FINAL REPORT

Volume I of I

on Contract FH-11-6528

BASIC VEHICLE HANDLING PROPERTIES, PHASE I

RFP-141 Project No. 10A

Submitted 15 November 1967

(Revised January 1968)

by the

Highway Safety Research Institute

The University of Michigan, Ann Arbor

to the

Federal Highway Administration

U. S. Department of Transportation

Prepared under Contract No. FH-11-6528 with
the U. S. Department of Transportation,
National Highway Safety Bureau.

CONTENTS

1.0 INTRODUCTION

This report presents findings, conclusions, and recommendations derived by the Highway Safety Research Institute (HSRI) in a Phase-I planning study performed on behalf of the National Highway Safety Bureau (NHSB) of the Federal Highway Administration and entitled "Basic Vehicle Handling Properties." The basic objective of the study was to plan a program that will lead to the formulation of interim standards for highway vehicle performance.

In this report, the terms "performance" and "handling properties" refer to equivalent concepts and should be interpreted to mean both the static and dynamic response characteristics of the motor car to the actions of a driver in steering, braking, and accelerating. Vehicle responses to disturbing forces originating from the highway environment are included as part of the performance or handling-property description. It should also be noted that a description of vehicle-performance characteristics requires the inclusion of measures or parameters defining the extent to which the driver must provide control forces and displacements to achieve a given level of vehicle response.

Within the scope of the above definitions for performance and handling properties, HSRI has sought to obtain both definitive and tentative answers to five major questions. These questions derive from the program-planning objectives cited in Request for Procurement No. 141, as issued by the Federal Highway Administration of the U.S. Department of Transportation. The five questions are:

(1) What is the existing state of the art on defining vehicle performance and man-vehicle relationships (at the vehicle-control interface) in objective, quantitative terms?

(2) What is the state of knowledge relative to requirements for vehicle performance and man-vehicle compatibility as dictated by safety criteria, of any manner or form?

(3) To what extent have available data been analysed to indicate the role of performance factors and man-machine matching factors in the production of accidents? What are the short- and long-term prospects for analysing existing data in such manner that it will be possible to clearly establish the need for (and format of) interim standards for performance?

(4) What should be the nature and scope of the follow-up study and test program to:

(a) create the data base required to support a case for interim standards for performance

(b) advance vehicle technology in order that this data base may be expanded and made more directly applicable to the problem of performance specification

(c) develop procedures wherein the priority, feasibility, and cost of a proposed standard may be evaluated

(d) develop procedures wherein the NHSB shall be able to determine that standards promulgated for new car production are being fulfilled and are, indeed, serving their intended purpose?

(5) What are the performance-standard action goals that will best serve the interests of the public, the government, and the automotive industry in achieving improved levels of highway safety?

Overall findings are summarized for the benefit of the reader, with this section followed by the main body of the report which is organized into four major divisions. These divisions embrace (1) a review of knowledge pertinent to the performance standard problem, (2) an assessment of this problem within the more general context of achieving improved levels of highway safety, (3) recommendations for a follow-on program leading to the development of interim standards for highway vehicle performance, and (4) a definition of a set of near-term goals for adoption by the NHSB. Supplementary material has been placed within sections that are appended to the main body of the report.

2.0 SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The Highway Safety Research Institute, under contract to the Federal Highway Administration, has engaged in planning a relatively short-term program whose execution will lead to the development of interim standards for highway-vehicle performance and man-vehicle interface characteristics. The objective has been to develop a program that rests in large measure on empiricism, in view of the urgency to assess rapidly the degree to which "pre-crash" safety is compromised by the lack of such standards.

Within this context, plans have been formulated to exploit the existing accident-data base, to the end that an analysis may reveal elements within the total highway vehicle population which can be identified as being "overinvolved" in accidents relative to their numbers and operational exposure. Accordingly, a systems study has been planned (a) to determine whether this overinvolvement can be attributed to deficiencies in vehicle-handling properties and (b) to examine the priority for establishing a corrective standard on the basis of the total accident cost created by any overinvolved vehicles positively identified as having performance deficiencies.

In view of the major deficiencies known to exist in the currently available accident data, HSRI feels that it is absolutely essential to improve the existing data base in order that an empirically based standards program be as valid as sound engineering and human-factors planning will permit. It was concluded that a program focusing exclusively on the need for interim decisions (namely, decisions that could be made within a one-year period) would be exceedingly short-sighted and subject to the risk of failure. This conclusion developed in the course of the study as a result of a careful look at what is known about (1) accident causation processes in terms of vehicle performance factors and man-vehicle relationships, and (2) the data base required to assess a relationship between vehicle factors and accident production.

At the outset it was found necessary to define some very precise terminology in order to place the role of "as new" performance in proper perspective with respect to the total number of variables that bear upon "pre-crash" safety. A survey of the literature and other data sources, and interviews with pertinent personnel, showed that:

(1) Extensive accident records exist, but these data have limited applicability and accessibility for purposes of evaluating a need for performance standards. The systems study recommended in this report must be carefully designed to obviate the difficulties presented by the existing data base.

(2) The technological base underlying the measurement of the handling properties of motor vehicles is exceedingly weak. Objective measures of performance and standardized test measures need to be developed as a first step towards establishing a data base defining the performance properties of the vehicle population.

(3) A significant quantity of human factors data, applicable to the specification of static man-vehicle matching requirements, exist in the literature. Knowledge gaps do exist with respect to the force and reach capabilities of the driving population, and with respect to human force outputs that can be achieved under emergency conditions. A human factors research program appropriate to filling the observed data gaps is recommended, and conclusions are drawn about the extent to which the expanded data base may be applied in setting standards for the man-vehicle interface. HSRI has concluded that such standards are justifiable without specifically demonstrating that the absence of such standards operates against the interests of the public in achieving increased levels of "pre-crash" safety.

This Phase I study has further indicated a need for establishing goals whose attainment will permit the National Highway Safety Bureau to promulgate a requirement for action steps leading to (1) a continuing expansion of the desired performance-data base and (2) an environment wherein full disclosure of vehicle performance characteristics will stimulate multilateral efforts to upgrade the "pre-crash" safety quality of our highway vehicle population.

3.0 STATE-OF-KNOWLEDGE REVIEW

3.1 VEHICLE-PERFORMANCE FACTORS

Project staff within HSRI had considerable familiarity with the subject topic prior to commencing this study, and it was anticipated that a minimal amount of information would be found in a literature search concerned with the specifics of vehicle performance standards, measurement standards, and the relationship of vehicle performance to accident involvement. This hypothesis proved to be correct.

In addition to surveying the open literature with respect to

(a) the relationships between vehicle performance and accident involvement

(b) objective measures of performance and the extent to which these measures have been standardized

(c) objective methods for evaluating vehicle performance and the extent to which test methods have been standardized,

HSRI undertook the expansion of the above data base by:

(a) making inquiries to consumer-oriented test organizations

(b) initiating a dialogue with the automotive industry to obtain engineering and management views on the form, scope, and objectives of vehicle-performance standards (both voluntary and statutory) developed both in the United States and abroad

(c) examining the technical and governmental standards (both voluntary and statutory) applicable to vehicle performance that have been developed both in the United States and abroad.

3.1.1 PERFORMANCE MEASURES: DEFINITION AND MEASUREMENT PRACTICE

Scholarly evaluations and discussions of performance factors, their definition, and their measurement, are virtually nonexistent. Most of the activity in this realm has taken place within individual companies and on a scale appropriate only to their own internal needs. In order to assess the sparseness of vehicle-performance literature realistically, the conditions that have influenced both the development of the technology and the extent to which this technology is documented must be considered.

It appears that the automobile industry has established design goals for vehicle performance as a result of balancing economic factors and their desire to make the product more attractive to the public. Product attractiveness is generally considered to derive from features related to low cost, appearance, performance and function, and reliability. It follows that the development of the motor car (including its performance characteristics) has been stimulated almost exclusively by competition in the market place, and has in no major way been influenced by externally imposed specific requirements for vehicle performance. The absence of any design constraints imposed by standards of any form created an environment that did not encourage the development of precise methods for predicting and measuring vehicle performance. Furthermore, it was not necessary to obtain a consensus on these matters.

Vehicle manufacturers readily admit that their normal priorities have not justified the expenditures necessary to develop precise objective methods to measure vehicle-handling properties when subjective measurements have, up to the present, adequately satisfied their needs. However, the technical community involved with automobile design and production has recently been motivated to consider the establishment of certain standards. In addition to design standards voluntarily adopted for purposes of reducing manufacturing costs, automotive engineers have generated standards for common test practice (cf., SAE Handbook [1]). Since adequate braking performance was generally conceded to be essential to safe driving, and in view of the braking performance requirement that was introduced into the Uniform Vehicle Code*, the technical community in the U.S. has generated a number of brake-test codes (SAE Recommended Practice J843, J786, J667, J658) and a brake-performance specification (SAE J937--Service Brake System Performance Requirements--Passenger Car) [1] which is claimed to "represent the minimum performance recognized as acceptable by vehicle, brake system, and component manufacturers."

A preliminary investigation of foreign statutes (cf. Appendix I) reveals that no standards exist requiring specific levels of performance in steering and acceleration by passenger vehicles. A large number of countries appear to have type-approval ordinances that impose many design limitations and requirements on vehicles. Braking-performance tests are sometimes specified in great detail; most often, they consist of methods for evaluating the capacity of the braking system to achieve specified levels of deceleration with a specified amount of pedal pressure.

*Uniform Vehicle Code, 1962, Art. III; Sect. 12-302; pp. 159, 160; National Committee on Uniform Traffic Laws and Ordinances.

(It is noted, in passing, that attempts have been made recently to create a standard braking-performance specification acceptable to all of the European countries. Several countries have either incorporated or are in the process of incorporating the proposed standard in their vehicle statutes. As in the case with the U. S. standard that goes into effect on 1 January 1968, the levels of braking performance specified have been established in an arbitrary manner.)

Examination of the procedures employed by consumer and user groups to evaluate vehicle performance [2-7] shows that these groups invariably employ qualitative, subjective procedures for evaluating the steering performance of a highway vehicle. With respect to braking and acceleration performance, quantitative measures are generally employed. There is, however, great variation in test practice and in the objective measures adopted by these test organizations. It is not uncommon to encounter substantial chauvinism in their reports, when, in fact, the resulting data seem to be deserving of considerable skepticism.

In those instances wherein performance data and test procedures were available for scrutiny, it was possible to ascertain that policies relative to the participation of the test driver (i.e., the degree to which the test was a test of vehicle-driver performance) were the major source of differences between the test results achieved by different test groups. Although vehicle manufacturers employ brake-system evaluation procedures that generally eliminate the human operator as a variable, they repeatedly use a driver as the "instrument" by which they assess the quality of the steering and road-holding performance of a motor vehicle. In the course of evaluating the performance characteristics of each model scheduled for production, the manufacturer accumulates objective and subjective data for a variety of internal reasons. These data are never publicly disclosed. They are not used, for example, to describe the desirable features of a given model when it is offered for sale.

To recapitulate, this study has indicated that there is no established technology for evaluating the performance of highway vehicles in a precise, objective manner. Even in those instances where objective measures have been developed, e.g., for braking, there is considerable question as to whether these measures have been adequately defined for purposes of assessing the safety quality residing in a vehicle when it becomes necessary (during emergencies) to approach the vehicle's maximum performance capability.

Braking-performance standards which call for minimum deceleration levels (such as are specified in the Uniform Vehicle Code) are relatively meaningless in that all vehicles can decelerate at a "g" level corresponding to the available friction coefficient between the tires and the road, provided that the wheels can be locked by the brakes. An objective performance criterion having more meaning for safety is the level of deceleration that can be produced prior to locking any of the wheels. A second and perhaps more important measure of stopping quality is the order in which wheel locking will occur. When one considers the total range of friction coefficients that can be encountered by a vehicle whose loading ranges from a single driver to a full-load condition, it is clear that an objective measure of the deceleration level at which the front or rear wheels will lock is a true assessment of those aspects of braking performance which are determined by the design decision governing front- versus rear-brake proportioning. Needless to say, there are other attributes of a braking system which need objective definition in order to make a complete assessment of the deceleration performance of a highway vehicle.

3.1.2 VEHICLE CHARACTERISTICS AND ACCIDENT INVOLVEMENT

The present state of knowledge regarding performance/accident relationships derives from data which relate to vehicle performance only implicitly, through definitions of vehicle type, style, make, year, and model. These data, however, are very sketchy and incomplete. Further, the data that do exist have not been evaluated to determine their full significance. In theory, definitions of vehicle type, etc. would allow the researcher to compile performance data on all the various vehicles, and thus eventually to perform a statistical analysis of accident involvement vs. performance. Such a procedure would be very deficient: the accident data which identify vehicle type are inadequate, and the subsequent data analysis would be prohibitively time-consuming.

The most consistent tabulation of statistics relating accidents and vehicle categories are those which appear annually in Accident Facts, published by the National Safety Council. These statistics are based on data from about half the United States (see Appendix

II) and hence rely on extrapolations to approximate national trends. It is commonly agreed that the potential for inaccuracy in these tabulations is large. Several summaries showing the percentages of vehicle categories involved in accidents are given in Tables I-VI.

Tables I-V demonstrate that (1) passenger cars are involved in the highest percentage, by far, of motor-vehicle accidents, (2) trucks have the next highest percentage, and (3) the remaining vehicle types have very small percentages. The data do not indicate the relative (or normalized) involvement in terms of percentages of registered vehicles involved in each category, or involvement per distance travelled. However, the data do show a strong consistency across several regions of the United States.

Although state accident reports are the most comprehensive source of raw data, research studies into accident causation have very seldom resorted to this data source and, instead, have used much smaller data samples collected specifically for the purposes of the study. Most of the studies have involved numerous factors either not reported in or not easily accessible from state records. It would appear, then, that accident records produced by the various states have not been used very extensively and that their potential as a research data base remains to be fully demonstrated.

The earliest comprehensive accident-data analysis that sought relationships between accident involvement and a few minor vehicle characteristics was performed in the late 1950's by the Bureau of Public Roads (BPR), under the direction of Mr. Charles W. Prisk. This study resulted in a congressional report entitled "The Federal Role in Highway Safety" [8] and was based on accident data collected over a three-year period on 35 sections of road in eleven states, with traffic volumes ranging from 1000 to 24,000 vehicles per day. The accident-involvement rates (accidents per 100 million miles) determined in this study are shown in Figure 3-1 for the major vehicle types. In addition to vehicle type, accident-involvement rates were computed as a function of passenger-car body style and vehicle age. Accident involvement rates were also computed as a function of vehicle horsepower and a limited study was made to examine the correlation of vehicle make with accident rate.

Although the results obtained were given wide circulation and publicity, there is no reason to believe that these data can be

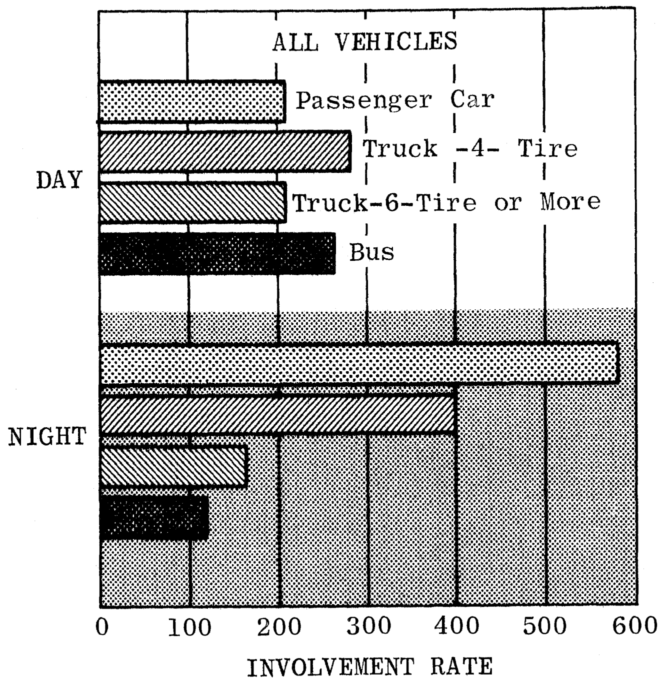


FIGURE 3-1. INVOLVEMENT RATE BY TYPE OF VEHICLE

TABLE I

NUMBER AND PERCENT OF VEHICLE TYPES INVOLVED IN ACCIDENTS

Statistics compiled by the National Safety Council. The percentages of accidents during 1965 are based on reports from 25 state traffic authorities, and 21 state traffic authorities for accidents during 1966.

