by Congress to study the need for uniformity in maximum truck size and weight limits throughout the U.S. An analysis of truck vehicle miles of travel (VMT) by truck weight and highway system in 1977 shows: (1) about 75% of truck VMT is by trucks weighing under 50,000 lb; (2) on all highways except Interstate or primary highways, nearly 85% of all truck VMT is from trucks weighing 50,000 lb or less; on Interstates, however, only 70% of truck VMT was from trucks in this category; (3) trucks weighing more than 73,000 lb are responsible for less than 10% of all VMT by trucks on any system and are especially low on non-Federal-aid roads; and (4) only a negligible percent of VMT on any highway system is attributed to trucks weighing more than 110,000 lb. (126)

A Texas study in which trucks were increased in axle weight and gross vehicle weight alone showed a great impact on highway pavement and bridge costs over a projected 20-year span. However the entire cost of maintaining, replacing, and rehabilitating bridges has not been included and would have to be added to the total costs of increasing weight alone. (155)

A presentation at a WASHTO meeting deals with uniformity in truck size and weight regulations in Western states. Except for a couple of states, there is agreement on the 20,000 lb single and 34,000 tandem axle allowances. Gross weights over 80,000 lb can probably best be handled through special permits. WASHTO is considering a maximum gross ending at 105,000 lb. (27)

The current trend is toward reduction in numbers of the heaviest axle loads. A uniform load limit at the 20-kip/34-kip level is recommended in this report. (135)

7.3 DIMENSIONAL RESTRICTIONS

This report documents state legislation on truck size and weight and summarizes the current status of truck size and weight and highway cost allocation studies. Laws on the operation of doubles or triples, overall vehicle length, width, axle weight, and gross vehicle weight were emphasized. Size and weight issues were studied by several states. Utah and California studied the effects of triples in their states. California was in favor of allowing them on Interstates but added that they would create problems on local roads and metropolitan area freeways. Utah found that increasing size and weight for certain combinations increases productivity and reduces fuel consumption without sacrificing pavement performance. Therefore, triples should be permitted to operate on Utah Interstates. (162)

This booklet, written in 1981 by the Texas Department of Public Safety, contains regulations governing the size and weight of commercial vehicles. (138)

This paper, presented at a WASHTO meeting, is on agreement or modification of Federal Table B truck size and weight regulations in the Western states. There is some disagreement on height and width. Oregon has had no problem with the 14-ft height and 102-in. width. WASHTO would not plan to increase the length of any combination beyond the present 75 ft maximum for truck-trailers or doubles and 105 ft for triples and auto transporters. Reduced axle loadings, fewer trucks on the road, fuel savings, and greater cost efficiency for the trucking industry would result. (27)

A Texas study in which size and weight of trucks was increased over the existing limit showed the increase to be favorable over a projected 20 years. Longer and wider trucks will necessitate improving the geometric design features of a highway network. (153)

7.4 ENFORCEMENT

This is a report on enforcement against overweight trucks done for Gov. Mark White of Texas in 1984. The Department of Public Safety enforces size and weight laws on state highways by (1) 7 permanent scales, (2) 12 semi-portable scales, (3) 704 portable scales (4) 37 permanent weight areas, (5) public and private scales, (6) public awareness campaigns, and (7) fines and penalties. Several programmatic, legal, and legislative recommendations to strengthen enforcement are made.(53)

This report describes the FHWA final highway designations for commercial vehicles, listing the roadways in each state which are designated for their use. Several issues addressed include: (1) All states must permit trailers longer than specified in the law (including automobile transporters with a minimum length of 65 ft, plus overhang) to operate on the national network if the state recognized such vehicles as legal on Dec. 1, 1982. (2) States may impose reasonable operating restrictions during peak hours (with prior FHWA approval) or on specific travel lanes to enhance highway safety. (3) Federal law allows the wider trucks to operate on routes included in the national network that have lane widths "designed to be 12 feet or more." A copy of the "Truck Size and Weight; Final Rule" from the Federal Register is attached. (148)

This report emphasizes the characterization of oversize-overweight movements in Texas and the cost of these movements and enforcement of state size and weight laws to the state. This report also presents current state laws on vehicle size and weight and agencies involved directly or indirectly in enforcing these laws. The study showed that, while the current oversize-overweight movements may save the trucking industry 1.4 billion dollars over the next 20 years, these movements are estimated to cost Texas an additional 261 million dollars over the same period. If the current fines and permit fees are maintained, enforcement of state laws is estimated to result in only 84 million dollars. The current fine and fee structure should be revised so that violators would pay for their share of the estimated damage to highways. A highway cost allocation study is also recommended. (159)

