TRANSPORTATION RESEARCH CIRCULAR

Number 273, April 1984
ISSN 0097-8515

Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, DC 20418

INCOMPATIBILITY OF DRIVER-VEHICLE-HIGHWAY STANDARDS: RECENT AND ONGOING RESEARCH

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COMMITTEE ON OPERATIONAL EFFECTS OF GEOMETRICS
(As of December 1983)

Sheldon Schumacher, President
Schumacher and Bowman, Inc.
550 West Fulton Street
Chicago, Illinois

Myung-Soon Chang
Julie Anna Cirillo
Robert E. Craven
George A. Dale
Ronald W. Eck
Daniel B. Fambro
Jerome W. Hall
Douglas W. Harwood
Robert P. Morris
Thomas E. Mulinazzi
Timothy R. Neuman
Ronald C. Pfefer
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OPERATION, SAFETY, AND MAINTENANCE OF TRANSPORTATION FACILITIES

Donald E. Orne, Chairman
Group 3 Council
Michigan Department of Transportation, Lansing, Michigan

FOREWORD

This circular represents the efforts of one committee within the Group 3 Council with respect to a subject that has been of broad concern within the Council for many years. The Task Force on Incompatibility Among the Vehicle, Driver and Highway, chaired by James L. Foley, Jr., is encouraging various committees within the Council to identify current research and identify areas of future research needs. The activities of this committee, as represented by this pubication, are likely to be followed by similar work by other committees, hopefully leading to a comprehensive survey of research and research needs in all the issues related to compatibility of standards.

INTRODUCTION

Committee A3A08, Operational Effects of Geometrics, has engaged in an activity which its membership believes is one of its several major charges, that of synthesizing the state of major knowledge in the fields of committee responsibility and communicating it to the research community. During the past eight years, the Committee has sponsored two workshops, one in Denver, Colorado, on safety evaluations, and one in Arlington, Texas, on the 3R program, and a symposium in Washington, D.C., on geometrics and energy. In addition, it has evaluated and published two sets of research problem statements. Publication of this Circular is a continuation of these activities.

On June 23, 1980, the Committee held its midyear meeting in Cherry Hill, New Jersey. Thirteen of its members were present. The objective of this meeting was to define future committee organization and activities. In response to this goal, it was agreed that the organization would be a combination of subcommittees working in several related problem areas.

One of the problem areas for which a subcommittee was formed was compatibility of standards. Members of this subcommittee were as follows: Daniel B. Fambro, Chairman, University of Tennessee; George A. Dale, Wyoming Highway Department; Ronald W. Eck, West Virginia University; Julie Anna Cirillo, Federal Highway Administration; Thomas E. Mulinazzi, University of Kansas; Robert B. Shaw, Wilbur Smith & Associates; Robert C. Winans, Federal Highway Administration; Walter E. Witt, Nebraska Department of Roads; and Ronald C. Pfefer, Northwestern University.

The subcommittee's primary charge was to identify and synthesize on-going as well as recent research in the field of driver-vehicle-highway compatibility. This Circular contains the results of this activity. Hopefully, its publication will allow the voids in the subject area to be identified and problem statements which address these issues to be developed.

A NATIONAL PROBLEM

The National Highway Safety Advisory Committee was created by Congress in 1966 to advise the Secretary of Transportation on highway safety programs carried out by the Department. During the summer of 1979, the members of this Committee became aware of developing incompatibility between the capabilities of the vehicle driver and what is expected of the driver by both automobile manufacturers and roadway builders when operating a vehicle on the highways. Further, because of the substantial changes being made in the vehicle fleet, the Committee members were concerned that the road system might not be compatible with future motor vehicles. For this reason, a Task Force on Driver-Vehicle-Highway Compatibility was formed. The following is a summary of their report to the Secretary of Transportation on June 17, 1980.

There is a growing number of examples where the standards used in qualifying drivers, building highways and designing vehicles are resulting in drivers being unable to control their vehicles on highways incompatible with the vehicle's characteristics and the driver's capabilities. The principal components of the ever-changing highway transportation system--the driver, the vehicle and the highway--are in need of thorough coordination to ensure compatibility.

The breakdown of the system--the motor vehicle accident--is commonly attributed to driver error. However, the number of "driver errors" and the involvement of drivers in accidents is too large to permit such a simple and convenient solution. The Advisory Committee recommended that the Secretary of Transportation adopt a five-part program to effect compatibility and thus to improve safety:

- Review for compatibility all standards, guidelines and regulations affecting highway safety which are issued or endorsed by the Department.
- Develop a plan to resolve incompatibilities which will consider the driver and the projected vehicle population.
- Urge and assist automotive manufacturers to voluntarily resolve incompatibilities between their own vehicles and safety hardware found on the highways.
- Take the lead to ensure the compatibility of standards sponsored by government and public organizations engaged in setting standards.
- Implement a process to ensure that future safety standards and regulations issued by standard-setting organizations, both government and public, are coordinated and reviewed for compatibility.