Vehicle Type	Number -1965-	Percent	Number -1966-	Percent
1. Passenger Car	20,300,000	86.	20,800,000	85.5
2. Trucks	2,550,000	10.8	2,650,000	10.9
3. Farm Tractors, Equipment	23,000	0.1	24,000	0.1
4. Taxicabs	160,000	0.7	160,000	0.7
5. Buses, Commercial	160,000	0.7	170,000	0.7
6. Buses, School	32,000	0.1	34,000	0.1
7. Motorcycles	200,000	0.8	260,000	1.1
8. Motor bikes, Motor Scooters	35,000	0.2	42,000	0.2
9. Other (fire equipment, ambulances, special vehicles, other.)	140,000	0.6	160,000	0.7
TOTAL	23,600,000	100.0	24,300,000	100.0

TABLE II
PERCENT OF VEHICLE TYPES INVOLVED IN ACCIDENTS

Vehicle Type	State					
	Arizona 1966	Connecticut 1966	New York 1966	North Carolina 1966	North Dakota 1966	Oklahoma 1966
1. Passenger Car	68.3	87.8	75.4	86.1	82.5	84.0
2. Compact Car	-	-	11.6	-	-	-
3. Passenger Car with Trailer	4.1	.1	.03	.21	.06	.33
4. Truck or Truck Tractor	16.2	6.4	6.8	9.5	10.7	12.5
5. Truck Tractor and Semi	5.3	1.2	.94	1.32	1.1	1.4
6. Other Truck Combinations	3.1	.1	-	.4	.05	.05
7. Farm Tractor &/or Farm Equipment	.1	.02	.03	.21	.20	.07
8. Taxicab	.01	.3	2.0	.52	.4	.12
9. Bus	.4	.4	.8	.3	.11	.16
10. School Bus	.03	.2	.1	.43	.20	.17
11. Motorcycle	1.0	1.0	.5	.71	.77	.8
12. Motor Bicycle or Scooter	.13	.2	-	.08	.07	.3
13. Others and Not Stated	.22	1.7	1.9	.2	4.0	.09
14. Emergency Vehicles	-	.03	.13	-	-	-
15. Military Vehicles	.1	.02	-	-	-	-
16. Other Publicly Owned Vehicles	1.12	.5	-	-	-	-
TOTAL VEHICLES	9072	113,669	849,347	167,289	36,263	104,843
TOTAL ACCIDENTS	6554	63,941	455,363	97,301	20,237	55,807

TABLE III

PERCENT OF VEHICLE TYPES INVOLVED IN ACCIDENTS

Vehicle Type	State			
	Oregon-1966			South Carolina 1966
	School Bus	Log Trucks	Trucks	
1. Passenger Car	40.7	39.3	45.2	84.4
2. Compact Car	-	-	-	-
3. Passenger Car with Trailer	0.	.4	.3	.2
4. Truck or Truck Tractor	.97	18.32	41.0	9.2
5. Truck Tractor and Semi	.48	40.1	6.8	1.8
6. Other Truck Combinations	0.	.9	5.4	.7
7. Farm Tractor &/or Farm Equipment	0.	0.	.05	-
8. Taxicab	0.	0.	.22	.45
9. Bus	0.	0.	.43	.3
10. School Bus	57.1	.23	0.	.72
11. Motorcycle	.72	.4	.31	.72
12. Motor Bicycle or Scooter	0.	0.	.06	.08
13. Others and Not Stated	.0	.4	.22	1.4
14. Emergency Vehicles	-	-	-	-
15. Military Vehicles	-	-	-	-
16. Other Publicly Owned Vehicles	-	-	-	-
TOTAL VEHICLES	413	857	8697	94,547
TOTAL ACCIDENTS	213	456	4465	55697

TABLE IV

PERCENT OF VEHICLE TYPES INVOLVED IN ACCIDENTS

Vehicle Type	State			
	Texas (Rural only) 1966	Vermont	Virginia	Wyoming
1. Passenger Car	75.3	87.5	84.63	82.3
2. Compact Car	-	-	-	-
3. Passenger Car with Trailer	.7	-	.1	.22
4. Truck or Truck Tractor	16.1	9.4	9.5	12.8
5. Truck Tractor and Semi	5.0	-	1.5	.77
6. Other Truck Combinations	1.1	-	.36	.04
7. Farm Tractor &/or Farm Equipment	.21	.2	-	.2
8. Taxicab	-	-	.8	-
9. Bus	.12	.15	.46	.05
10. School Bus	.3	.16	.34	.2
11. Motorcycle	.6	1.0	.7	1.35 (scooter & bike)
12. Motor Bicycle or Scooter	.14	-	.05	-
13. Others and Not Stated	.43	1.6	1.2	2.06
14. Emergency Vehicles	-	-	.4	-
15. Military Vehicles	-	-	-	-
16. Other Publicly Owned Vehicles	-	-	-	-
TOTAL VEHICLES	83,578	26,738	207,422	12,425
TOTAL ACCIDENTS	524,972	16,330	116,275	10,739

TABLE V
PERCENT OF VEHICLE TYPES INVOLVED IN ACCIDENTS

Vehicle Type	Nation
	Canada 1965 (excluding Quebec)
1. Passenger Car	85.3
2. Compact Car	-
3. Passenger Car with Trailer	-
4. Truck or Truck Tractor	12.0
5. Truck Tractor and Semi	-
6. Other Truck Combinations	-
7. Farm Tractor &/or Farm Equipment	-
8. Taxicab	-
9. Bus	0.7
10. School Bus	-
11. Motorcycle	.86
12. Motor Bicycle	-
13. Others and Not Stated	1.3
14. Emergency Vehicles	-
15. Military Vehicles	-
16. Other Publicly Owned Vehicles	-
TOTAL VEHICLES	476,897
TOTAL ACCIDENTS	398,127

interpreted in any reliable manner with the objective of isolating meaningful relationships between vehicle-handling properties and accidents. The BPR report noted that the identification of vehicle defects as a contributing factor in the accident-causation process is particularly difficult, due, in part, to destruction or inaccessibility of the evidence after the accident takes place. In addition to difficulties in evaluating the role of defects or failures, there was the more formidable task of determining whether accidents attributed to driver error were actually due to the driver's inability to surmount difficulties inherent in his vehicle's design.

This latter question or hypothesis has never been examined in the light of data obtained from the field, and it appears that considerable improvements in the data base will be required before researchers will seriously contemplate such a study.

In 1964, the Bureau of Public Roads published another report [9] which was touted as the successor to the 1959 congressional report. However, little, if any, of the data were new. One slight difference appeared in the treatment of accident-involvement data by make. The earlier report had concluded that make was "not a significant factor" but did not present any data. The 1964 report, however, presented accident-involvement data with the various makes, grouped by price. In view of the role played by public and human factors in the production of accidents, it is not clear how one can make any reliable interpretation of the results when they are grouped in this fashion. Reports having similar deficiences have been published since, but their citation does not seem particularly worthwhile. However, the Bureau of Motor Carrier Safety's recent disclosure that empty commercial carriers account for approximately 50 percent of the total accidents reported for a selected sample of accidents involving commercial vehicles is viewed as a particularly valid finding relating a vehicle characteristic to accident involvement.

3.2 THE MAN-VEHICLE CONTROL INTERFACE

3.2.1 HUMAN ENGINEERING VARIABLES: OBJECTIVE MEASURES

3.2.1.1 General Remarks. The human-operator interacts with his vehicle in two major ways, dynamically and statically. In the first instance, he is part of a man-machine highway system, in which he perceives the results of his previous decisions and motor actions and proceeds on a continuing basis to behave as a dynamic controller. In the second instance, man interacts with the fixed features of the driver's compartment, and part of his ability to perform the required control tasks becomes a function of the static geometry and force levels prevailing at this control interface between the man and the machine.

The dynamic man-vehicle interaction studies that have been reported in the literature to this time [10, 11, 12, 13, 14, 15] represent a beginning attempt to analyze a complex problem, and the results are not yet adequate for deriving standards for vehicle-handling properties. Further work is needed in order to understand the role of the parameters affecting driver-vehicle compatibility utilizing dynamic criteria of performance: It appears that considerable time will elapse before the dynamic interactions affecting handling performance are adequately understood so that this knowledge may be applied to the specification of performance standards.

There is, however, a significant amount of information bearing on man's relationship to the devices with which he controls an automobile. Although the precise nature of the relationship between these static interactions and system performance is not yet known, it is fully apparent that the positioning and the operating characteristics of these controls must permit the driver to make full use of the performance provided in the other components of the automotive system. For the purpose of this report, the primary controls are taken to be those that directly affect the lateral and longitudinal motions of the vehicle. This means that the controls of primary interest at this time are the brake, steering wheel, accelerator, clutch, and parking brake. Secondary controls are considered to be those that do not directly affect the lateral and longitudinal motion of the vehicle. As such they are used less frequently than the primary controls.

Basic to the design of the primary controls are (1) their distance from the operator and (2) the forces that are required to operate them. Adequate control location is determined on the basis of anthropometric data and is also a function of the drivers' capability of exerting the necessary force at various given angular positions of the limbs. Thus the location and force requirements of man-machine matching cannot be determined independently. Rather they are interacting requirements and must be considered simultaneously. This situation adds complexity to the design task and means that a considerable quantity and variety of data must be available to the designer.

Data pertaining to the design of secondary controls are also reviewed in this report. This review appears desirable since the driver may need to operate these additional controls while the vehicle is in motion, and it is important that they permit quick and accurate manipulation with minimal distraction from or interference with the primary handling task.

In line with the foregoing remarks, the following categories of human factors data were sought in the literature: (a) the reach capability of the civilian population at various angles about the body, (b) the forces that could be generated by the various limbs of the body at various angular positions, (c) the ability to grasp objects in various ways and the forces that could be exerted, (d) the anthropometric data related to the driving population or to certain specified segments within that population, and (e) the results (including the methodology) of studies directed specifically towards investigating the static and dynamic interface between a driver and automotive control systems.

3.2.1.2 <u>The Scope Of The Literature Review</u>. A few research studies have been performed to ascertain the optimum geometry of foot pedals, such as the accelerator pedal on a motor vehicle [16, 17, 18, 19]. These studies have also been concerned with a determination of optimum restoring force characteristics [20]. Information also exists with respect to the limiting force capability of drivers for foot- and hand-operation of controls. Many measurements have been taken, in some instances on quite large samples, on the human's ability to exert pressure in pushing movements with the feet at various lateral positions with respect to the midline of the body and at various horizontal angles and distances from the body [21]. Similarly, considerable data have been collected indicating man's capability in pushing and pulling tasks and the extent to which the hand can be moved in pronation and supination. The data are largely of value for design applications other than those of concern in the present study, since almost all studies concerned with human force capability have been carried out upon samples selected from military populations. For those few studies in which data were obtained for civilian populations the samples were small in size and, in any event, were not obtained for the American civilian population. It has been demonstrated though, that the force capabilities and indeed the anthropometric measurements of German, Russian, Australian, and certain other populations are quite similar to the American population [22, 23]. However, the meager data for Japanese males and a selected group of young Japanese females which showed percentile force capabilities could not be applied to the objectives of the present study.

It is of interest to note that the 5th percentile young Japanese female could exert a maximum brake pedal force of only 37 lbs [8]. This means that, on a dry surface, she would be unable to obtain the maximum braking capability of any American car without power-assisted brakes. Similarly, for a hand-operated parking brake, the 50th percentile young Japanese female was able to exert a pull of 50 lb, which would not be sufficient to hold most U. S. passenger vehicles on a 27% grade.

While it is essential that the driver be able to exert sufficient force to move the control so as to obtain the desired output, it is obviously even more essential that he be able to reach the control with the limb used to operate it. In order to obtain data describing the reach characteristics of the driving population, the literature search sought anthropometric data relating to the driving population. Many studies in which anthropometric data were collected have been found, but again, most of these studies were performed on armed forces personnel. We are concerned, however, with the civilian population, and in this regard two important sources were located. In the more minor of these two studies [24] data were found presenting basic anthropometric measurements as obtained from a sample of commercial vehicle drivers. The more important study [25] was much larger in scope and deals with measurements carried out on about 7000 representative members of the civilian population between the ages of 18 and 74. The latter data are by far the best available source of anthropometric measurements for the American civilian population, and they are quite applicable to the requirements of the present study. Twelve important dimensions for the standing and seated subject were derived. Although the study was not exhaustive, these data have been accepted as adequate by those personnel engaged in the design of automotive seating and the interior workspace.

The problem of determining the workspace required for the driver is, however, not a simple task. Static anthropometric data are not sufficient because the driver can frequently utilize body motions which may enlarge or decrease his functional reach distance. The Society of Automotive Engineers has developed an anthropometric dummy by which they can take static reach measurements as well as make estimates of dynamic reach [26]. This is one approach to resolving this complex problem and it is probable that further investigations are warranted in order to develop a uniform and acceptable methodology for delineating the driver's workspace. Although data concerning reach exist in the literature, reach-force interaction data are not in hand at the present time.

The specific findings of the review of data that are currently available and that are applicable to the human factor aspects of vehicle handling properties are discussed in the following section [3.2.2].

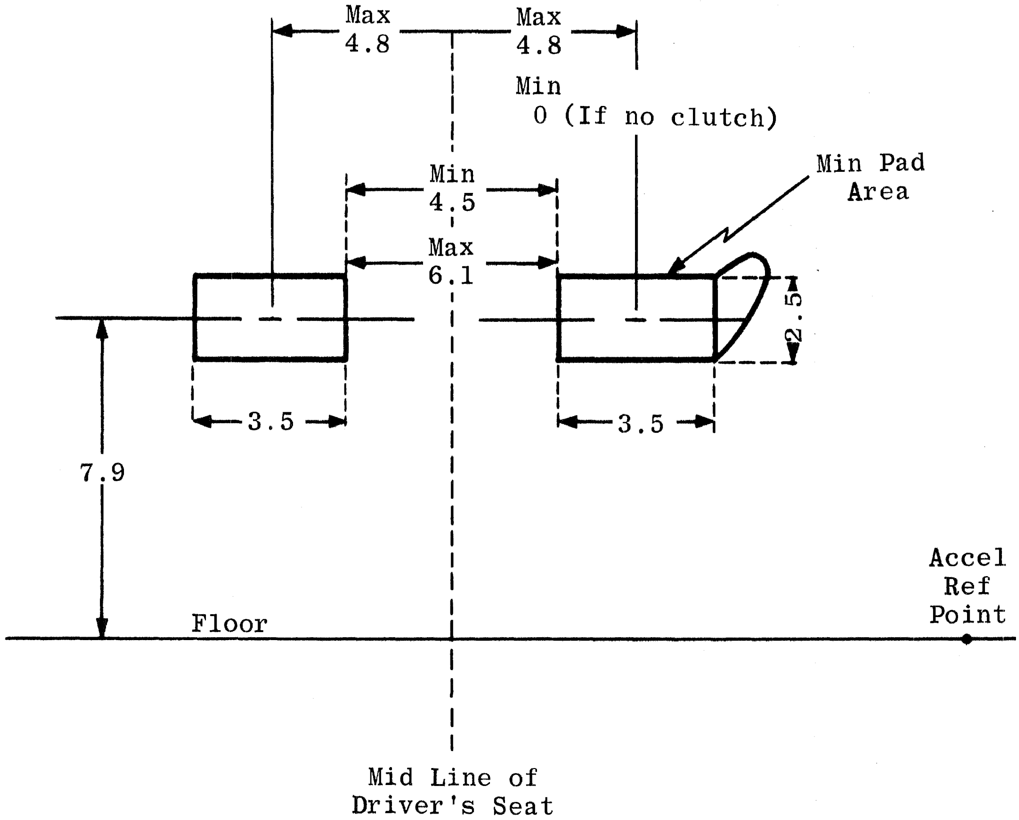
3.2.2 MAN-VEHICLE MATCHING DATA: AVAILABLE AND REQUIRED

The literature survey conducted on static man-vehicle relationships revealed a great deal of applicable data. These data are summarized below. They are organized as a series of recommendations for the design and placement of specific control elements. Where appropriate, the logic employed to develop these recommendations is also presented. A summary tabulation of the findings in the literature and their interpretation (in the context of this study) is provided at the end of this section.