This paper discussed current Texas regulations affecting motor vehicle sizes and weights, the agencies directly or indirectly enforcing these regulations, the characteristics of oversize and overweight vehicle movements within Texas (both legal and illegal), and the cost of these vehicle movements to the state. To study the economic effects to the state, a 100 % compliance case was set up to compare with the actual case. Although the current oversize and overweight movements may save the trucking industry up to $1.4 billion over the next 20 years at current conditions, these movements are estimated to cost the state an additional $261 million. Similarly, enforcement of the state laws is estimated to result in only $84 million if the current fines and permit fees are maintained. These current fines and fees should be revised to discourage violation. (160)

This NCHRP report establishes criteria for evaluating state truck weight enforcement programs and report practices that can improve them, based on a survey of 27 states. States must compare truck population with the number of vehicles being weighed in evaluating a truck weighing program. They also must know major truck routes and probable truck volumes on these routes, the nature of the truck movement (interstate or intrastate), the classifications of trucks, the types of cargo and tonnage, and the distances traveled. The overweight truck survey can be taken by weigh-in-motion (WIM) equipment in an undetected site on a segment of highway that trucks cannot bypass. Enforcement practices in states is summarized, and recommendations are made for evaluating these programs. (33)

This NCHRP report summarizes the major differences among states in truck size and weight enforcement and permit operations and makes recommendations for coordinating these operations. The enforcement of weight and size limits is strictly a state matter. Each state uses a combination of portable, semi-portable, fixed, and weigh-in-motion scales. Enforcement strategies differ widely between states. Usually the state police are responsible for enforcement but the agency can vary. The agency responsible for issuing permits is usually not the enforcement agency. Also penalties for violations vary between states. (87)

This report is based on the Bureau of Motor Carrier Safety's roadside vehicle inspections of 1979. Of the 23,838 property carrying vehicles inspected, 9,671 (41%) were found to have a mechanical defect serious enough to be declared out-of-service. A total of 81,867 defects were found, with 15,770 defects serious enough to classify the vehicle as imminently hazardous. The braking system accounted for the largest number of defects, 8.3% of the total. The largest percentage of the 18,871 driver violations were violations of Hours of Service of Drivers, Part 395 of the Federal Motor Carrier Safety Regulations (FMCSR). Failure to keep a current driver's log was the largest single type of service violation (17.6%). In 1979, 1,320 accidents were reported as having occurred as a result of a mechanical defect or failure. The most common defect involved wheels and tires, and brake systems. (116)

States which do not enforce their truck regulations in effect liberalize these limits. This report indicates a need to study enforcement programs and the effects of poor enforcement, especially increased equivalent axle loadings on the highways. (135)

This critique of NCHRP Report 198 states that the study should have computed the costs of controlling weight limits on roads outside the highway arterial network which are designated for heavier and longer trucks. An effective enforcement program to restrict heavy traffic to the arterial highways must be included to prevent the rapid destruction of off-network roads. Costs of such a program and of predicted damage to off-network roads should be included in an analysis of increasing truck size and weight limits. The need to design a fair heavy truck user charge to recover revenue for upgrading pavements is only treated cursorily by Hansen. Truck user charges should increase exponentially with truck axle weight and linearly with the quantity of axles or axle sets of similar weight to pay for increased highway damage. (28)

This report recommends states adopt a licensing classification system with special requirements for drivers of large trucks. The higher proportion of large truck drivers found to be in violation in two vehicle crashes, and the greater risk of serious injury for the driver of a car hit by a truck constitute a basis for seriously considering a requirement that drivers of large vehicles demonstrate special competence in order to obtain a license. (92)

7.5 TRUCK WEIGHING

This paper presents a sampling plan to determine the number and location of sampling stations as part of a new Wisconsin truck weight study. Previous weight studies have produced data of limited value due to inadequate road type and geographic coverage. The use of new weigh-in-motion technologies and the emphasis on the collection of basic weight data permit a more random selection of weigh stations and a more comprehensive sample of truck traffic. The sampling plan developed relies heavily on user needs and statistical criteria to help insure a valid and meaningful sample. (44)

The Truck Weight Study should be completely redesigned to: (1) establish a statistically representative network of WIM scale sites for collecting non-interview data on a continuing basis and (2) collect interview data either at static scale sites every five years or on a case study basis. The non-interview data to be collected as a minimum should be axle weight, gross weight, axle spacing, and vehicle type/classification. Interview survey data to be collected should include but not be restricted to gross weight; axle weight; vehicle type; load status; e.g., loaded, empty, permitted overload; commodity; fuel type; registered weight; and horsepower. A 10-year phase-in of this recommendation is suggested. FHWA should adopt a set of standard vehicle class definitions and promote their use by the States. The revised Highway Performance Monitoring System Vehicle Classification Case Study definition of vehicle classes should be adopted, with a minor change. Legislation should be developed to set aside special Federal-aid funds or create new funds for buying and installing WIM equipment and conducting interview type truck surveys. A subset of WIM sites should be chosen as a national continuing panel of truck data sites. Improved procedures should be developed by FHWA to estimate historical and projected traffic loading for pavement performance studies and for the design of highway pavements. The Office of Highway Planning should assess TWS data analysis procedures to reaffirm that maximum use is made of the TWS data. (149)