The remainder of this Circular is comprised of summaries of recent and on-going research related to driver-vehicle-highway compatibility problems. These summaries are confined to research within the past five years and resulted from contacts with the following groups:

- Auto Manufacturers;
- Federal Highway Administration;
- Institute of Transportation Engineers;
- National Cooperative Highway Research Program;
- National Highway Traffic Safety Administration;
- State, County, and City Departments of Transportation;
- Transportation Research Board; and
- University Researchers.

For convenience, the summaries have been classified into one of the three incompatibility areas relevant to the charge of Committee A3A08: Driver-Highway, Vehicle-Highway and Vehicle-Vehicle.

DRIVER-HIGHWAY INCOMPATIBILITY

"Highway Design Criteria:
Problems and Projections"

Performing Agency: Texas Transportation Institute, Texas A&M University

Authors: G.D. Weaver, C.V. Wootan, D.L. Woods

Publication: Proceedings of the Specialty Conference on Implementing Highway Safety Improvements, American Society of Civil Engineers, San Diego, California, March 12-14, 1980.

Date: June 1980

A paper presented at the 1980 ASCE Specialty Conference on Implementing Highway Safety Improvements noted a number of graduate student research projects at the Texas Transportation Institute which dealt with compatibility problems. Current highway geometric design policies were examined in view of the changing vehicle population to determine changes that will be needed to ensure safe transportation in the future.

Visibility was noted as the primary design criterion related to vehicle size. In two studies reported, driver eye heights of several hundred vehicles were measured photographically. It was concluded that over 60 percent of all passenger cars in the U.S. currently had driver eye heights lower than the current design standard of 3.75 feet. A 3.25-foot driver eye height was advocated as a value that would exclude virtually none of the driving population.

"Driver Eye Height Trends and Sight
Distance on Vertical Curves"

Performing Agency: Ford Motor Company

Author: Eugene I. Farber

Publication: Presented at 61st Annual Meeting of the Transportation Research Board

Date: January 1982

A review of U.S. passenger car eye height trends shows only a slight decrease in eye heights since the early 1960s. Eye heights in contemporary small cars fall on or within the lower eye height boundary for U.S. sedans. Based on the trend of the last four or five years, passenger car eye heights do not appear to be decreasing.

Analyses were performed to determine the sensitivity of stopping sight distance on vertical curves to driver eye height and other parameters entering into the stopping sight distance equations. Sight distance was found to be relatively insensitive to eye height. On a given hill crest, sight distance for a driver whose eye height is 6 inches lower than the design eye height (3.75 ft) is only 5 percent less than the design sight distance. On the other hand, stopping distance is very sensitive to travel speed, pavement friction and reaction time. For example, a 1.8 mph decrease in speed reduces stopping distance by the same amount that a 6 inch decrease in eye height reduces sight distance. Also, sight distance is about 2.5 times more sensitive to obstacle height than eye height. It is argued that reductions in travel speed since the introduction of the 55 mph speed limit compensate for any recent or projected decreases in driver eye height. In addition, because the hazard posed by a 6 inch high obstacle has not been established, it is suggested that vertical curves designed for that obstacle height probably incorporate a considerable safety factor.

"The Impact of Small Cars and Other
Changing Factors on Stopping Sight
Distance Requirements"

Performing Agency: Wayne State University

Authors: Snehamay Khasnabis, T.R. Reddy, and Mani S. Poola

Publication: ITE Annual Meeting Compendium

Date: August 1982

Two aspects of stopping sight distance are important to the roadway designer--the computation of stopping sight distance requirements at various speeds and the measurement of the roadway length to test if available sight distance, at a given point on the roadway, meets the stopping sight distance requirements. The procedures used to compute the stopping sight distance at a given speed, as well as those used to measure available sight distance on a given roadway, can have significant implications on the safety elements of the roadway. The manner in which sight distances are determined and measured today may not accurately reflect the changing pattern in vehicular operation, technology, sizes and weight, and the composition of the driving population.

The specific conclusions of this study were as follows. The reaction time of 2.5 seconds as currently used in computing stopping sight distances appears to reflect the brake reaction time of most drivers. There has been a significant change in the age distribution and composition of the driving population during the last 20 years. Further tests on actual reaction time are needed to determine more accurately if changes in reaction time should be made in the computation of stopping sight distances. The AASHTO recommended friction values for wet pavements in computing braking distance may not reflect the worst or nearly the worst pavement conditions. The validity of the assumption of a speed differential for wet pavement conditions between design speed and top driving speed can be questioned. There is very little evidence in the literature to substantiate the assumption that all motorists are likely to reduce their speeds on wet pavements. If stopping sight distances are computed based upon the design speed and reduced pavement friction, the resulting stopping sight distances are considerably higher than those that are currently used by the AASHTO.