3.2.2.1 Brake And Clutch. Figure 3-2 shows the basic layout of the brake and clutch pedals and the dimensions that appear to be definable on the basis of presently available data.

(1) Lateral Location: An individual's ability to push with his legs drops off sharply as the pressure point is displaced from the center line of the torso [16]. Accordingly, the brake should provide a surface as close as possible to the center line of the body. The clutch pedal, in cars so equipped, should be lined up with the center line of the left leg. The clutch would then be placed about 4.8 in. from the center line of the body [16]. To minimize the possibility of a driver inadvertently operating both pedals, a minimum clearance of 4.5 in. is recommended. This recommendation

BRAKE AND CLUTCH



MAX DEFELCTED LONGITUDINAL POSITIONS OF PEDALS ARE REFERENCED TO A.R.P.

FIGURE 3-2. RECOMMENDED BRAKE AND CLUTCH PEDAL DIMENSION AND CLEARANCES is based on the dimensions of a 95th percentile male foot with shoe [21].

(2) Vertical Location: The center of the undeflected brake or clutch pedal should be 10°-20° below the H point [16].

(3) Longitudinal Location: It is desirable that at the maximum travel point for both brake and clutch, the driver's knee be at an angle of not more than 170°, and preferably within a range of 160°-170°. There are two reasons for this: (a) it insures that the operator may fully release the clutch and fully apply the brake, and (b) these are the knee angles at which maximum force application is achieved.

(4) Pedal Dimensions: The minimum horizontal dimension of the brake and clutch pedals should approximate the width of a small female foot. Hence, a minimum width of 3.5 in. is recommended [27]. Additional width appears desirable, particularly in the case of the brake pedal in cars not equipped with a clutch in order (a) to minimize the probability that the driver may miss the pedal altogether or hit it with such a small area of the foot as to render his action ineffective; (b) to make available a force point for the brake as near the center line of the body as possible; and (c) to allow two-footed brake applications where it is deemed expedient.

The vertical dimension of the pedal is determined by the difference between the heel-to-ball length of a large male foot and a small female foot. Available data [28] indicate that a 5th percentile female foot length is 8.8 in. and a 95th percentile male foot length is 11.5 in. The heel-to-ball foot length is about 75% of these dimensions. Hence, the female length is 6.6 in., the male length 8.6 in. Adding 0.5 in. to the male length to allow for elevation of the foot caused by the heel of the shoe, this length becomes 9.1 in. This value (9.1 in.) defines the minimum height of the top edge of the undeflected brake and clutch pedals as measured from the floor. The female heel-to-ball foot length (6.6 in.) defines the maximum height of the lower edge of the brake and clutch pedals as measured from the floor. Human-engineering consideration of the design of foot pedals also leads to the following conclusions:

(A) If the undeflected brake pedal is positioned to the rear of the accelerator, a downward-projecting flange should be attached to the side of the brake pedal next to the accelerator; the dimension of the flange should be at least equal to the distance that the brake pedal is above the accelerator. Such a flange will help prevent a driver from catching his foot under the brake while moving the foot from the accelerator to the brake pedal.

(B) The surfaces of the brake and clutch pedals should be faced with material that would minimize the possibility that the foot might slip from the pedal.

(C) Brake and clutch pedals should be slightly convex with the radius about the horizontal dimension. This geometry would adjust for the inclination of the foot to the pedal surface an inclination which varies as a function of the operator's seated position.

(5) Maximum Force Requirements: The pedal forces required to achieve maximum deceleration on dry pavement should not exceed the force capabilities of a small female. While many studies have investigated the leg-strength characteristics of certain specialized populations (e.g., military truck drivers), our intensive literature search has failed to discover any investigations in which the force capabilities of a representative civilian population were established. The best approximation is a Japanese study in which the capabilities of a fairly large sample of 16-year-old school girls were investigated. The pedal force achieved by the 5th percentile of this population was 37.0 lb [8]. Other studies involving male U. S. military personnel have resulted in much higher 5th percentile values, e.g., 407 lb [29] and 484 lb [30]. All available data are considered suspect. It appears that studies should be conducted to establish the leg strength of a representative female driving population. The force-endurance characteristics for the same population should be assessed as well.

(6) Force-Displacement Characteristics: The force-displacement characteristics of both the brake and clutch constitute a direct and important feedback loop to the operator. There are two values of interest in establishing the operating parameters of each of these controls: (a) the maximum output capabilities of the weakest people who are apt to operate the vehicle, and (b) a minimum force or displacement determined operationally by the point at which the driver's ability to modulate the control is degraded. The conflicting nature of these requirements can be readily appreciated. For instance, reduced gain may make the brake, largely a force-

modulated control, easier to modulate, particularly under conditions of icy pavement. But if the gain is made too low, it may become impossible for weaker females to achieve maximum deceleration on dry pavement. If the gain is increased in consideration of these weaker females, the range of force through which modulation is possible is reduced, making accurate control of deceleration more difficult, particularly under conditions of reduced coefficient of friction. This conflict seems to be a very delicate one, and it is essential that the optimum gain or the region of best performance be defined through careful research. Figure 3-3 illustrates the form in which the data may appear as the result of such an investigation.

3.2.2.2 Accelerator Pedal.

(1) Dimensions: In addition to reach, a criterion of comfort is involved; hence the minimum contact area of the accelerator should be within reach of the ball of the foot of, for example, the 1% female and a 99% male. In each case, the heel should rest on the floor. Based on the compilation by Damon, et al. [21], the foot length of the 1% female foot appears to be approximately 8.3 in. The distance from the heel to the ball of the foot in this instance, is about 6.2 in. The same source indicates the foot length of the 99th percentile male to be about 12 in. and the heel-to-ball foot length to be about 9 in. Thus, the vertical dimension should be not less than 2.8 in., and it appears advisable that an inch be added to provide a pedal at least 3.8 in. long. The minimum horizontal dimension (width) is recommended as 1.0 in. The minimum height of the top of the pedal should be not less than the heel-to-ball foot distance of a 99% male (9.0 in.), this distance being measured from the accelerator reference point. To the extent that the top of the pedal is above this point, the length of the minimum pad should be increased by a like distance.

(2) Clearances: Obviously, there must be clearance between the center line of the pedal and stationary objects in order to accomodate the foot width of the 95% male (4.3 in. [31]) over the full range of pedal travel. Adding 0.25 in. on each side for shoes, the clearance about the center line of the pedal should be (4.3 + 0.50)/2, or approximately 2.4 in. The proper minimum clearance between the accelerator and brake pedal would be the same as that between the brake and clutch pedal, i.e., 4.5 in. In order to minimize the time required to move the foot between the accelerator

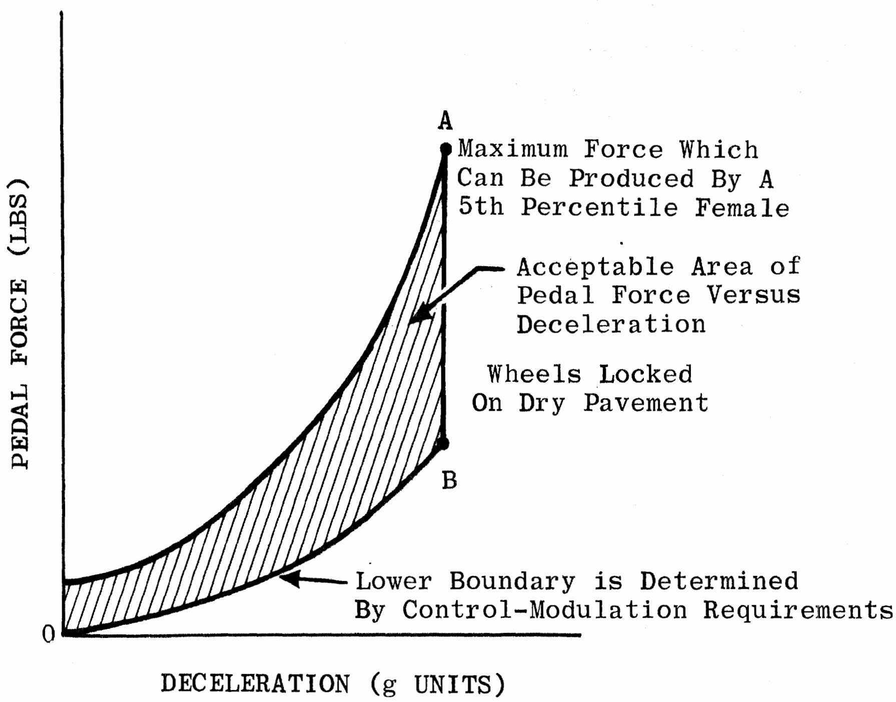


FIGURE 3-3. DIAGRAM OF HYPOTHETICAL FORCE-DECELERATION FUNCTION FOR BRAKING SYSTEMS

and the brake, a case exists for recommending the above cited minimum clearance as a maximum separation between the accelerator and brake pedal. The clearance dimension is particularly critical because it is necessary to preclude inadvertent operation of the accelerator during braking. The recommended dimensions for the accelerator pedal are given in Figure 3-4.

(3) Accelerator Displacement Characteristics: Maximum angular displacement should be 20° [16, 32] and linear displacement at the ball of the foot should be about 1.5 - 2 in. [16, 32, 33]. It appears advisable that the maximum displacement for the throttle be at a point about 15° before the foot is fully extended. In full release position the ankle angle should not be less than 90°.

Several investigators have published recommendations dealing with the restoring force of the accelerator pedal. The recommended values are 7.7 lb [16], 9 lb [32], or a range of 6.5 to 9 lb [33] and it follows that a range of 6.5 to 9 lb is indicated, where these forces are measured at the center of the ball-of-foot contact patch. The pedal should rotate about a point at the heel reference point, since this geometry is associated with minimum response time, minimum effort, and greatest accuracy in a control task [9, 18, 19, 17]. It is believed that the existing data pertaining to static design of the accelerator are adequate. However, additional information is needed to determine the desirable displacement-performance characteristics of the accelerator.

3.2.2.3 Parking Brakes.

(1) Hand Operated: Some studies have been carried out to determine the effect of limb position in pulling and pushing with the hand [34, 35, 36, 37]. It is concluded that the handle of the hand-operated parking brake should be located within the dynamic reach of at least the middle 90% of drivers, and the operating forces required to hold the car on a reasonable grade must be within the force capabilities of a 5th percentile female.

(2) Foot Operated: The maximum travel required to set the brakes to hold the car on a reasonable grade should not be beyond the maximum reach of the 5th percentile female, for example. The maximum knee angle should not be in excess of 170°. The vertical and lateral location and the force requirements should be within the capabilities of, for example, the 5th percentile female. At the same time, knee angles of less than 90° should be avoided for

ACCELERATOR

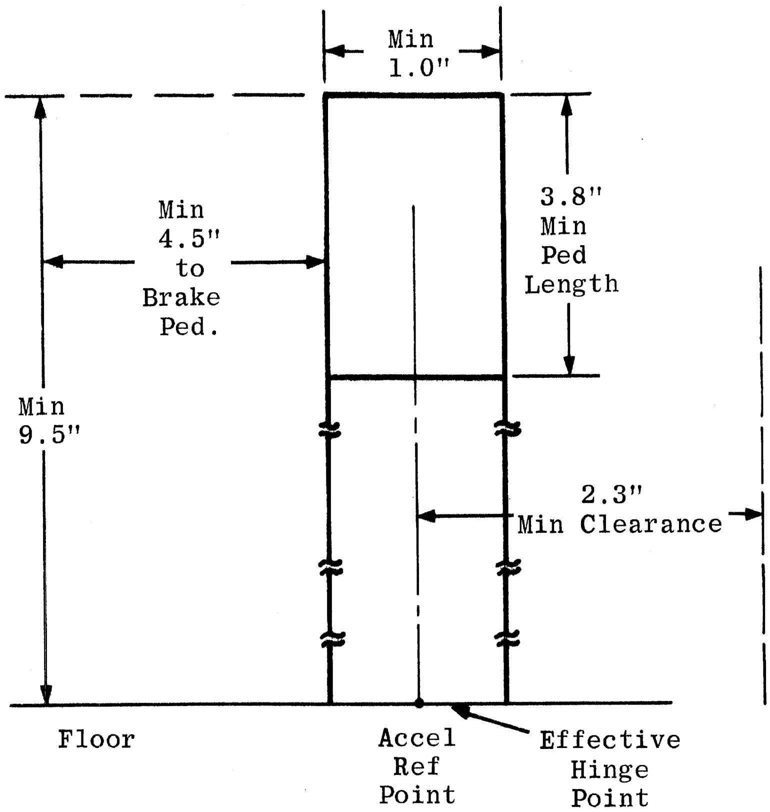


FIGURE 3-4. RECOMMENDED ACCELERATOR PEDAL DIMENSIONS AND CLEARANCES

two reasons: (a) to avoid placing the driver in awkward positions, and (b) because the push capability of human beings is greatly reduced at knee angles of 90° or less.

(3) Release Mechanisms: For thumb-operated release mechanisms the maximum recommended force is 4 lb and for hand-squeezed release handles a maximum release force of 22 lb is recommended [16]. However, the characteristics of the population on which these values are based has not been adequately specified. For parking-brake release mechanisms which require a twisting motion of the hand, data are available on the pronation and supination capabilities of 5th percentile university students [38] which indicate a maximum twisting force capability of 29 lb. Again, however, this population was not truly representative of drivers. No relevant data appear to exist for the very common T-handle pull release mechanism.

(4) Recommended Additional Information: Additional information is required in order to properly establish the limiting parameters for the various types of parking brakes:

a. Dynamic reach capability of 5th percentile females;
b. Force capability of the 5th percentile female tested on representative configurations;
c. Maximum forces on various release mechanisms for the 5th percentile female;
d. A definition of a reasonable test grade to establish the conditions under which parking brakes should be tested.

3.2.2.4 Steering Wheel. There are basic dimensional restrictions on the steering wheel. A 26-in. maximum dimension between the lower steering wheel rim and the undefelected brake pedal allows clearance for the 95th percentile lower leg length as indicated by McFarland [39]. The 8 in. minimum between the lower rim and the top of the seat allows thigh clearance plus 1 in. for a 95th percentile male [25]. The minimum-maximum range of 12 to 18 in. between the lower rim and seat back allows abdominal clearances for 95th percentile individuals with range adequate for adjustment to 5th percentile dimensions [39]. The upper rim of the steering wheel must not protrude into a line of sight established from the eye point for a 1st percentile female to some point on the road surface [40]. These dimensions are shown in Figure 3-5. The distance from the automobile to the contact point of the line of sight with the road needs to be determined. One effort to determine the line of sight resulted in a recommendation for a standard in England [41].