This NCHRP report summarizes a 1980 FHWA report that describes the state of the art for weigh-in-motion (WIM) techniques and equipment. The three types of WIM operations are high speed, low to moderate speed, and low speed. High-speed WIM is more effective on low-traffic-volume highways. Low- to moderate-speed WIM is effective at locations with high volumes of truck traffic. Low-speed WIM is not currently in use in the U.S., but is recommended for temporary use on low-volume routes until permanent operating conditions can be constructed. The recent new WIM method of using highway bridges as equivalent to static scales is described. It can provide numerous locations for sites, and can be used for loadmeter studies for pavement design as well as an unbiased evaluation of truck weight enforcement. The location and design of scale houses and weigh stations, essential in truck weight enforcement, are described. Permanent scales, including portable and semiportable, are also described. (33)

This NCHRP report summarizes the major differences among states in truck size and weight enforcement and permit operations. Mechanical and electronic scales are used by state agencies in truck weighing at an installation cost of $60,000 to $200,000, which includes weigh platforms, aprons, and buildings. Portable scales placed on alternative routes increase enforcement efficiency. The two types are semiportable and portable. Semiportable scales require a shallow pit to operate but weigh more trucks in a short time. They cost about $10,000 per standard pair. A portable scale weighs about 50 lb and cost about $3,200 for a set of four. It can be set up anywhere but requires a lot of time to weigh each truck. (79)

This report describes a comprehensive plan to expand the Pennsylvania vehicle size and weight program to become a combined system of strategically located permanent weigh stations, semi-permanent weigh stations, leased municipal scales, and enough mobile teams to effectively patrol all the highway systems in the state. The mobile teams were to work primarily on off Interstate systems. The six permanent weigh station sites were selected by truck traffic volumes which mainly identify the major Interstate trucking corridors. (26)

This NCHRP report summarizes the major differences among states in truck size and weight enforcement and permit operations. Weigh-in-motion scales are used for screening purposes and are placed before a permanent scale. In this way, trucks obviously within the limits will not be delayed and large queues will not be formed. The WIM scale is accurate up to 5% if the vehicle is traveling between 35 and 45 mph, up to 1% if it is traveling less than 10 mph. A semipermanent WIM system may have an initial cost of about $60,000. (79)

A system for weighing highway vehicles in motion is described in this report. It was concluded that individual axle weights can be estimated by this means within about 11% and gross vehicle weights within about 6% with 70% confidence. Vehicle configuration, vehicle loading condition, and speed account for the variability. An economic analysis showed in-motion weighing to be more cost-effective than conventional static weighing. Safety benefits to road users and to the survey agency are further advantages of in-motion weighing. (93)

7.6 TAXATION

This paper describes aspects of overweight truck traffic on Texas highways in recent and ongoing research by Texas research centers. The status of a Highway cost allocation study which was to be completed by September 1985 was reviewed. Its purpose is to provide a methodology to determine an equitable highway cost responsibility various classes of highway users should pay. This paper discusses overweight truck loads and present truck size and weight enforcement. Recommendations are made for equitable fines, the permit procedure, and license fees. (7)

AASHTO officials commissioned this "Study of Motor Carrier Taxation and Registration Issues" to help resolve several closely related issues. When existing truck tax procedures and issues which help determine the need for revisions to these procedures were inventoried and evaluated, administrative costs were found to vary as percentage of revenues collected varied. Recent highway cost allocation studies and issues associated with the allocation of cost responsibility to different types are discussed. Highway user revenues of 1981 by state and level of government, road user taxes on heavy combinations, and revenue projections for 1985 by vehicle class and by state are presented. Factors motivating industry positions are also discussed. Tax alternatives are then presented. (64)

The purpose of this study was to relate the loadmeter and registration data of cargo vehicles operating in Texas to fuel consumption curves developed from secondary data and adapt these results to highway user taxation. Two objectives of this report were to (1) analyze the present system of motor fuel taxation in relation to highway use by weight classes of cargo vehicles, and (2) correlate total highway taxation (fuel imports plus licenses and fees) with highway use by weight classes of vehicles. (17)

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