Over the last 30 years, there has been a gradual decrease in the median eye height for passenger cars in the U.S. It appears that a height between 3.3 feet to 3.5 feet (as opposed to the currently used 3.75 feet) would better represent the eye height of a majority of passenger cars in the U.S. An object height of six inches, as currently used for computing crest vertical curve lengths, appears to be a reasonable figure, although there is no objective basis for this decision. Reducing the object height to three inches would improve the safety elements of crest curves. The length of the crest vertical curve is much more sensitive to changes in object height than to changes in eye height. The analysis indicated that a three-inch reduction in object height causes a 17.5 percent change in K, whereas a similar reduction in eye height causes only a 5.5 percent change in K.

The combination of selective changes in certain parameters, i.e., pavement friction, object height and the use of design speed as opposed to an assumed speed for computing stopping sight distances produces values that far exceed the K values currently used for design. The affect of the speed parameter in particular is the most pronounced, as the stopping sight distance is a squared function of V and K is a squared function of stopping sight distance, making K a function of V^4. The net affect of this exponent 4 is a significant increase in K value.

"Driver Characteristics Impacting on Highway Design and Operation"

Performing Agency: Bellomo-McGee, Inc.

Principal Investigator: H.W. McGee

Sponsoring Agency: Federal Highway Administration

Completion Date: August 1983 (Publication Pending)

The purpose of this project was to identify highway design standards, traffic operations standards, regulations and guides that involve driver characteristics. The distribution of the identified driver characteristics in the U.S. driver population was derived from available anthropometry sources. The sensitivity of these standards to changes in the driver characteristic specifications was determined. The proportion of the driver population excluded or inconvenienced by changes in the driver characteristic specifications was determined from distribution data.

This study included U.S. drivers of all ages, both male and female. The driver characteristics of interest included static and dynamic driver characteristics involved in highway design and traffic operations standards.

"The Effect of Limited Visibility on Geometric Design Criteria"

Performing Agency: Bellomo-McGee, Inc.

Principal Investigator: H.W. McGee

Sponsoring Agency: Federal Highway Administration

Completion Date: August 1983 (Publication Pending)

Limited visibility has not, as a rule, been explicitly considered in establishing geometric design criteria. For example, the effect of limited visibility is shown in only one of the three criteria for vertical curve design--stopping sight distance for sag vertical curves; there the consideration is the headlight sight distance or the length at which the assumed upper edge of the diverged headlight beam would intersect the pavement. Since geometric design criteria for highways were first compiled in the 1940s and modified in the early 1960s, changes in the vehicle fleet have led to a diversity of head lamp locations and powers. Thus, there was a need to explicitly evaluate geometric design criteria under limited visibility conditions. An additional factor that was considered is that a driver's reaction-response time may be longer under reduced visibility conditions.

This project used available information to derive the distribution of driver and vehicle characteristics which affect geometric design criteria under limited visibility conditions. The sensitivity of the geometric design criteria to changes in the identified factors were then determined. From these data, recommendations were developed for necessary modifications to the geometric design criteria to ensure coverage of the 50th, 85th, and 95th percentile driver in the 50th, 85th, and 95th percentile passenger car operating under limited visibility conditions.

The parameters of interest were those which affect the geometric design under limited visibility conditions, such as the headlight pattern, the target height, etc. Sensitivity analyses were conducted to determine the effect of these parameters upon geometric design criteria without consideration of limited visibility and to determine the difference between tangent and curve design requirements under limited visibility conditions, i.e., are headlights being "overdriven?"

"Limited Sight Distance Warning for Vertical Curves"

Performing Agency: Ketron, Inc.

Principal Investigator: Mark Friedman

Sponsoring Agency: Federal Highway Administration

Completion Date: January 1985

The purpose of this project is to: (1) develop alternatives to the present limited sight distance sign for warning on crest vertical curves; (2) test the relative effectiveness of developed devices; (3) provide recommendations concerning warning device application and utilization; and (4) compare the effectiveness of vertical curve warning devices to other traffic control devices.

"Parameters Affecting Stopping Sight Distance and Vehicle Acceleration/Deceleration Characteristics"

Performing Agency: Highway Safety Research Insitute University of Michigan

Principal Investigator: Paul L. Olson

Sponsoring Agency: National Cooperative Highway Research Program

Completion Date: June 1985

Parameters used to derive sight distance have, with the exception of single adjustments in the heights of eye and object, remained constant since the criteria were first promulgated by the American Association of State Highway Officials (AASHO) in 1940. These original criteria, as well as subsequent adjustments, were based on passenger cars only because it was assumed that the higher eye height of truck and bus drivers in combination with their slower operating speeds compensated for their longer stopping distances. However, all motor vehicles have undergone both mechanical and physical changes in these past 40 years. Passenger vehicles have become lower and lighter in weight. Trucks and buses have increased in size and weight, and loads legally permitted on trucks have increased. At the same time, truck and bus speeds have increased to the point that they no longer travel slower than automobiles and, in some instances, are the faster vehicles. Recently reported stopping tests and accident data indicate that trucks and buses may need over twice the distance that cars need to stop from the same speed. As a consequence, trucks and buses may be a major consideration in design stopping sight distance.