STEERING WHEEL

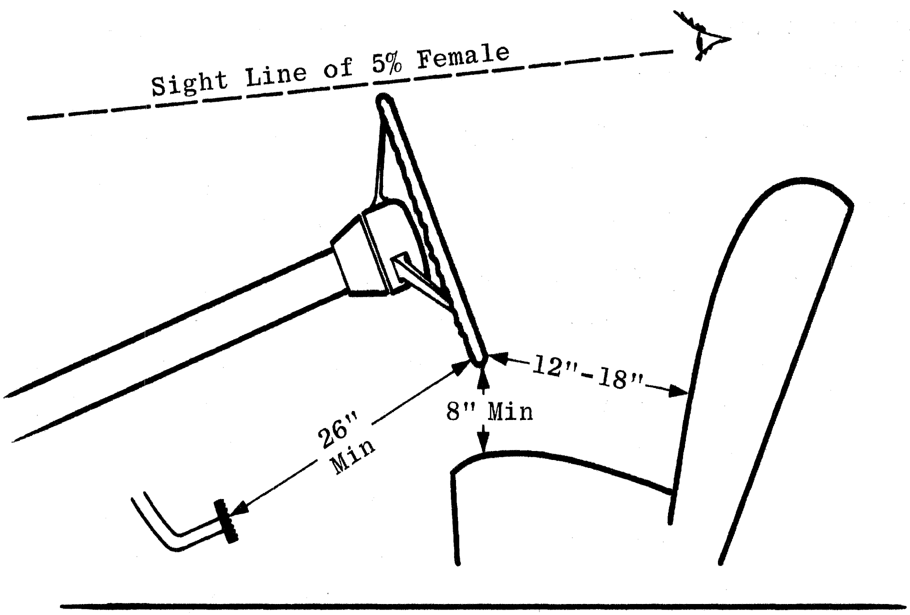


FIGURE 3-5. SPATIAL CONSTRAINTS ON THE STEERING WHEEL.

It appears that the steering wheel should be so positioned that it is possible for all drivers to adjust their position to achieve an elbow angle of approximately 90°. This is the best angle from the point of view of comfort and ease of rapid wheel turning [16].

The importance of the vertical orientation of the wheel is illustrated in Figure 3-6, which indicates the maximum forces, rates of turn, and energy expenditures which can be produced by human subjects at various wheel angles [16]. Data are also available relating to desirable minimum force levels (2-5 lb [16]), minimum clearances around the wheel (3 in. [39]), rim diameters (0.75-2.00 in. [32]), wheel diameter (5-21 in. [32]).

In HSRI's view there are significant knowledge gaps in the area of steering wheel design that should be eliminated. Much of the available data, such as those cited above, are inadequate.

3.2.2.5 Miscellaneous Hand-Operated Controls. In automobiles that are well-equipped with optional devices, there are a great number of hand-operated controls. A considerable amount of data pertaining to the size of these controls, the forces required in their operation, and their separation distances are already available [42]. However, reach distances are not available and must be collected on representative populations.

3.2.2.6 Seating. The general dimensions of vehicle seats necessary to conform to the known characteristics of the civilian population [21] have been well specified and are illustrated in Figure 3-7. In addition to these static dimensions, fore and aft adjustments of 8 in. appear to be indicated. This adjustment is necessary in order to accomodate variations in leg length. Vertical adjustment capability is felt to be desirable and a range of 4.5 in. for the civilian population has been recommended [21].

While very good anthropometric data (viz., 12 body dimensions) are available [21] for the civilian driving population, the values were obtained for application in static anthropometry. Additional data are presently being collected by McFarland, et al., to obtain indications of the values that may be more realistically applied to problems of functional reach. This program will also collect data on the dimensions of women in various stages of pregnancy; when these data become available they will form a valuable adjunct to the currently available anthropometric measures.

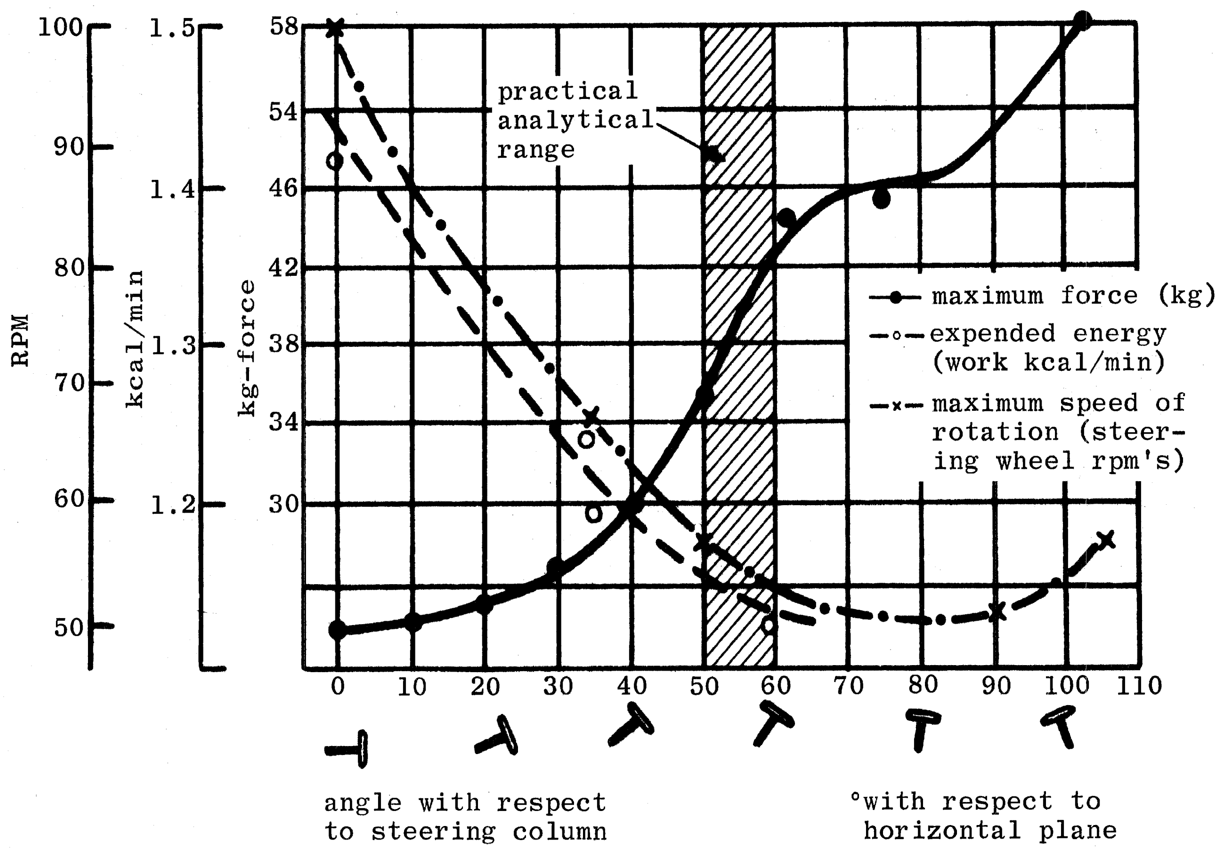


FIGURE 3-6. THE EFFECT OF STEERING-WHEEL ANGLE OR RATE OF TURNING, MAXIMUM TORQUE, AND ENERGY EXPENDITURE (Taken from Dupuis [16])

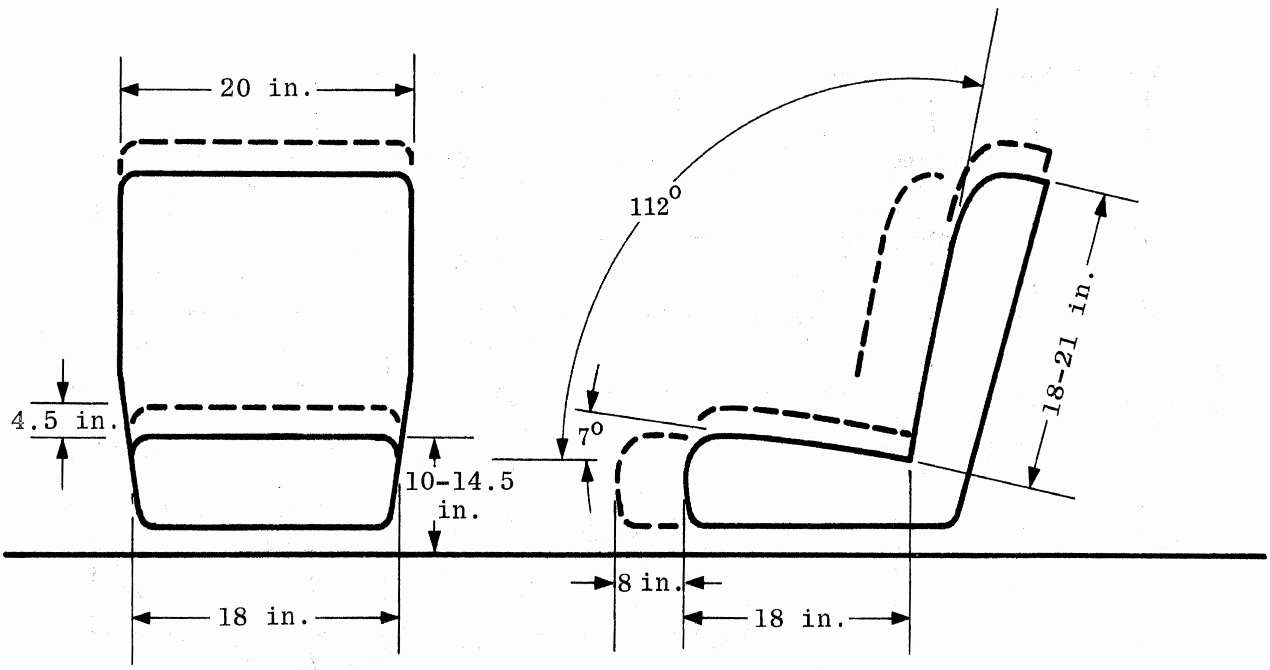


FIGURE 3-7. RECOMMENDED SEAT DIMENSIONS AND RANGES OF ADJUSTMENT (Taken from Damon et al. [28])

3.2.2.7 Tabular Summary of Human-Factor Data Applicable to Man-Vehicle Matching (Static).

I. Foot Pedals

   A. Brake and Clutch

      1. Lateral Location

         a. Brake as close to torso center line as possible

         b. Clutch center line 4.8 in. left of torso center line

         c. Minimum clearance of 4.5 in. edge to edge

      2. Vertical Location: 10°-20° below H point

      3. Minimum Pad Dimensions: 3.5 in. wide, 2.5 in. high

      4. Height From Floor: Top edge 9.1 in. from floor (minimum)
         Bottom edge 6.6 in. from floor (maximum)

      5. Data Needed

         a. Maximum force requirements

         b. Force-displacement characteristics

   B. Accelerator

      1. Dimensions

         a. 3.8 in. long, 1 in. wide (minimum)

         b. Top of pedal 9.6 in. above ARP* (minimum)

      2. Clearances

         a. To stationary object: 2.4 in. from pedal center line

         b. To brake: 4.5 in.

      3. Displacement characteristics

         a. Maximum displacement: 20°

         b. Minimum ankle angle: 90°

         c. Maximum travel point: 15° before full ankle extensions

      4. Restoring force
         6.5-9 lb.

      5. Data Needed
         Displacement-performance characteristics

II. Parking Brakes

   A. Hand-Operated
      (No data)

   B. Foot-Operated
      (No data)

*ARP: Accelerator Reference Point

C. Release Mechanisms

1. Thumb-operated: 4 lb. maximum
2. Squeeze-operated: 22 lb. maximum
3. Twist-operated: 29 lb. maximum

D. Data Needed

1. Dynamic reach capability - 5% female
2. Force capabilities - all configurations - 5% female
3. Test grade definition

III. Steering Wheels

A. Clearances

1. Brake to wheel rim: 26 in.
2. Seat to wheel rim: 8 in.
3. Seat back to wheel rim: 12-18 in.
4. Upper rim must not protrude into visual field of 1% drivers
5. All around wheel: 3 in.

B. Driver relation to the wheel

Elbow angle of 90°

C. Sizes

1. Wheel diameter: 5-21 in.
2. Rim diameter: 0.75-2.0 in.

D. Data needed

1. Maximum rim pull of 5% female
2. Minimum rim pull for good control
3. Best wheel angle and diameter
4. Operator response to power failures

IV. Seating (see Figure 3-7)

A. Fore and aft adjustment: 0.8 in.

B. Vertical adjustment: 0.45 in.

Section 3
REFERENCES

1. SAE Handbook, Standards, Information Reports, Recommended Practices, S.A.E., 1967, New York, N.Y.

2. Jon S. McKibben, Engineering Editor, Car Life, Newport Beach, California. Personal communication dated August 17, 1967.

3. G. R. Wynne, Director of Transportation, Los Angeles Police Dept. Personal communication dated Sept. 5, 1967.

4. Robert D. Knoll, Auto Test Division, Consumers Union, Mt. Vernon, N. Y. Personal communication dated Sept. 22, 1967.

5. Jim Matthews, Managing Editor, Road Test Magazine, Los Angeles, Calif. Personal communication undated.

6. F. T. Finnigan, Supervisor of Products Research, Union Oil Company of California, Brea, California. Personal communication dated August 25, 1967.

7. Donald McDonald, Motor Trend, April 1967, p. 48-51, "The Pure Performance Trials: Were They?"

8. K. Aoki,"Human Factors in Braking and Fade Phenomena for Heavy Application." Bulletin of J.S.M.E. Vol. 3, No. 12, 1960, pp. 587-594.

9. R. M. Barnes, H. Hardaway, and O. Podolsky,"Which Pedal is Best." Factory Management and Maintenance Magazine. New York, McGraw Hill Book Co., January, 1942, pp. 98-99.

10. R. T. Bundorf, "The Use of a Variable-Stability Vehicle in Handling Research." S.A.E. Report SP-275, November 1965.

11. N. Shoemaker and F. DellAmico, "A Pilot Experiment on Driver Task Performance with Fixed and Variable Steering Ratio." C.A.L. Report VK-2185-V-IR, September 1966.

12. L. Segel, "An Investigation of Automobile Handling as Implemented by a Variable Steering Automobile." Human Factors, 1964, 6, No. 4, 333-342.

13. P. L. Olson, "The Driver's Reference Point as a Function of Vehicle Type, Driection and Radius of Turn." Human Factors, 1964, No. 4, 319-326.

14. P. L. Olson and R. A. Wachsler, "Relative Controllability of Dissimilar Cars." Human Factors, 1962, 4, No. 6, 375-380.

15. E. R. Hoffman and P. N. Joubert, "Just Noticeable Differences in Some Vehicle Handling Variables." Report HF-12, Department of Mechanical Engineering, University of Melbourne, January 1967.

16. H. Dupuis, "Arbeitsphysiologische Verhaltnisse im Fahrerhaus" (Biomechanics and the Driver's Area). VDI-Berichte Bd. 25, p. 1-15, 1957.

17. D. Trumbo and M. Schneider, "Operation Time as a Function of Footpedal Design." Journal Engineering Psychology, No. 4, October 1963, pp. 139-143.

18. L. Lauru, "Physiological Study of Motions." The Advanced Management Magazine, Vol. 22, No. 2, pp. 17-24.

19。 J。 Ensdorff, "An Optimal Design for a Foot Activated Lever Mechanism。" M。S. Thesis, Texas Technological College, 1964。

20. G. Lehman, "Physiological Basis of Tractor Design。" Ergonomics, 1958, 1, 197-206。

21. A。 Damon, H. W。 Stoudt, and R。 McFarland, "The Human Body in Equipment Design," Harvard University Press, 1966.

22。 Australian Army Operational Research Group: Anthropometric Survey of Male Members of the Australian Army; Part I - Clothing Survey。 Report 3/58, June, 1958.

23。 K。 H。 E. Kroemer, "Neglect of Biomechanics in Car Design as an Accident Cause。" ATZ 68 (1966) 11, pp。 380-385。

24。 R。 A。 McFarland, A. Damon and H。 W. Stoudt, "Anthropometry in the Design of the Drivers Workspace。" American Journal of Physical Anthropology, Vol. 16, No。 1, March 1958, pp。 1-23。

25。 H。 W. Stoudt, A。 Damon, R。 McFarland, and J。 Roberts, "Weight Height and Selected Body Dimensions of Adults。" U。 S. Department of Health, Education and Welfare, National Center for Health Statistics, Series 11, No. 8, June 1965.

26。 Standard J-826, Handbook, Society of Automotive Engineers, New York, 1967。

27。 F。 E。 Randall and E. H。 Munro, "Reference Anthropometry of Army Women." Report No. 159, Environmental Protection Section, Quartermaster Climatic Research Lab., Lawrence, Mass., 1949.

28。 A。 Damon, H. K。 Bleibtreu, O。 Elliot, and E. Giles, "Predicting Somatotype from Body Measurements。" American Journal of Physical Anthropology, 1962, 20:461-473.

29. E。 R. Elbel, "Relationship Between Leg Strength, Leg Endurance and Other Body Measurements。" Journal of Applied Physiology, Vol。 2, 1949, pp. 197-207.

30。 P. Hugh-Jones, "The Effect of Limb Position in Seated Subjects on Their Ability to Utilize the Maximum Contractile Force of the Limb Muscles。" J。 Physiol., 1947, 105, 332-344.

31. R。 W. Newman and R. M. White, "Reference Anthropometry of Army Men." Report No。 180, Environmental Protection Section, Quartermaster Climatic Research Laboratory, Lawrence, Mass。, 1951。

32. R。 F. Chaillet, "Human Factors Engineering Design Standard for Wheeled Vehicles," Report AD 646681, Human Engineering Laboratories, Aberdeen Proving Grounds, Maryland, Sept. 1966.

33。 C. T. Morgan, et al。, "Human Engineering Guide to Equipment Design." McGraw Hill, New York, 1963, p。 279.

34. L. S。 Caldwell, "The Load-Endurance Relationship for a Static Manual Response." Human Factors, Feb. 1964, pp. 71-79。

35. L. S. Caldwell, "Measurement of Static Muscle Endurance。" Journal of Engineering Psychology, Jan. 1964, pp. 16-23.

36. L. S. Caldwell, "Body Stabilization and the Strength of Arm Extension." Human Factors, June 1962, pp. 125-130.

37。 L. S. Caldwell, "Body Position and the Strength and Endurance of Manual Pull." Human Factors, October 1964, pp。 479-484。

38。 P。 Hunsicker and G. Greey, "Studies in Human Strength." Research Quarterly, 1957, 28:109-122。

39. R. A。 McFarland and R. G。 Domey, "Human Factors in the Design of Passenger Cars: An Evaluation Study of Models Produced in 1957。 HRB Procedures 39, 1960, pp。 565-582.

40. J。 F。 Meldrum, "Automobile Driver Eye Position。" S.A.E。 meeting May 1965。

41。 R. A。 C。 Fosberry and B. C. Mills, "Measurement of Driver Visibility and its Application to a Visibility Standard." Proceedings of the Automobile Division, The Institution of Mechanical Engineers (London)。 1959-60, No. 2, 50-63.

42。 P. M. Fitts and C. Crannell, "Location Discrimination II: Accuracy of Reaching Movements to 24 Different Areas. AF-TR-5833, 1950。

4.0 AN ASSESSMENT OF THE PERFORMANCE-STANDARD (INTERIM) PROBLEM

4.1 THE SYSTEMS ANALYSIS REQUIRED TO INITIATE AND MANAGE A PERFORMANCE-STANDARD PROGRAM

The complexity inherent in the problem of developing motor vehicle performance standards--even interim ones--requires a systems approach to construct a satisfactory solution. This means that the problem should be structured in terms of a system of interacting components and processes which are integrated in optimum fashion, then analyzed objectively, step by step. The system analysis required should be based on a model of the appropriate part of the highway safety problem, on comprehensive criteria for optimum standards, and on answering the most penetrating questions in logical sequence. The system analysis should treat all major parts at each level of the problem equally to avoid bias through either overemphasis or neglect.

The development of the system-analysis plans presented in this report is based upon consideration of only one portion of a total system model of the highway-safety problem. This portion consists of a model of the relationships between motor-vehicle performance standards and accidents. The portion of the total highway-system model applicable to this study is shown in Figure 4-1.

By using the diagrammed model, an analysis can be structured that proceeds through several steps to the derivation of interim performance standards. These steps would appear to be a follows: (1) Determine, by type, configuration, make, or model, those vehicles which are overinvolved in accident production. (2) Determine the extent to which performance factors, as such, are, in large measure, responsible for the observed overinvolvement. This determination is a critical feature of the analysis and may employ testing or the application of vehicle dynamic analyses. (3) Compare "marginal" and average vehicles with regard to performance capabilities so that reasonable performance levels may be chosen as tentative standards. The success or failure of this idealized procedure is, or course, a function of the existence and accessibility of an applicable data base.

The systems approach may also be used to derive a recommended program for administering the standards. This task would involve defining and comparing all possible program alternatives, on the basis of pre-established criteria. The most satisfactory alternative could

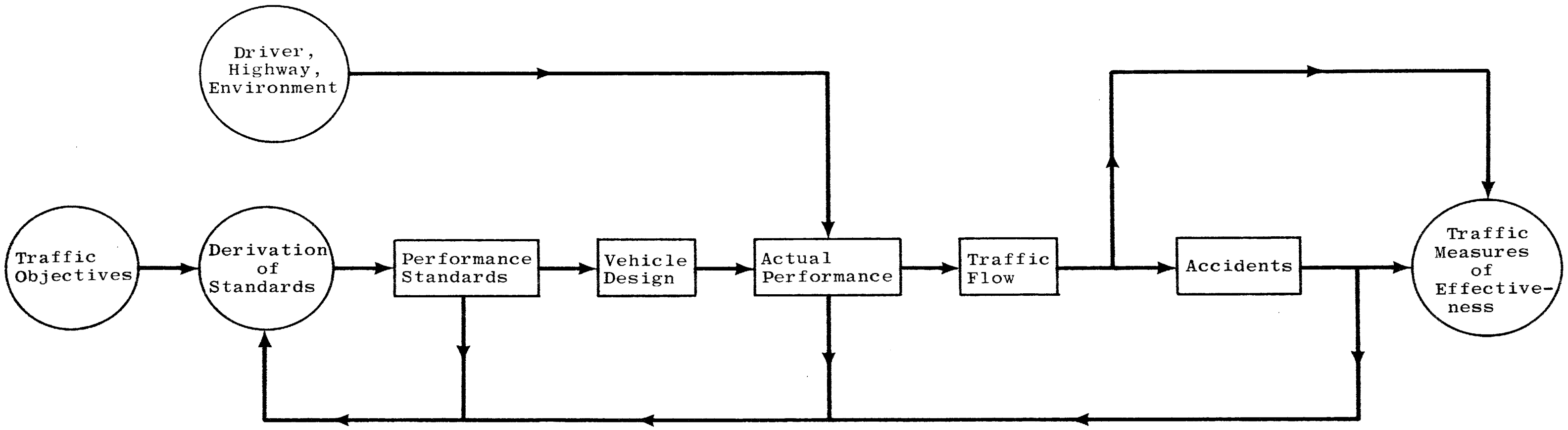


FIGURE 4-1. SYSTEM MODEL RELATING VEHICLE PERFORMANCE AND HIGHWAY ACCIDENTS

then be selected. At this point, the cost of the standards program could be estimated using straight-forward accounting procedures.

The key to effective use of a system model is the selection of a set of "measures of effectiveness" which apply to the particular problem under consideration. The main categories of these measures appear to be system service (e.g., vehicles/hour at a given intersection), system comfort, and system cost. In examining the problem of performance vs. accident involvement, it is likely that only safety and cost measures should be considered.

4.2 THE COMPONENTS OF A VEHICLE-PERFORMANCE STANDARD

The review of knowledge presented above is predicated on the assumption that there are two major components of a vehicle- performance vector or description. One component is viewed as the motion response which a vehicle is capable of producing as a result of the design characteristics of various vehicle subsystems, e.g., power plant, drive train, running gear, suspension, chassis geometry, etc. The second component is viewed as the level of the control action or input that must be provided by the driver in order to obtain a given "output" response on the part of the vehicle. The definition of this second component may be broadened to include considerations of man-vehicle compatibility in the region where the driver comes into contact with his vehicle, namely, the control interface.

In deriving a standard for vehicle performance, the question of whether the output performance is satisfactory from the standpoint of achieving safer operating levels must be addressed. In addition, one must address the question of whether conditions at the interface between the driver and the vehicle are such that a selected percentage of the driving population can provide all the control action or input to which the vehicle can respond. It appears that the decision as to whether the nature and level of "output" performance is sufficient (by whatever safety criteria are selected) is fundamentally different from and more difficult than the decision which must be made for the requirements for the man-vehicle interface. Discussions held with representatives of the three major automobile manufacturers indicated that while from their point of view no data base exists to indicate what levels of output performance should be designed into an automobile, they acknowledged that as many drivers as possible should be able to extract from a vehicle all of the performance that has been built into the vehicle. Thus there appears to be general agreement that good "human engineering" should be incorporated into automotive design without requiring justification in terms of possible increased levels of safety.

It should be understood that "human engineering," as used here, applies to the task of ensuring that, for example, the static force and reach capabilities of the driving population have not been exceeded. However, man-machine matching involves more complicated considerations than the human engineering of the driver's work space. At this time, the logical demand for good man-machine matching practice can not be extended to the question of whether there is an optimum match between the dynamic characteristics of the driver and those of the highway vehicle. Obviously, some categories of vehicle behavior make greater demands on driver skill. It may be argued that interim performance standards should eliminate the more obvious mismatches such as may be indicated by accident experience in the field.

4.3 A NEAR- AND FAR-TERM APPROACH IN RESOLVING THE NEED AND PRIORITY FOR A PERFORMANCE STANDARD

As was discussed in the state-of-knowledge review, the accident data available in the past have been of such character that extreme care must be exercised in analysis to isolate those vehicles that are over-involved in the accident process. If it is hypothesized that within the total population of vehicles there are vehicles whose performance charateristics can be considered marginal or deficient, in that they impose a sufficient burden upon the driver to increase the potential for an accident, then it is essential that we distinguish between "new car" or prototype performance and the actual performance of an operational vehicle.

In a subsequent section of this report a follow-on program of accident-data analyses will be proposed and discussed, in light of the urgent requirementto identify those vehicle categories that may warrant an interim standard for vehicle performance. In this section, we wish to comment on several very real problems imposed by the nature of the highway transportation system. It has been argued on previous occasions that a large majority of the analyses performed on accident data were seriously deficient. The deficiencies stemmed either from inappropriate (or invalid) statistical treatments of the raw data or from inadequacies in hypotheses or theoretical constructs--either because these hypotheses were too simplistic in form, or because the data base was not appropriate to test or confirm the hypothesis. Experience has shown that in any effort to analyse and interpret data not specifically created for the purpose, the need to proceed with caution cannot be overemphasized.

In the real world of accident production, new-car performance is truly a theoretical quantity. When vehicles are involved in accidents, their handling properties may range over a specturm of performance characteristics departing widely from the performance "built into" a new car. New-car performance exerts a considerable influence on "operational" performance which, in turn, may have a bearing on accident production. We cannot apply the inverse of this statement; namely, we cannot deduce from accident data whether new-car performance per se was a contributing factor. Rather we must distinguish among performance properties that result from (1) off-design operation, (2) degraded vehicle components, and (3) original new-car characterisitics.

The foregoing is not to argue that the marginal-vehicle hypothesis is invalid, but rather that it is not a straightforward matter of isolating those vehicles whose original new-car performance may be judged not conducive to safe operations. Nevertheless, there is still the overriding requirement that overrepresentation in accidents be the criterion determining the need for a standard. Since the standard must deal with objective and quantitative measures of performance, it would be very desirable to link accident involvement rates with all of the elements in the performance-parameter space occupied by our operating vehicle population. HSRI suggests that there is merit in working toward this goal even though there are many problems and practical reasons that will prevent completely satisfactory attainment. First, there is the problem of an inadequate data base. If we seek to relate vehicle performance to accident involvement, then it is mandatory that data be developed to describe the performance properties of the operating-vehicle population. On the other hand, it has been established that there are no demonstrated and established procedures for either defining or measuring the performance characteristics of automotive vehicles. In HSRI's view, it is essential that steps be taken first to establish standardized objective measures and standardized test procedures. Until this step is accomplished, the data base required for assessing the need for a standard, let alone defining that standard, will be seriously deficient. When standardized performance data become available for the record, the prospects of making meaningful correlations between accident involvement and performance characteristics will be considerably enhanced.

In assessing the performance-standard problem, we have noted that the performance-data base must be expanded in order to meet the needs of those charged with the task of setting standards. Not to be overlooked, however, are the long-term gains that would accrue to the government, the public, and the industry as a result of developing standardized measures of performance and associated test procedures. Public disclosure of vehicle performance properties produces an environment in which the vehicle manufacturer will be motivated to challenge the integrity and safety of every new design in a manner more efficient than is presently the case. Currently, every vehicle producer runs a prototype development effort in which he determines that he is offering for sale a vehicle that is basically roadworthy. Since (as pointed out earlier) the evaluation procedures are largely subjective, the producer has no exact method for assessing forward progress, or possible retrogression, from year to year. Over the long term, advances are made. But whether the producer has made a gain for safety objectives or whether he has not, he cannot really document his case; the data are not available. It would appear that everyone stands to gain by modifying the current situation, albeit there will be an initial cost for generally upgrading the performance evaluation technology associated with highway vehicles.

5.0 A PLAN FOR A PHASE II-PROGRAM IN "BASIC VEHICLE HANDLING PROPERTIES"

5.1 GENERAL REMARKS

This section of the report defines the Phase II program which has emerged from the studies pursued in Phase I. Since in HSRI's view there are many difficult problems confronting an attempt to link measures of "pre-crash safety" with vehicle handling properties, we have concluded that a follow-on program should contain components that are more long-term in nature, in addition to a major program element that would seek to attain its objective within a one-year period. The latter program element is envisioned as satisfying a requirement for the NHSB to determine, by means of data resources currently available, whether there are vehicles which, by virtue of their handling properties, are overinvolved in accident production. This portion of the follow-on program is viewed as a direct attempt to resolve the question of the need for and form of interim standards. The remaining portions of the program are viewed as essential backup activities which HSRI believes will generate, in due course, the data base required by the NHSB to formulate, and where necessary to justify, standards of performance for highway vehicles.

It should be further understood that whereas the development of the proposed data base is held to be necessary to formulate standards for "output" performance, the existence of a data base is not necessarily sufficient. It will be necessary to supplement the activities described herein with long-term research efforts specifically directed towards improving our understanding of the accident-causation process. In particular, we need to increase our understanding of the extent to which the handling properties of the vehicle population, together with the variable properties and attitudes of the driving population, interact with each other and with the variables deriving from the highway environment and the transport objective to produce a potential for those system failures which we call accidents. Since the total system process of producing accidents is so complex, it appears logical for future research to consider the manner in which vehicle-handling properties contribute to the potential for loss of control when the human operator is required to execute demanding maneuvers as a result of (1) his own errors in judgment, (2) errors made by other drivers, or

(3) exigencies deriving from the operational environment. It is believed that the knowledge produced by long-term research of this kind in combination with actual data on vehicle performance and accident production will produce the background of information that is essential for controlling and managing our highway-transportation system in the public's interest.

To better organize the definition of the work that should be pursued in "Basic Vehicle Handling Properties," we have grouped the tasks into systems-analysis and technical activities. A program is described in both areas. We have elected to single out those tasks and objectives that should be sought within a one-year time span and the activities that would be part of a continuing effort to upgrade and expand the data base necessary to the setting of performance standards.

5.2 A RECOMMENDED FOLLOW-ON PROGRAM: PHASE II

5.2.1 SYSTEM ANALYSIS TASKS

The requirement for interim performance standards, their form and their scope, constitute a series of questions that can be addressed simultaneously, provided care is taken to formulate an appropriate systems study. Although this report has sounded many words of caution, both with respect to the inadequacy of the data base and the many analytical hurdles which would have to be overcome in identifying overinvolvement that stems from performance factors, HSRI recognizes that this attempt needs to be made in view of the mandate set forth by the Congress. Thus, the question is not whether there are vehicles in the total population that could be labeled as providing unacceptable levels of "pre-crash" hazard, but whether such vehicles could be identified within a time period compatible with NHSB objectives for establishing interim performance standards.