The objective of this research is to evaluate those parameters affecting stopping sight distance, including, but not limited to: (1) perception and reaction time; (2) driver eye height; (3) height of an object in the roadway; and (4) braking distance as affected by tire performance, brake system performance, pavement skid resistance and grades. The parameters will be representative of current conditions and will reflect the full range of speeds. Following the evaluation of the individual parameters, their combined effect will also be assessed.

VEHICLE-HIGHWAY INCOMPATIBILITY

"Passing Sight Distance and No Passing Zones: Present Practice in Light of Needs for Revision"

Performing Agency: National Capital Commission

Author: W.G. Weber

Publication: ITE Journal, Volume 48, Number 9

Date: September 1978

The article points out the differences between design and marking practices for passing zones on vertical and horizontal curves in both the United States and Canada. The differences are basically these: (1) assumed speeds of passed, passing and opposing vehicles for a given design speed; (2) minimum sight distance; (3) critical point for decision on whether to complete or abandon passing; and (4) speed of passing vehicle when it enters the left lane.

A Texas report that is based on field observations of 500 successful passing maneuvers at three test sites is referenced as providing a rational compromise between present design and marking practices. The Texas report determines three critical lengths: (1) minimum length of passing zone; (2) minimum sight distance throughout passing zone; and (3) minimum sight distance at beginning of passing zone.

The advantages of using the system advocated by the Texas report are: (1) the marginal passing zones are eliminated in the process of marking; and (2) the designers of new roads would be able to fit passing zones for less expenditure for earth work than would be possible under present design policy or the designers would be able to supply more passing opportunity per length of highway for the same expenditure for earth work than is possible using the present policy.

The author suggests that the United States and Canada work together to make the design and marking policies of passing zones more compatible.

"The Yaw Stability of Tractor-Semitrailers During Cornering"

Performing Agency: Highway Safety Research Institute, The University of Michigan

Principal Investigator: R.D. Ervin

Sponsoring Agency: Federal Highway Administration

Completion Date: June 1979

Due to fundamental differences in design characteristics, large trucks and tractor-semitrailer combinations have narrower control limits than passenger cars. Under certain conditions, when these vehicles are changing direction or stopping, they can respond in unintended and undesirable ways. This project examined some of the responses, the design characteristics that cause them and the types of accidents that may result from them.

Four types of unintended responses were enumerated: (1) loss of control during braking, which can result in jackknife or trailer swing; (2) directional instability during cornering; (3) roll instability for loaded heavy vehicles--the threshold of roll instability is so low that rollovers could easily occur during medium-level maneuvers on paved surfaces; and (4) amplified directional motions occurring with full trailers. It was indicated that highway design plays a definite role in loss of directional stability in heavy vehicles even though such loss-of-control incidents could not be properly identified using available data bases. Such accidents would most likely occur on sustained curve sections, such as exit ramps, which may be traveled at excessive speed.

"The Influence of Vehicle Design and Operating Characteristics on Roadway Design"

Performing Agency: Institute of Transportation Engineers, Committee 5B-3

Chairperson: Ned Walton

Publication: None as of December 1983

Completion Date: June 1982

The purpose of this Committee was to update the standards currently used in roadway design which were influenced by the latest motor vehicle design and operating characteristics.

"Vehicle Downsizing and Roadway Design in Canada"

Performing Agency: Road and Motor Vehicle Traffic Safety, Transport Canada

Authors: Terry M. Burtch, Randolph W. Sanderson, Philip S. Irwin

Publication: ITE Annual Meeting Compendium

Date: August 1982

The purpose of this study was to examine the relationship between motor vehicle design and the design of roadway and roadside elements. Accordingly, the first step was a review of current geometric and roadside design standards to identify the vehicle performance and size characteristics used in the formulation of these standards. At the same time, 1980 passenger car sales data were used to develop a representative sample of vehicles in profiles of selected vehicle dimensions for a 1980 "design vehicle."

The second step was an assessment of how these vehicle characteristics could be expected to change over the period 1980-1990. This time period was deemed sufficiently compressed to permit reasonable estimates, recognizing the relatively long lead times for change in the vehicle fleet. At the same time, this period would permit roadway authorities to adapt to any necessary changes and to incorporate them into the roadway system through ongoing construction, reconstruction and rehabilitation programs.

The third step included a "sensitivity analysis" of roadway and roadside design elements, using representative vehicle characteristics for both 1980 and 1990. This type of analysis identified to what extent design elements are influenced by changes in vehicle dimensions or, in other words, to what degree existing design standards can accommodate change with no significant change in system safety.

The authors concluded that current buying trends indicate that subcompacts, compacts, and intermediates will increase their share of the market by 1990, and past experience suggests that large car travel will decrease relative to today. The information available from manufacturers, government and industry suggests that vehicle dimensions for each vehicle class will not change significantly, indicating that current geometric design standards will not result in any undue decrease in system safety.

However, there appear to be reasons for concern when existing (and future) smaller vehicles collide with roadside objects, including those installed to protect the vehicle occupant from other hazards. These simulation results suggest a need for continued efforts to design roadside fixtures that can accommodate a vehicle of smaller mass, as well as continuation of on-going construction and maintenance programs to upgrade roadside features.