Posing the problem in this manner and considering the alternatives for attacking the problem, HSRI concludes that a several-pronged systems analysis needs to be pursued, together with the two technical programs recommended in Sections 5.2.2 and 5.2.3 for a follow-on Phase II study. A flow chart diagramming the recommended systems analysis is presented in Figure 5-1. It is seen that the analysis begins with an "Accident-Data Correlation Study." In many respects, this task constitutes the heart of the systems study.

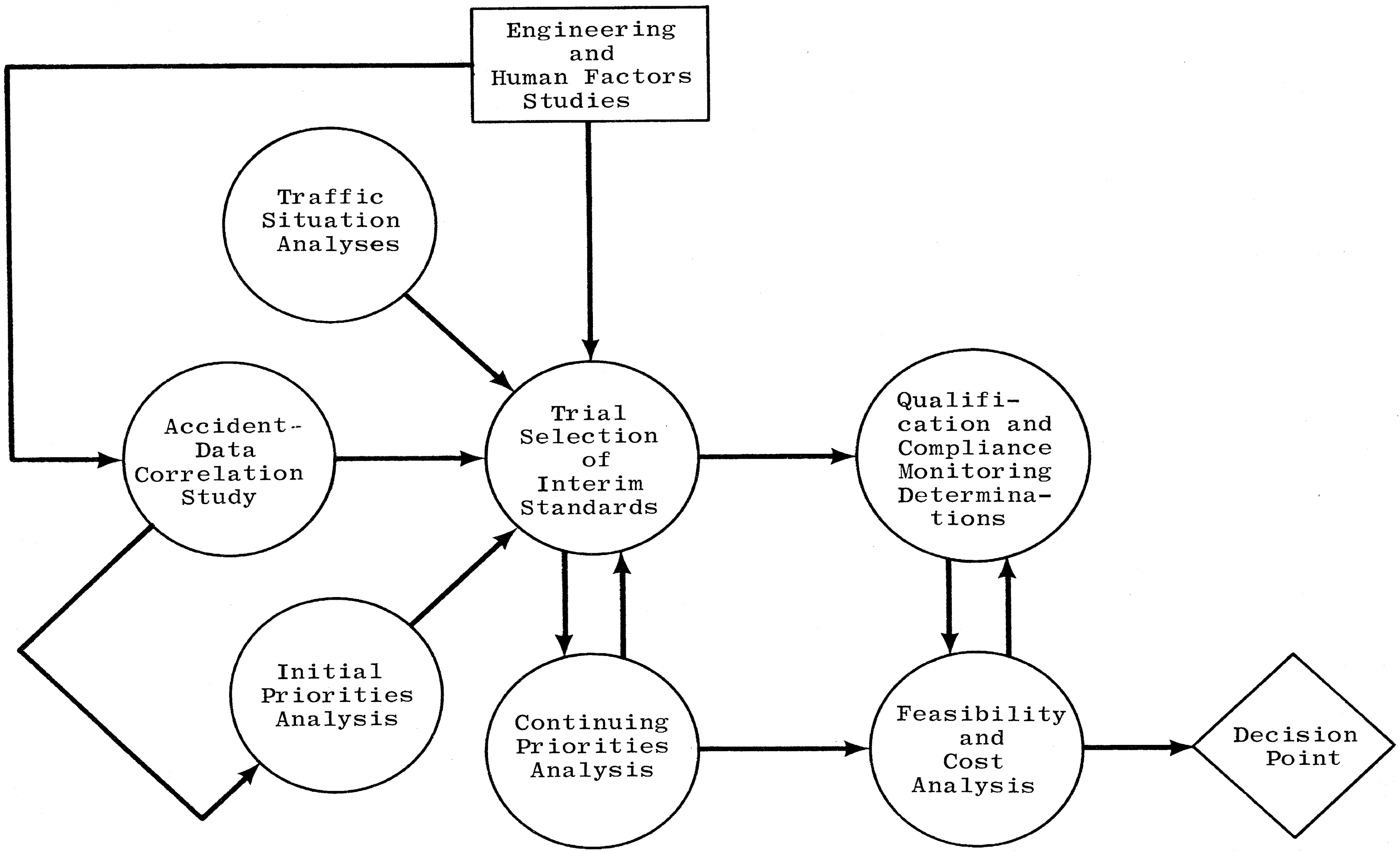


FIGURE 5-1. PHASE II, SYSTEMS ANALYSIS STUDY PLAN.

The difficulties inherent in this task can not be overemphasized and it is noted that the manpower and time requirements could be rather extensive.

From this beginning point, the main flow in the recommended systems analysis effort proceeds to a "Traffic Situation Analysis," whose purpose would be to provide the analytical foundation required to derive conclusions about the form and scope of interim performance standards.

The next analysis (see Figure 5-1) would be to isolate the specific performance areas indicated by the field data and the traffic situation analyses as deserving further examination and study. At the completion of this task a tentative selection of interim standards could presumably be made and could serve as a basis for analyzing alternative qualification and compliance monitoring procedures. A subsidiary (but parallel) line of analyses would consist of evaluating priorities on a continuing basis, leading finally to an evaluation of feasibility and costs.

To establish more clearly the objectives and scope of the recommended systems study, each of the tasks indicated in Figure 5-1 is further discussed below.

5.2.1.1 Accident Data Correlation Study. The objective shall be to employ presently available accident data (primarily those data that are stored in a fashion permitting machine sorting and analysis) to establish involvement rates for highway vehicles both grouped into categories and identified as specific vehicles (i.e., make and model). It is believed that this task should be concerned only with identifying overinvolved vehicles, without attempting at this point to explain or determine the reasons for any observed overinvolvement. It is recognized that overinvolvements, if they exist, may stem from many sources. In subsequent analyses, it will be necessary to conclude whether a given overinvolvement is performance-related. At this point in the study, analysts would be well-advised to concentrate on obtaining an adequate sample of accident data which would then be normalized for exposure as accurately as the data base will permit.

Since the data collected by the various states to identify the make and model of vehicles involved in accidents are exceedingly sparse, care should be taken to select data from sources that maintain computer-stored accident files. At the present time, several state governments and insurance companies are developing computer systems that will be of value to the researcher while satisfying the operational requirements of these jurisdictions and/or institutions as well. It is noted that one of the objectives of Project 17-1 of the National Cooperative Highway Research Program was to determine "the adequacy, reliability, and utilization of present accident reporting and records." Garrett [1] has pointed out that the majority of accident records are geared to the operational requirements and procedures of state agencies. Accordingly, the data system developed over the years to meet the day-to-day operational demands of the states is not well-suited to the needs of the research community. It is absolutely essential that this situation be recognized as a fact of life, or the researcher will find himself frustrated at every turn.

A review of the possible data sources has indicated that the New York State Department of Motor Vehicles is probably in the forefront of the current effort to modify reporting procedures in order to facilitate various research programs. Inquiries have established that the Allstate Insurance Company has instituted a number of computerized files which, when proper integration and sorting procedures are initiated, can yield incidents that contain vehicle make and model information. In this regard, the California and Oregon accident reporting systems are considered to offer significant potential, including accessibility. A listing and evaluation of data sources applicable to fulfilling the objectives of the recommended study is given in Appendix II.

5.2.1.2 Traffic Situation Analysis. In order to provide broad theoretical support for the rational selection of the format and scope appropriate to interim performance standards, it is recommended that a variety of emergency traffic situations be analyzed. This recommendation is based on the belief (or rather, the conviction) that only in emergency situations are the vehicle handling properties likely to be major contributing factors in causing accidents. There appear to be four basic types of driver action which can place demands on handling properties. These are (1) normal, (2) causative, (3) preventive, and (4) corrective actions. In normal driving actions, there are no unusual demands which might lead to accidents. In causative actions, the driver makes unnecessary control inputs (perhaps inadvertently, unconsciously, or in anger) which can cause accidents; obviously the handling properties are not involved. In preventive actions, the driver makes careful control changes in response to a situation well in advance of the critical point, and again, it is not likely that handling-properties would contribute to an accident. However, in the last category (namely, corrective actions) there are likely to be extreme demands placed on handling properties as a result of sudden emergency maneuvers.

It appears advisable that mathematical models of emergency situations be constructed to analyze "worst-case" vehicle trajectories for a set of postulated emergency conditions. Emergency situations should be selected such that the greatest possible demands are placed on the braking, steering, and acceleration performance of a pneumatic-tired vehicle. Foundation studies exist for some of the possible analyses that could be made. For example, the work of Lehmann and Fox [2] on car-following is directly applicable to the analysis of minimum braking performance and the work of Silver [3] on overtaking and passing is directly applicable to the analysis of minimum acceleration performance.

The key element in the recommended analysis effort is the selection of appropriate and specific emergency traffic situations for analysis. Each of these situations should be developed from a starting point defined by a specific critical maneuver that may be performed by a vehicle in traffic. It would appear appropriate to formulate a complete listing of such maneuvers in the acceleration, braking, and steering categories, and combinations thereof. The objective should be to determine critical relationships between emergency-maneuver requirements and the handling properties of highway vehicles.

5.2.1.3 <u>Trial Selection of Interim Standards</u>. The two tasks outlined in Sections 5.2.1.1 and 5.2.1.2 could be pursued in parallel. These tasks are logically followed by an analysis which examines each vehicle, identified as being overinvolved, to determine whether the observed overinvolvement can be attributed to performance factors.

Since it is not possible to speculate on the findings that would be obtained in the recommended "Accident Data Correlation Study," one cannot predict in advance the depth of the analyses that would be required to establish that performance factors are, in fact, responsible for an observed large involvement rate. Definitive performance data would greatly enhance the effectiveness of this discrimination procedure, and thus it appears advisable, in the event that sufficient performance data could not be supplied by the vehicle manufacturer, that steps be taken to procure the needed data. The details of this procurement should be guided by statistics defining the kinds of accidents in which the vehicle being scrutinized was involved. Therefore, to the extent that the raw data base can be interrogated to supply statistics describing the general character of the collision trajectories produced in the field, it should be possible to identify the specific handling properties that should be considered suspect.

These recommendations provide an excellent example of the kinds of accident information needed by researchers whose needs, in most instances, were not anticipated by those agencies responsible for deciding the content of accident reports. HSRI submits that one of the most valuable products of the systems study recommended herein would be the findings specifically indicating how present reporting procedures could be substantially improved to aid in studies concerned with vehicle factors.

Ideally, the presence of a performance deficiency responsible for a record of overinvolvement should be established as definitively as possible. This will be a most difficult task. It would appear that the major piece of evidence indicating that a specific vehicle is marginal with respect to some aspect of performance would be a finding that the handling properties of the overinvolved vehicle depart considerably from norms established by the total vehicle population. Objective performance data suitable for carrying out this determination, as precisely as one would like, do not exist today. Recommendations are made in Section 5.2.3 below; in HSRI's view, they constitute the first steps to be taken to eliminate this data gap.

5.2.1.4 Definition of a Standards Administration Program. In the following sections, a number of system analyses are recommended to identify a performance-standards administration program which could be considered to be the "optimum" program. The questions of precedence, qualification, compliance monitoring, and costs are discussed in the order named.

5.2.1.4.1 Examination of Precedents: Among the various existing precedents for establishing handling-properties standards for highway vehicles are the standards in force for other products in the U. S., and the motor-vehicle-performance standards in force in other countries. It is recommended that each of these precedents be evaluated in order to determine their effectiveness and the extent to which they provide guidelines for setting performance standards for highway vehicles. Appendix I is a preliminary example of the kind of information that can be gathered from foreign sources.

All standards programs have a requirement for evaluating compliance. However, the programs of major interest to this study are those which bear on the public safety. On the national level, two of the most notable programs are found in the aircraft and the food and drug fields. The aircraft performance standards, established and administered by the Federal Aviation Administration, are designed to achieve a desirable level of airworthiness for all aircraft operating in the United States. (This objective is quite analogous to the goal of achieving a desirable level of roadworthiness in the motor-vehicle population.) Before being offered for sale, every aircraft is required to undergo inspection and testing for "type certification," namely, a general approval of its safety and airworthiness qualities. The Food and Drug Administration administers food and drug standards by inspecting, grading, sampling, and licensing. Meats, for example, are inspected and graded at the source, whereas new drugs are licensed after extensive testing, and drug manufacturing processes are monitored by batch sampling.

It is recommended that these U. S. precedents be analyzed to produce a tabulation of specific standards, their associated verification techniques, their costs, and their relevance as guides for setting vehicle performance standards. Brief assessments should also be made of standards programs in other areas in order to uncover any unique methods for dealing with qualification and/or compliance problems. In evaluating vehicle standards programs in other countries, emphasis should be placed on handling or performance requirements, as differentiated from design features.

5.2.1.4.2 Qualification and Compliance-Monitoring Procedures: Qualification procedures generally involve testing a few representative prototype vehicles to ensure that they meet the minimum level specified in the standard. In certain instances, qualification processes employ analytical procedures. The extent of the process depends on the complexity of the standards.

Until the format and scope of interim standards are established in the "trial selection" portion of the recommended systems study, it will not be possible to estimate the extent of the required qualification program. Accordingly, at this time, a system study should derive basic qualification objectives and define grossly the various alternatives for checking compliance with key aspects of the standards. In this manner qualification requirements could be derived without significant delay, after the format and scope of the interim standards have been derived. The possibility of substituting analytical methods should be investigated and, if this appears feasible, estimates should be made of the time that would be required to establish these methods. Obviously, if analytical methods appear feasible, plans should be made to incorporate them into the overall qualification program. In this portion of the study, the magnitude of qualification activity should be reviewed in terms of the actual number of vehicle models that must be considered as units to be qualified in any given year.

Whereas qualification procedures deal with the prototype vehicle, compliance monitoring is concerned with assuring that production vehicles continue to exhibit performance characteristics meeting the minimum levels specified in the standard. The latter procedure introduces the question of where and how this sample should be obtained. A properly designed systems study should carefully investigate the manner in which cost and effectiveness are influenced by the various alternative procedures that could be adopted in the qualification and compliance-monitoring tasks.

5.2.1.4.3 Costs: In evaluating the costs of a motor-vehicle performance standard program, HSRI recommends that emphasis be placed on the distinctions between costs to the government and costs to the automobile manufacturing industry. Costs to a third segment of society, the general public, should be derived entirely from the other two.

The nature of the cost estimation problem is largely dependent on the tradeoffs involved in selecting an optimum performance-standard administration program. Especially crucial are the variations among the alternatives for qualification and compliance monitoring procedures. These procedures will have to be established before the program costs can be estimated.

Facilities and manpower considerations are believed to be the two major aspects of total costs, and each should be broken down into cost elements as small as necessary to achieve reasonable estimating accuracy. Estimates should be based on extrapolation from existing data and on experience with similar programs, such as have been developed in the aerospace industry.

5.2.1.5 Establishment of Priorities. HSRI conceives a priorities analysis as a continuing task following the "Accident Data Correlation Study" and interacting with most of the succeeding system analysis tasks.

An appropriate starting point for a priorities analysis would appear to be the involvement-rate data to be sought in the correlation study outlined in Section 5.2.1.1. For each vehicle model identified as overinvolved in accident production compared with the norms established by the vehicle population as a whole, it will be necessary to reinterrogate the data file to obtain data pertaining to the consequences of the accidents experienced by the overinvolved models. Up to this point, the question of accident severity has not been raised since it is assumed that the "pre-crash" safety designed into a motor car is best assessed by the accident-involvement measure. If interim standards of performance are conceived as a means to eliminate from the total vehicle population those vehicles whose overinvolvement in accidents can be attributed to performance deficiencies, then the question of which "case" to treat first should logically be decided by the total property damage, personal injury, and income loss ascribed to each case of overinvolvement. Since these accident costs are often not explicitly given in the accident records available for analysis, it will be necessary to establish a method whereby total costs are approximated from an extrapolation of information included in the accident report. In this manner the priorities analysis becomes weighted both by (1) the "crash safety" quality and (2) the damage-inflicting potential of the overinvolved elements of the total vehicle population.