"Vehicle Characteristics Affecting Highway Design"

Performing Agency: Bellomo-McGee, Inc.

Principal Investigator: H.W. McGee

Sponsoring Agency: Federal Highway Administration

Completion Date: March 1984

Highway geometric design and traffic control procedures were initially catalogued by the American Association of State Highway Officials (AASHTO) in the late 1930s and early 1940s. They are reviewed periodically by representatives of AASHTO and the Federal Highway Administration, and are modified based upon changing requirements for mobility and safety. The basic geometric and traffic control design procedures were developed utilizing the standard-sized passenger car. Recent changes in both the passenger and commercial vehicle fleets to smaller, lighter and less powerful passenger cars and larger, heavier and more powerful commercial vehicles raise the issue of applicability of current standards.

The objectives of this study are: (1) to identify the highway geometric design and traffic control criteria which are affected by vehicle characteristics; (2) to determine the relationship of these vehicle characteristics to geometric design and traffic operations criteria and the appropriateness of that relationship; (3) to develop trends and distributions of the vehicle characteristics which affect current criteria; and (4) to determine the sensitivity of these criteria to changes in the vehicle characteristics.

The vehicle characteristics of interest include static and dynamic characteristics which are either directly or indirectly considered when developing highway geometric design and traffic control criteria. Vehicle characteristics being examined in depth are those which are typical for selected major vehicle type classifications.

"Small Car Impacts on Highway Design"

Performing Agency: Texas Transportation Institute, Texas A&M University

Author: Donald L. Woods

Publication: ITE Journal, Vol. 53, No. 4

Date: April 1983

The 10-year period since the oil embargo has produced many changes in American life. This change is most apparent in the cars we drive. The necessity for greater fuel economy has generated many vehicle changes which have resulted in down sizing the American automobile. Vehicle weights which presently average near 3,500 pounds are expected to average just over 3,000 pounds by 1985, and near 2,500 pounds by 1990.

These changes have also had a dramatic effect on certain design parameters including eye height, bumper height, vehicle length and width, turn radius, acceleration ability, braking ability and vehicle stability. Design standards, on the other hand, have not really changed. This paper provides insight on the impacts of smaller vehicles on design as it is not practical to write off the small car drivers simply because they choose a smaller vehicle.

In his conclusions, the author makes several interesting points. The small car is not coming--it is here. Therefore, design and maintenance practices must adapt to it as quickly as practical. The level of maintenance of highway hardware will most certainly be higher in the future. There will be less money available to accomplish a more sophisticated level of maintenance in the future. The bottom line is more fatal accidents with highway hardware in the future unless we begin to immediately address these problems.

Highway engineers must begin to redesign the safety system they have been developing over the past 20 years. The problem will not go away. Only by developing, designing, installing and maintaining hardware that is compatible with the emerging vehicles in the traffic stream can they live up to, in good faith, the safety charge which they have been given.

"Centerline Crown"

Performing Agency: Jack E. Leisch and Associates

Principal Investigator: J.C. Glennon

Sponsoring Agency: Federal Highway Administration

Completion Date: August 1983 (Publication Pending)

Geometric criteria for maximum centerline crown, "rollover," for tangent highway sections cannot be substantiated. Recent research, Tentative Pavement and Geometric Criteria for Minimizing Hydroplaning, indicates that 2 percent is the minimum pavement cross-slope which will provide adequate drainage. Using this research as a basis, the maximum centerline crown for various design speeds were extrapolated. From this analysis the maximum centerline crowns were found to vary from 12 percent at 80 km/h to 5 percent at 140 km/h. Generally, the maximum pavement cross-slope is one-half the maximum centerline crown or 6 percent and 2.5 percent, respectively.

Current design criteria set the maximum centerline crown at 7 percent, which is the same value currently used for cross-slope break. However, results of the "HVOSM Cross-slope Break Study" indicate that 8 percent is an appropriate maximum. Thus, a higher maximum centerline crown may also be appropriate.

The objective of this project was to prepare a table of recommended maximum centerline crowns and pavement cross-slopes for automobiles and trucks at various speeds. This work included analyses or simulation of several vehicles at various speeds traversing a centerline crown. It was performed to establish the maximum centerline crown which vehicles can negotiate in a safe manner on tangent highway sections. These results were verified by use of existing data and, when appropriate, to fill data gaps by performing field tests.

Parameters of interest were those which will determine appropriate centerline crowns and pavement cross-slopes under various operating conditions, such as comfort indices based upon acceptable levels of acceleration at the center of gravity, acceptable levels of steering (aligning) torque, or the dynamic response of the vehicles' suspension to the centerline traversal. Vehicles that were considered were compact and standard-sized passenger automobiles and single-unit and combination trucks.

"Truck Stopping Sight Distance Requirements"

Performing Agency: Automated Sciences Group, Inc.

Principal Investigator: P. Middleton

Sponsoring Agency: Federal Highway Administration

Completion Date: September 1983

The current design criteria for stopping sight distance is based on passenger automobile performance. The design policy does recognize that the larger and heavier trucks require longer stopping distance from a given speed than do passenger vehicles. However, two factors are usually considered to compensate for the additional braking distance needs. First, because of the height of the vehicle the driver of a truck can see further over a vertical sight restriction. Second, it is generally assumed that trucks travel slower than the other vehicles on the road.

Since the above assumptions were formulated, the typical truck has become larger and heavier. Horsepower to weight ratio has become more favorable for maintaining higher speeds, and the 55 mph national speed limit has made the truck and automobile speeds more or less equal. Even without the national 55 mph speed limit, the truck speeds would be much higher and closer to automobiles than before. At the same time, it should be noted that the stopping capability of trucks has probably improved in recent years due to improved braking equipment.

Trucks and other commercial vehicles are a substantial portion of the traffic stream, 10-15 percent. Because of the changes in the equipment and driving habits, the current assumptions in regard to truck stopping distance should be studied and either verified or modified along with the resulting geometric criteria.

The objectives of this study are to determine the stopping sight distance requirements of the existing truck population and to determine how well the stopping sight distances provided by American Association of State Highway and Transportation Officials (AASHTO) design standards meet these requirements.

This study is analytical in nature. No major data collection is planned, although it is possible that some data collection may be necessary to supplement existing data, especially truck population figures and possibly some eye height measurements. Truck braking data will be provided from several sources.

"Severity Indices for Roadside Features"

Performing Agency: Texas Transportation Institute, Texas A&M University

Principal Investigator: L. I. Griffin

Sponsoring Agency: Federal Highway Administration

Completion Date: April 1984

This research will establish severity indices for collisions with roadside features and objects based on currently available information. It will examine the need or possible benefit for greater accuracy and specificity including vehicle type and highway class for these measures and, where warranted, will develop a plan for obtaining them through a combination of accident studies, crash tests and simulation.

"Impact of Specific Geometric Features on Truck Operations Safety at Interchanges"

Performing Agency: Highway Safety Research Institute, University of Michigan

Principal Investigator: R.D. Ervin

Sponsoring Agency: Federal Highway Administration

Completion Date: October 1984

In the case of large trucks, interchanges pose a special problem. This is true because trucks experience a disproportionately large number of rollover and run-off-the-road accidents at on and off ramps. The causes of these accidents are not clear, but there appear to be specific ramps with histories of such accidents which could indicate a design problem. Another problem trucks have is off-tracking on short radius curves as are found on some interchange ramps, ramp crossroad terminals and highway intersections. Often, trucks with long wheelbase trailers have difficulty negotiating tight curves, especially when constrained by curbs, guardrails or other physical barriers. In order to make such turns, trucks must encroach beyond the width of the operating lane. In instances where there is an adjacent lane encroachment, the truck can cause safety problems for other vehicles or pedestrians.

When designing intersections or interchanges, the tracking characteristics of trucks using the facility need to be taken into account. Alternatively, before longer trucks are allowed to use a facility, their ability to negotiate within the facility must be determined. The objectives of this study are to evaluate the safety problems associated with truck operations at interchanges, to develop possible solutions to identified truck safety problems at interchanges and to develop a dynamic off-tracking model capable of calculating the wheel path of any truck or other large vehicle.

The portion of this study dealing with interchange safety will not go beyond the identification and general assessment of possible countermeasures. No field testing or evaluation of countermeasures will be conducted as a part of this study. The off-tracking model will be user oriented. Instructions will be made simple, and output will be in highway engineering terms. The program will have the graphic capability to draw turning radius plots of vehicles for given radius curves. The swept width of vehicles will also be an output of the model. The model will be capable of handling any reasonably configured vehicle from single unit trucks to triple-trailer combinations. This will include the ability to eliminate articulation points on multi-trailer combination trucks.

"Side Friction for Superelevation on Horizontal Curves"

Performing Agency: Highway Safety Research Institute, University of Michigan

Principal Investigator: C. MacAdams

Sponsoring Agency: Federal Highway Administration

Completion Date: July 1985

Current design practices for determining side friction factors and superelevation rates are based on idealized assumptions (e.g., constant speed, treatment of vehicle as "point-mass"), and empirical data that are over 40 years old. The laws of kinematics applied to a "point-mass" fail to represent accurately the dynamics involved as a vehicle traverses a horizontal curve. Frictional forces at each tire, improper steering, variable acceleration and braking forces, vehicle attitude and weight distribution all affect the performance of a vehicle on a horizontal curve.

The frictional forces that act on a vehicle are applied at the tire-pavement interface. This means that the force of friction is applied on at least four points of the vehicle (each tire) as opposed to the "point-mass" representation of one force at one point. This consideration becomes even more complex when front-wheel drive and four-wheel drive vehicles are analyzed since the forces acting on the front wheels are subject to additional variation due to steering and braking.