A few cases will show how this weighting would be meaningful to the priorities issue. For example:

(1) Vehicle A has an accident-involvement rate similar to the rates exhibited by vehicles B and C, but represents a much smaller proportion of the vehicle population so that its total "accident cost" is much smaller than the costs imposed by vehicles B and C.

(2) Vehicle A has a higher accident-involvement rate than vehicles B and C, represents a greater proportion of the vehicle population than do vehicles B and C, but because of associated factors (such as speeds, transport objectives, etc.) produces accidents of a lower average cost than vehicles B and C and thereby produces a total accident cost that is less than that produced by vehicles B and C.

(3) Vehicle A has an accident-involvement rate similar to vehicles B and C, represents a smaller proportion of the vehicle population than do vehicles B and C, but because of its size and weight frequently involves more severely damaged vehicles and consequently is responsible for a greater accident cost than vehicles B and C.

The foregoing approach to the priorities question is characterized by its simplicity. In HSRI's view, this approach will get to the nub of the issue. However, the validity of the answers will depend on the adequacy of our existing data resources and on the ingenuity that can be brought to bear in resolving the detailed, practical issues that will be encountered by researchers wrestling with the existing data base.

5.2.2 EXPANSION OF THE DATA BASE ON THE MAN-VEHICLE INTERFACE

The following sections summarize studies which, in HSRI's view, will provide the additional data needed to set standards for the driver-vehicle interface. A sizeable number of studies appear to be required and these are outlined in sufficient detail to establish the specific nature of the data to be acquired. Recommended for follow-on Phase II effort are:

(1) a number of studies to gather information relative to acceptable location and application force levels for the service brake, parking brake, and clutch controls (5.2.2.1)

(2) investigations of the influence of force-displacement levels upon brake, clutch and accelerator controllability (5.2.2.2)

(3) an investigation of the control consequences of a failure

in the power-assist brake servo (5.2.2.3)

(4) studies of steering control variables, analogous to those recommended for brakes (5.2.2.4, 5.2.2.5)

(5) a development of schemes for rank ordering of hand-operated controls, for applying coding techniques, and for determining spacing distances between control elements (5.2.2.6)

(6) a survey of man-vehicle interface characteristics for a representative sample of 1968 vehicles (5.2.2.7)

These recommendations are followed by a listing of specific man-machine interface elements for which standards may be created upon amalgamation of currently available data and data that would be produced as a result of the research recommended herein for Phase II (5.2.2.8)

5.2.2.1 Maximum Forces: Service Brake, Parking Brake, and Clutch Controls. The studies recommended in this section determine the force capabilities of a representative female population in operating various parking and service brake and clutch configurations. Data should be collected first under ideal conditions; that is, subjects should be positioned with reference to the controls in such a way that their force outputs would be maximum. Subsequent studies should investigate the effects of a variety of design parameters under less than ideal conditions. These later investigations could, presumably, be conducted with much smaller samples. Performance of the subjects should be compared under the "ideal" condition and under the altered condition of interest.

Study 1. The purpose of this study is to define the maximum forces which a 5th percentile female can exert on a variety of parking-brake, clutch, and service-brake configurations. A sample of at least 300 representative female subjects should be employed. Care should be taken (through the use of known anthropometric distributions such as height or weight) to insure that the test population is indeed representative of the known female population. Each subject should be tested under ideal conditions on the brake and clutch configurations of interest.

Study 2. A study is recommended to assess the effect of motivation on the force-output capabilities of a group of subjects.

Study 3. A study is recommended to assess the effect of a variety of pull brake locations on the ability of subjects to exert a pull force.

Study 4. A study is recommended to assess the effect of limb position on the ability of subjects to exert force. This study will complement results reported in the literature showing the effect of limb position on the maximum forces that subjects could exert. A number of knee angles, elbow angles, and torso positions should be evaluated for their effect on the maximum force output of the operator.

Study 5. Since there is reason to believe that drivers often assume seating positions detrimental to force output, realistic assessments of the output of the 5th percentile driver should take this possibility into account. A survey is recommended to determine whether smaller females do, in fact, tend to assume driving positions which lead to degradation of their force capabilities.

Study 6. A study is recommended to assess the effect of seat compliance on the force capability of human subjects.

Study 7. A study is recommended to provide data indicating the force capabilities of 5th percentile females in operating typical parking-brake release mechanisms.

5.2.2.2 Brake, Clutch and Accelerator Force-Displacement Characteristics. A study is recommended to establish the optimum force-displacement characteristics for the brake, clutch, and accelerator controls. It must be recognized that these static interface characteristics interact with the dynamic properties of the vehicle and ultimately these characteristics should be established by means of research involving the total man-vehicle system. However, it is felt that for the short term some approximate values may be obtained by means of simulation techniques and relatively simple field checks.

5.2.2.3 Power Failure Investigations: Braking. A study is recommended to determine the additional force that a 5th percentile female can and will apply to a braking system which has failed under emergency conditions. It appears that a full-scale car should be employed and a realistic and taxing driving situation provided in which the brake system can be failed and the pedal forces exerted by the driver can be measured.

5.2.2.4 Maximum Steering Forces. A study is recommended to assess the maximum torque capabilities of a 5th percentile female on a typical steering wheel. It appears desirable that this study be run at the same time (and employ the same sample female population) as the brake and clutch force capability study mentioned earlier. During this study an attempt should be made to assess the frequency with which drivers will select positions which place them at a disadvantage in terms of strength and speed with which the wheel can be turned. If it is found that a significant number of drivers assume poor positions, a revision of percentile cut-offs may be indicated.

5.2.2.5 Power Failure Investigations: Steering. A study is recommended to provide data indicating the torques that can be produced by a 5th percentile female under conditions of power-steering failure. It is noted that the actual torque output produced by an individual during an emergency condition is determined, in part, by the circumstances surrounding the failure. Hence, this investigation should be conducted in such a manner as to make due allowance for this effect.

5.2.2.6 Classification, Coding, and Separation Distance for Hand-Operated Controls. A study is recommended to establish, on a rational basis, the relative importance of the large number of hand-operated controls which a car might carry; to determine the best position for those controls deemed of maximum importance; and to specify the separation distances necessary to prevent confusion between these and other controls in emergency blind-reach situations.

5.2.2.7 Survey of 1968 Vehicles. It is recommended that measurements be taken on a selected sample of 1968 vehicles to evaluate all static interface factors for which it is anticipated that standards should be developed. Such a measurement program would indicate current practice and provide a baseline from which one could assess the magnitude of the changes from current practice that may be recommended on the basis of the findings obtained in Phase II.

5.2.2.8 Human Factors Standards Which May Become Feasible at the Conclusion of the Recommended Phase II Study. Based on data presently available and data which would be generated by the research recommended by HSRI, it would be possible to set standards with respect to the below listed elements of the man-vehicle interface.

I. Foot pedals

A. Brake and Clutch

1. Location: horizontal, vertical, and longitudinal

2. Minimum pedal pad dimensions

*3. Maximum force requirements

*4. Force thresholds for power failures

*5. Force-displacement characteristics

B. Accelerator

1. Dimensions

2. Clearances

3. Displacement characteristics

4. Restoring force

*5. Displacement-performance characteristics

II. Parking Brakes

A. Hand-Operated

*1. Locations and distances

*2. Maximum force requirements

B. Foot-Operated

1. Maximum displacement

*2. Location

*3. Maximum force requirements

C. Release Mechanisms

* Maximum force requirements

III. Steering Wheels

A. Clearances

B. Driver relationship to wheel

C. Wheel geometry

*1. Angle

*2. Diameter

3. Rim diameter

D. Force Characteristics

*1. Maximum force requirements

*2. Force thresholds for power failures

IV. Seating

A. Seat dimensions

B. Adjustment parameters

---

*New data to be supplied by proposed research

5.2.3 THE DEFINITION AND MEASUREMENT OF "OUTPUT" PERFORMANCE

HSRI's assessment of the technology applicable to defining and measuring vehicle-performance properties indicates that there are serious shortcomings which should be eliminated as rapidly as it is feasible to do so. Although it is possible to justify an immediate search for marginal vehicles in the absence of available methods of defining and measuring vehicle performance, it would be in the interests of highway safety to take immediate steps to acquire the needed performance-data base. It would appear that the refinement of interim standards will be impossible without a data base defining the steering, braking, and acceleration properties of the highway-vehicle pouplation, and there is no assurance that interim standards can even be developed without this data base. Thus there are good reasons for making the development of standardized performance measures and test practices a first order of business.

In order to expedite the attainment of this goal, a tentative set of performance measures have been defined in this Phase I study. In HSRI's view, these measures should be characterized by

(1) An appreciation for the control inputs that must be provided by the driver

(2) The requirement for selecting measures that describe vehicle behavior near or at the limit of tire-road adhesion

(3) The recognition that performance measures should relate to the driving process, yet remain open-loop measures of vehicle behavior

(4) An appreciation for the prospects of developing reliable test procedures whose format and scope will enhance the possibilities for industry acceptance and further development.

These measures are summarized and discussed below. A more detailed outline of the measures that are proposed (on the basis of the thinking done to date) are presented in an appendix to this report. Also presented below are the elements of a program which, in HSRI's view, will assist in developing a vehicle-test technology capable of producing the desired performance-data base. Difficulties to be resolved in the development of a performance identification code are also discussed below.

5.2.3.1 <u>A Tentative Set of Performance Measures</u>. Performance measures derive, a priori, from vehicle-mechanics considerations. Control of the position of the automobile in the horizontal plane involves both longitudinal and lateral positioning tasks. Three basic controls are available to the driver: he uses his throttle and brake to control his acceleration, velocity, and position in the longitudinal direction and his steering mechanism to control his acceleration, velocity, and position in the transverse (lateral) direction. The manner in which these maneuvers are accomplished and the extent to which there is interaction between longitudinal and lateral vehicle control behavior is primarily a function of the mechanical properties of the pneumatic tire. This interaction increases as maneuvers are made which require larger horizontal forces at the tire-road interface. Since the maneuver levels influence the vertical load between the tire and the road, and the maximum obtainable horizontal forces are a function of the vertical load and the available friction coefficient* at the tire-road interface, the motion behavior of a vehicle in the near-skid regime is a complex interaction (non-linear) of the mechanics of the vehicle (plus tires) and the level of tire-road friction.

Measures of vehicle performance in the near-skid regime are believed to be a very important aspect of the performance properties of pneumatic-tired vehicles. Accordingly, it is necessary that any proposed measure of near-skid performance be normalized in terms of the friction coefficient available at the tire-road interface. It is extremely important to observe that the so-called "friction coefficient" is not a simple number but is, in fact, a complex function of the slip ratio between the tire and the road. Thus, the normalization of braking-performance measures should utilize friction coefficients derived as a function of longitudinal slip, whereas the normalization of steering-performance measures should utilize a friction coefficient achieved by a sideslipping tire. Furthermore, this normalization procedure must use friction-coefficient data obtained by means of a test in which a tire (i.e., a tire of the same design, mechanical properties, and tread stock as that of the tires mounted on a given vehicle) is operated at loads and inflation pressures corresponding to the loads encountered and inflation

*The terms "friction coefficient" and "friction" are being used here in a very loose sense (as indicated in the subsequent paragraph).

pressures used on the test vehicle. In view of the large influence of the location of the center of gravity on the static distribution of vertical tire loadings and on the mechanics (both statics and dynamics) of the vehicle, per se, it appears necessary that vehicle-performance measures be defined rather rigorously in terms of a specified loading condition.

Two extremes of loading are proposed as a means of bounding the performance exhibited by a pneumatic-tired vehicle. One obvious extreme is the empty vehicle plus driver. The other extreme is the full load condition, and here it is proposed that full load be defined as vehicle, plus the maximum number of 150-pound adults which the vehicle was designed to seat (in comfort), plus a trunk load which instead of being a fixed number of pounds would be specified as being a load to be derived from the trunk volume (ft^3) times a standardized cargo-density factor (lb/ft^3). In this manner, every vehicle model establishes its own minimum and maximum load configuration, with tire pressures set at values in accordance with the recommended practice of the manufacturer or in accordance with inflation pressure-load schedules that may be standardized at some future date.

Examination of Appendix III will show that measures of acceleration performance are proposed which will yield the longitudinal acceleration produced by an application of full-throttle (in a stepwise manner) through a range of initial steady-velocity conditions corresponding to the steady driving speeds which the vehicle-power plant combination is capable of achieving. This acceleration-performance measure is conceived as a steady-state measure influenced by vehicle drag in addition to the available propulsive thrust. The test emphasizes the acceleration performance achieved by applying full throttle, as in a passing maneuver, and arbitrarily attempts to minimize certain transient aspects of this process by calling for the acceleration attained when the velocity has increased to a certain level (e.g., five or ten mph) above the steady velocity established prior to the initiation of the throttle opening.

Proposed measures of braking performance stress (1) normalized braking deceleration versus applied pedal force and (2) the order of wheel locking, as pedal force is increased to the point at which all wheels will lock up on the vehicle. In contrast to the proposed measures of acceleration, the braking decelerations are measured for a complete range of pedal-force applications. However, the braking performance measure is similar to the acceleration measure in that it is conceived as a steady-state measure which is a function of the initial velocity established prior to the application of the brake. The deceleration reading would be taken at some arbitrarily established decrement in velocity from the initial velocity.

The braking-performance measure, as proposed, requires measurement of the longitudinal acceleration, vehicle velocity, and wheel rotation rate, as well as an independent measurement of the tire-road friction coefficient existing at the test site. Care would have to be taken to control the effects of brake temperature on brake lining effectiveness. Note, however, that the measures outlined in Appendix III do not require that the vehicle come to a full stop but merely achieve the arbitrarily established velocity decrement. Thus, the proposed test procedure will tend to minimize the total horsepower or energy that must be absorbed by the braking system.

Consideration of the brake-fade phenomenon indicates that this condition will most likely affect the average driver when he is operating his vehicle in hilly or mountainous terrain. A braking-performance measure is required to indicate the deceleration performance of a vehicle following a constant-velocity descent down a grade of specified slope and length. It is obviously not practical to provide this idealized operational situation. Thus, a performance measure is needed which is defined in terms of a lining-temperature increase produced by absorbed horsepower equivalent to a specified descent condition, with allowances made for cooling processes which would be influenced by the velocity of the assumed descent.

A variety of objective measures of steering performance are proposed for defining the steering properties of the vehicle population. The proposed measures stress steady-state input-output relationships. No measures of dynamic or transient behavior are proposed, since a selection of same is not obvious in view of the existing knowledge on driver-vehicle interaction. Rather, it is proposed that a dynamic index, namely, the ratio of vehicle mass (lb-sec^2/ft) to the total cornering stiffness of all four tires (lb/rad), be used to classify vehicles according to their speed of response to a steering displacement. The proposed index is proportional to the basic time constant of the automobile when the automobile is characterized as a linear dynamic system [4]. It is postulated that the proposed index together with (1) measures of path curvature as a function of steering-wheel displacement and torque and (2) measures of the maximum lateral acceleration, normalized in terms of the existing friction coefficient, will give a fundamental description of steering properties that have a meaningful relationship to the control of a vehicle in both normal and emergency situations. If tests are performed in an appropriate manner (see Appendix III), data will be obtained defining the free play and friction in a steering system. These data derive from the hysteresis loop to be obtained in the various input-output measurements.