Another omission in the "point-mass" analysis is the effect of the vehicle's suspension system. As a vehicle traverses a curve, its attitude (roll, pitch and yaw) will introduce a gyroscopic force that tends to straighten the wheels and supplement the centrifugal force. The improved design of vehicular suspension and stability lessens this problem, yet the net effect of vehicle attitude remains unknown.

"Point-mass" analysis of force is most accurate for small, uniform objects in which weight is evenly distributed. To gain a more accurate assessment, weight distribution must be accounted for. This is especially true in cases of longer vehicles (e.g., trucks, recreational vehicles) where the torsional effect is magnified due to the increased length of the moment arm about the center of mass. The length of the vehicle may also add to the effect of improper steering by increasing the differential in slip angles between front and rear wheels.

The objective of this study is to determine the values for side friction factors in calculating superelevation on horizontal curves. This study will analyze the forces on each wheel in lieu of "point-mass" in the calculation of superelevation. This will involve: (1) investigation of various tire configurations (e.g., radial tires); (2) investigation of various vehicle characteristics, including front wheel drive and four-wheel drive; and (3) investigation of various vehicle classifications, including passenger cars and trucks.

"Rollover Potential of Vehicles on Embankments, Side Slopes and Other Roadside Features"

Performing Agency: Calspan Field Services

Principal Investigator: N. J. DeLeys

Sponsoring Agency: Federal Highway Administration

Completion Date: December 1985

Rollover accidents are generally more severe than nonrollover accidents. In fact, a major study of almost 8,000 single vehicle run-off-the-road accidents found that rollover accidents resulted in injury in 67 percent and fatalities in 6.6 percent of the cases while nonrollover accidents resulted in injury in 49 percent and fatalities in 4.9 percent of the cases. Several studies have shown that small cars are three to five times more prone to roll over in an accident than large cars. Light trucks, vans and other utility-type vehicles show an even greater propensity to roll over. The issue is complicated by a host of characteristics that differ between vehicle classes such as differences in the distribution of mass, heights, track width, wheelbase, tire size, suspension, drive location and steering mechanisms.

Modern highways, along with roadsides and safety devices such as guardrails and breakaway sign supports, were designed when the typical automobile weighed 4,000 pounds and was mechanically quite different from modern automobiles. Modern vehicles are shorter and lighter, have different steering and suspension and almost invariably have front wheel drive. By 1990, 50 percent of all automobiles may weigh under 1,800 pounds.

The goal of this research is to examine roadside design relative to vehicle rollover potential. Concurrent research is examining guardrail accident severity by vehicle class. Subsequently, warrants may be developed balancing roadside design with the need for guardrail protection. This study will examine the critical effect of roadside features on vehicle rollover. While emphasis will be placed on small, modern automobiles and utility type vehicles, larger vehicles comprising a significant part of the vehicle population will be considered. The interaction of roadside features and vehicular structural and design characteristics will, of necessity, be examined, but the study will focus on the influence of roadside features on vehicle rollover.

VEHICLE-VEHICLE INCOMPATIBILITIES

"The Small Car with a View Toward a Safety Index"

Performing Agency: Villanova University

Author: David J. Schorr

Publication: ITE Journal, Volume 51, Number 7

Date: November 1981

There is a trend to greater use of small economy vehicles in this country. The safety implications of this trend are not fully known. Transportation and design engineers should keep ahead of the trend to prevent the environment from further increasing the accident and severity rate. Critical elements include how the smaller vehicle interacts with highway design elements and hardware and the relative safety of small cars compared to larger vehicles.

The author suggests a three-step approach to studying the problem: (1) examine conditions contributing to the growth of the small car population and their effect on the accident rate; (2) look at attributes of the small car that could influence the accident rate and injury severity; and (3) plan a course of research that would be required to rate the vehicles and develop a safety index.

The results of research on the relative accident involvement and injury severity of occupants of small cars vs. large cars are reviewed. The smaller cars have had a higher accident rate since 1974, and occupants are much more likely to be severely injured in the lighter cars.

The author presents a conceptual model of accident rate including elements of driver need, vehicle selection process, vehicle use, driver age, changing environmental conditions and the interaction of the driver, vehicle and environment. He concludes that a realistic long-range forecast of the small car accident rate, at this time, would be very unreliable.

An injury severity model is presented that contains factors which relate to the interaction of the driver, vehicle and environment in the pre-crash and crash sequence.

A safety index is suggested that takes six factors into account: (1) energy developed in a crash; (2) energy absorbed by the vehicle; (3) crushability rating for the vehicle; (4) restraint rating; (5) maneuverability of the vehicle; and (6) visibility. The index would provide a guide to the buying public as to the relative safety of various vehicles and would serve as an incentive to automakers to improve the safety of vehicles.

"Car Size, Deaths Linked; Small Cars Found Worst--A Special Issue"

Performing Agency: Insurance Institute for Highway Safety

Author: W. Haddon, Jr.

Publication: Status Report, Vol. 17, No. 1

Date: January 1982

The number of subcompacts and small subcompacts on the road has increased dramatically in the last few years, and is likely to increase further. With fuel prices high and automobile efficiency at a premium, there is little reason to think Americans will reverse their trend toward buying small, light vehicles instead of larger, safer ones. This report focuses on the high numbers of deaths in small cars, and notes that deaths per registered vehicle in the smallest cars on the road are twice as high as in the largest cars. The report also examines the vital need for implementing already available technologies to reduce the number of people who are killed and injured every day in crashes of their subcompacts and small subcompacts.

"The Effects of Truck Size on Driver Behavior"

Performing Agency: The Institute for Research

Authors: Edmond L. Seguin, Kenneth W. Crowley, Paul C. Harrison, Jr., Kenneth Perchonok

Publication: Report No. FHWA/RD-81/170, Federal Highway Administration

Date: March 1982

Safety aspects of car/truck interactions were evaluated in light of the increasing size of trucks and the decreasing size of automobiles. Truck length interaction was examined in a freeway entrance merge, mainline lane change and narrow bridge situations. Truck width interaction was addressed in a rural two-lane, two-way passing situation. In addition to observations of erratic maneuvers and truck type for the length/ configuration studies, other traffic measures were recorded using the Traffic Evaluator System.

In general, it was concluded that no serious hazards were created by the interaction of automobiles and nonconventional truck configurations. Several specific conclusions were drawn. Increasing truck width was associated with increased pre-pass headways, reduced lateral clearance between passing vehicles and the truck and reduced lateral clearance between oncoming vehicles and the road edge. There were no increases in shoulder encroachments by passers or acceptances of small gaps. Data indicated that truck length/configuration had little or no effect on interacting drivers.

"Small Car Accident Experience in Washington State"

Performing Agency: Washington Department of Transportation

Author: Robert S. Nielsen

Publication: ITE Annual Meeting Compendium

Date: August 1982

Increases in the cost of fuel have caused American motorists to seek smaller, lighter, more fuel efficient automobiles. In 1976, small car sales represented 47 percent of total new car sales in the United States. Four years later (1980), 64 percent of the new car sales were small cars. With a national fuel economy goal of 27.5 miles per gallon set for the 1985 motor vehicle fleet, this strong growth in the number of smaller, lighter vehicles can be expected to continue. The same fuel cost problem, which is increasing the use of small, light vehicles for personal use, is causing the trucking industry to increase truck size so as to increase their payload. These two divergent trends are creating a hazardous situation on streets and highways. There seems little likelihood that this problem will be eliminated--particularly in the near future.

This paper presents the results of a study which documented the Washington State experience for the 1973-1980 time period. Based on his analysis, the author concludes that the smaller automobiles are experiencing increasing numbers of accidents. This fact is important because the smaller, lighter cars will represent a greater percentage of the future vehicle population, and a disproportionate increase in deaths and serious injuries can be expected unless countermeasures are taken. Specifically, the study showed that small vehicles are experiencing the following problems: (1) a higher percentage of fatal and injury accidents; (2) a greater proportion of accidents occurring on wet, snowy and icy roadways and on horizontal and vertical alignments; and (3) a high frequency of overturning and rear-end collisions.

The author recommends that a collective assault be made on this problem. Transportation engineers and vehicle designers should work as a team to alleviate the problems caused by the sudden influx of small vehicles onto a street and highway system not specifically designed for them and which also carries much larger and heavier vehicles. The transportation community should design any new facilities and upgrade existing ones to make the systems safer. While some of the improvements can be made now and will have an immediate effect, the total solution is essentially long-run. The vehicle designer can make required structural changes to the vehicle and can assist in making the entire vehicle population compatible within ten years. Many of the needed changes, such as tail lights located higher on the rear of the vehicle and automatic restraints, are relatively straightforward. Other changes are needed in the structural integrity of the passenger compartments.

SUMMARY

Twenty-four recent publications and/or on-going research projects related to driver-vehicle-highway compatibility have been identified and synthesized. Hopefully, this list represents the majority of the work that has been done within the subject area; however, by no means, should it be considered complete. In reviewing these various efforts, at least two areas appear to need further research. They are as follows:

- Design Driver. Although much work has been done relating the impact of various driver characteristics on design and operations, there are not adequate data to determine a reasonably accurate estimate of the profile distribution for many of the characteristics. Thus, the percentage of drivers excluded by most standards cannot be determined. Two characteristics for which this is especially important are vision and perception-reaction.

- Vehicle Mix. Data are available reasonably to define both the largest and the smallest vehicles that are expected to operate on a highway network; however, not all of these vehicles will operate on every roadway. As vehicle size is especially important when considering geometric design and roadway hardware, the appropriate mix of vehicles for different classes of highway should be defined better.

Other voids in the compatibility subject area exist; however, it is not the intent of this Circular to identify them each and every one. Rather, it should serve as an up-to-date reference for researchers as well as practitioners. By identifying research projects aimed at solving driver-vehicle-highway compatibility problems, it will allow members of the traffic engineering profession to ascertain quickly the current state-of-the-art.