5.2.3.2 Development of Test Procedures. Consideration of the need for a performance-data base and a corollary assessment of the state of the vehicle-testing art forces HSRI to conclude that it is both desirable and feasible to develop standard test procedures (yielding valid and reliable values for the proposed measures) within a one-year time period. It would appear to be advisable to pursue the proposed objective on a non-unilateral basis. This is to say that attempts should be made to promote multilateral activities within the vehicle industry which would aid in achieving the desired objective, namely, standardized performance-testing procedures. Very likely, the industry would conclude that their own cooperative mechanisms for working towards this goal would require time periods far in excess of a one-year period, and under present conditions, this conclusion is undoubtedly correct. Thus, a requirement is posed for accelerating activities beyond that rate which could be pursued by means of committee-type organizations within the industry or within the automotive-engineering community. Accordingly, HSRI has concluded that the NHSB should support a performance-measure definition and test development program which, by means of independent and cooperative activity, would seek to demonstrate adequate test methods within a one-year period.

The proposed measures introduce several new requirements for vehicle performance tests. First, it will be necessary to have a mobile tire-test device that can be taken to a given test site to obtain the required measures of tire-road interface friction. Second, sufficient tire test facilities must be made available to provide the cornering-stiffness data required to define the proposed index for the total number of vehicle-tire combinations and loading conditions. Last, the proposed tests for steering properties (see Appendix III) make sizeable demands on the availability of paved areas which are large, level, and smooth.

In addition to the other activities recommended for implementation in a one-year, Phase II effort, HSRI recommends that the NHSB support an integrated program having as its general objective the forced extension of technology applicable to measuring the performance of pneumatic-tired vehicles. Specifically, we recommend that NHSB support programs designed to

(1) Extend and refine measures of vehicle performance beyond those offered in Appendix III

(2) Develop instrumentation methods and packages expressly suited to the vehicle-performance measurement needs

(3) Develop test procedures that are acceptable with respect to scientific rigor and practical implementation

(4) Encourage the development of tire-road interface test devices suitable for evaluating the proposed performance measures, and

(5) Encourage the expansion of the tire-test capability existing within the industry and the research community.

5.2.3.3 Development of a Performance Identification Code. The performance or handling-property data to be generated by the proposed standardized test procedures will constitute a data package that will vary in one or more respects for each chassis-power plant combination produced by a given manufacturer. Since it is desirable that future accident records include reference to the specific handling properties of the involved vehicle in its "as new" condition, it is obvious that a means must be developed whereby the total performance description can be identified by a code "number" which can be placed on the vehicle by the manufacturer.

It is merely necessary to consider for a short period the information elements required in the proposed code and many problems are discovered. For example, a method may be needed for modifying the code number to account for changes that may be introduced at a sales agency. Questions arise as to the total number of model configurations (for any given make) that should be considered to possess significantly different performance characteristics. Powerplant and tire options available to the purchaser are factors which may be significant in increasing the total number of possible combinations. Certainly, the presence or absence of power steering, power-assisted brakes, and automatic transmission directly influences the steering, braking, and acceleration properties, respectively, of the vehicle to be coded. It is recommended that efforts to be directed towards extending performance-test technology for pneumatic-tired vehicles be supplemented by a study which shall consider all possible alternatives for implementing a so-called performance code.

Section 5
REFERENCES

1. John W. Garrett, "Development of Improved Methods for Reduction of Traffic Accidents." Paper presented to the AASHO Committee on Traffic, October 17, 1967 (Salt Lake City, Utah).

2. Frederick G. Lehmann and Phyllis Fox, "Safe Distances in Car Following," Traffic Safety Research Review, September 1967, p. 80.

3. C. A. Silver, "Conceptualization of Overtaking and Passing Maneuvers on Two Lane Rural Highway," The Franklin Institute (report in preparation).

4. Leonard Segel, "Theoretical Prediction and Experimental Substantiation of the Response of the Automobile to Steering Control." Proceedings of the Automobile Division of the Institution of Mechanical Engineers, 1956-57, No. 7.

6.0 RECOMMENDATIONS FOR ACTION GOALS

It is fairly obvious by now that setting standards can be a very messy business, no matter how carefully the groundwork is laid for the establishment of the standard. Standards which are designed to minimize the occurrence of an undesirable event are, by their very nature, more difficult to derive than those standards which are designed to minimize the consequences of the undesirable event. It should not be necessary to elaborate, here, on the very real differences that face the researcher and the administrator in deriving and promulgating standards related to "pre-crash safety" as opposed to "crash" and "post-crash safety."

In view of the complexities and uncertainties that will continue to plague the efforts of those who are striving to increase the levels of "pre-crash safety" in our highway system, it appears prudent for the NHSB to consider action steps other than standard-setting. As a result of deliberations pursued in this Phase-I study, HSRI has concluded that there are three action steps which, if implemented, would significantly upgrade several activities bearing on the undesirable end result, namely, the vehicular traffic accident. The first activity is one in which the vehicle manufacturer generates a product which he feels confident is as "safe" as the state of the engineering art and economic constraints will permit. The second activity is one in which the public, as represented both by elected and appointed officials, ascertains whether the public's welfare (in this case, safety) is being compromised by the activities that take place in private sectors. The third activity involves the systematic generation of data relevant to each sector, public and private, and to researchers and decision-makers. (In connection with this last point, it should be realized that the existing collected and processed accident data have very little relevant value--we repeat, very little relevant value--to the specialist who needs to know more than that there is a highway-safety problem.)

The recommended action steps derive, in part, from the discussion presented in Section 4.3 of this report and, in part, from the recognition that these action steps constitute goals that would provide a very desirable focus for the studies and programs to be supported by the NHSB. Even more important, the proposed action steps are deemed to be in the interest of all groups such that these groups, with otherwise opposing interests, would be motivated to work cooperatively (on a multilateral basis) towards the day when these action steps could be made effective. At such time that sufficient progress has been made by the NHSB and the automotive industry in establishing standardized objective measures of performance and standardized test methods, HSRI recommends to the NHSB:

A. The promulgation of a requirement that a manufacturer disclose the performance and man-vehicle interface characteristics of new cars in terms of a standardized set of objective measures prior to offering the vehicle for sale.

B. The promulgation of a requirement that vehicles be marked with a code number identifying that vehicle with respect to the performance-data tabulations disclosed by the manufacturer.

C. The promulgation of a requirement that the accident-recording procedures employed in the various state jurisdictions include the code number identifying the "new car" performance and man-vehicle interface characteristics of vehicles involved in reported accidents.

Appendix I

A PRELIMINARY INVESTIGATION OF THE PERFORMANCE MEASURES, STANDARDS, AND COMPLIANCE PROCEDURES EMPLOYED IN OTHER COUNTRIES

INTRODUCTION

The purpose of this survey was to review foreign literature relating to test specifications, levels of performance, and levels of acceptability, defining a vehicle's longitudinal and lateral performance characteristics resulting from inputs by the human operator. Information was also reviewed relating to the compliance monitoring technique used by various countries or organizations to insure that specifications or statutes defining minimum levels of acceptability are met.

Written requests were made to fifteen countries for information used by government, professional organizations, or manufacturers, and replies were received from seven of these countries. In addition, personal contact was made with an official from Australia.

The results of the survey are given below.

AUSTRIA

A new motor vehicle code [1] will become effective in Austria on January 1, 1968, and new regulations specifying construction, components, and testing of motor vehicles are being prepared at the present time.

The text of the new code contains the following information:

Type Approval. The request for an examination requesting type approval of a series of vehicles may be presented only by the manufacturer through an agent who is a resident of Austria and a fully authorized representative of the manufacturer.

Federal experts are required to examine the vehicle type and to sign affidavits summarizing the results of the examination. If one of a given type of vehicles is approved, then all of that type are approved. Owners of vehicles that have type approval receive certificates when the car is purchased; these certificates are later used for periodic inspections.

Every three years after a vehicle is purchased an inspection is required to insure that the vehicle continues to comply with regulations; however, the inspection can take place sooner if an offical considers the car to be unsafe. The owner must pay a fee to cover the costs of the examination.

If the vehicle does not comply with regulations, the owner must have the car repaired and reinspected. There is no specified time limit for this repair and reexamination.

Brake Specifications.

1. Two brake systems (service and emergency) must be provided; they must operate independently of each other, but may have a common braking device. During application, the braking action must be equal on both sides of the longitudinal center plane of the vehicle.

2. The service brakes must operate effectively under maximum permissible loads, on all slopes that may be encountered, while pulling a trailer, and at all permissible speeds, to insure a safe and quick stop over the shortest possible distance under surrounding traffic conditions.

3. The service brake must be operable with both hands on the steering wheel. The emergency brake must be operable while the driver has at least one hand on the steering wheel, and can be less efficient than the service brake.

4. The parking brake must be operable from the front passenger's seat to permit easy access to the brake if the vehicle is rolling when the driver is absent.

Other Specifications. The following reference relating to the need for steering specifications is contained in the motor vehicle code:

> Insofar as the present state of technology is concerned, regulations must establish more precise definitions of the maximum permissible turning radius, the maximum permissible width of the described circle, as defined by the distance between the extreme outside and extreme inside of the vehicle when turning under maximum conditions, and the need for an auxiliary steering system.

No information was found relating to horsepower requirements or acceleration performance.

AUSTRALIA

The information regarding motor vehicle regulations in Australia was obtained from a conference held with Dr. Peter Joubert, a member of the Australian Motor Vehicle Design Advisory Panel. The purpose of this panel is to advise a group called the Australian Transportation Advisory Council, which includes the Ministers of Transport for the Australian state governmental units, and includes several of the Federal Ministers of Transport.

In Australia the responsibility for setting rules of operation on the highway, for controlling vehicle design, and authorization to operate is delegated to the states by the Australian Constitution. The purpose of the Transportation Advisory Council is to achieve a desirable degree of coordination and standardization among the various state jurisdictions. The Council is presently reaching agreements on standards for motor vehicles which will constitute advice and recommendation for the various state governmental units.

The panel has dealt at great length with the question of compliance monitoring. Deliberations of the panel led to the adoption of a recommendation for type certification of vehicles. The procedure is relatively easy to implement in Australia, which has a semigovernmental organization called The National Association of Test Authorities. This group has in effect issued a national standard for good test practices for all test laboratories operating within Australia. Testing laboratories are periodically visited and checked for adherence to recommended practice. Their measurement procedures are monitored and their instruments checked for proper calibration. Individual laboratories are then certified to conduct tests in specific areas. The manufacturers submit their product or component (in this instance a vehicle component) to the appropriate certified laboratory. A statement by this laboratory that the manufacturer has complied with the motor vehicle standard is considered sufficient for governmental purposes. It appears that this procedure is very similar to the types of certification procedure used in Germany.

DENMARK

The office of the Federal Car Superintendent is the technical and administrative center for vehicle inspection in Denmark, and is responsible for type-approval of new cars.

During type-approval tests, the vehicle being tested is driven on the road and its behavior in regard to steering, service and emergency braking, backing up, and acceleration is studied. The effects of side winds, bumpy roads, and the behavior of the vehicle on curves is also noted. No written standars exist regarding the above tests, and the test ride only serves to ascertain if anything is radically wrong with the behavior and construction of the vehicle.

ECONOMIC COMMISSION FOR EUROPE

Test specifications and levels of performance relating to brakes have been established by the Economic Commission for Europe Document W/Trans/WP29/157/Rev. 2 [2]. Both Holland and Spain have adopted the provisions of this document, and Ireland intends to adopt them.

The Economic Commission for Europe has not provided performance specifications relating to steering or acceleration and none of the three countries above have them.

Document W/Trans/WP29/257/Rev. 2 is summarized below:

1. All vehicles must be equipped with service, emergency, and parking brakes.

2. Service brakes, Type O Test:

   a. With the engine disengaged, the vehicle must come to a stop from 80 km/hr (50 mph) in the distance $s \geqq (V/10) + (V^2/150)$ (s in meters and V in km/hr). (The term V/10 designates a "slack" in the brake system amounting to 0.36 second, and $V^2/150$ corresponds to an average deceleration rate of 19 fps^2).

   b. With the engine engaged, stopping tests must be carried out at various speeds ranging from 0.3V to 0.8V where V is maximum vehicle design speed. The performance figures must be recorded in the test report (no minimum levels of acceptability are specified).

   c. Force applied to brake pedal $\leqq$ 50 kg (110 lb).

3. Service brakes, Type I Test:

   a. The vehicle is fully loaded to its maximum gross weight and braked to one-half its test speed for 15 trials with 45 seconds of time duration per trial. The test speed is designated as 80% of the maximum design speed, but not over 120 km/hr (approximately 75 mph). In the event that the acceleration characteristics of the vehicle make it impossible to abide by the 45 second requirement, the duration may be increased. Also, an additional 10 seconds may be allowed for stabilizing the speed prior to braking.

b. The braking force should be adjusted to provide a mean deceleration of 3 m/sec^2 (9.8 fps^2) for all of the above 15 trials, with the highest gear ratio engaged. At the completion of the 15 trials the Type O Test is repeated and the stopping distance should not be more than 1.25 of the stopping distance described by the equation $s = 0.1V + V^2/150$, and not more than 1.66 of the distance attained during the Type O Test carried out in 2a.

4. The emergency brake must be variable in action, must be capable of stopping the vehicle in a distance $<0.1V + 2V^2/150$, and must not require more than 40 kg (81 lb) to actuate. It should be controllable with at least one hand on the steering wheel and be available in the event of service brake failure.

5. The parking brake must be capable of holding the vehicle stationary on an up or down gradient of 16%, be purely mechanical in action, and should not require more than 40 kg (81 lb) to actuate.

ENGLAND

The Road Traffic Act of 1960 [3] forms the basis of the vehicle regulations in England. This Act provides for a Minister of Transportation to make regulations regarding the use of motor vehicles on roads, their construction and equipment, and the conditions under which they may be used; to make provision for the examination of vehicles in accordance with these regulations; and to provide the driver with a test certificate indicating that the vehicle complies with the regulations.

More specifically, the Minister is allowed to regulate the design, testing, and inspection of brakes, steering gear, tires, lighting equipment, and other items of equipment that affect the performance of the vehicle. He also has the responsibility of assigning other persons to stop, test, and inspect vehicles wherever they may be to insure that the prescribed statutory requirments are complied with.

<u>Type Approval</u>. The Minister is allowed to make regulations that apply to different classes of vehicles, and authorizes the use of new types of vehicles on the roads after testing the vehicles and granting

a test certificate. No license for the vehicle will be issued unless a test certificate has been granted. Once a test certificate is granted for a class of vehicles, the class is exempted for five years from any subsequent changes in the regulations affecting that class.

The Act authorizes compulsory vehicle inspection by authorizing an examiner to stop a motor vehicle on any road at any time to inspect brakes, mufflers, steering gear, tires, lighting equipment, and reflectors. On being stopped at a compulsory vehicle inspection station, the driver may elect to defer the test for a period of up to 30 days; however, the test cannot be deferred if, in the opinion of the constable, the vehicle is so defective that it should not be allowed to operate on the streets.

This Act also provides that any person that sells, supplies, or operates a vehicle deemed to be unroadworthy is liable to conviction and subject to a fine not exceeding 20 pounds or, in the case of a second conviction, to a fine not exceeding 50 pounds or imprisonment for a term not exceeding three months. Unroadworthy condition is defined as noncompliance with any of the regulations established by the Minister of Transport relating to size, weight or vehicle, mufflers, brakes, steering gear, tires, lighting equipment, etc.

This Act refers to the Motor Vehicle (Construction and Use) Regulations, 1955 [4], for test performance requirements relating to the various components of the vehicle. These requirements were later updated and the applicable test performance requirements are contained in the Motor Vehicle (Construction and Use) Regulations of 1966. These requirements specify that:

<u>Brakes</u>. All vehicles require parking brakes that will prevent two of the wheels from rotating when the vehicle is left unattended. After January 1, 1968, the parking brake must be independent of the other braking system and should be capable of holding the vehicle on a gradient of 1 in 6.25.

After January 1, 1968, all vehicles must have a service brake with a Total Braking Efficiency (TBE) of 50% affecting all four wheels. [TBE = (total drag on all four wheels / weight of vehicle).] If the system is not a split system, a second means must be provided to brake at least two wheels with a TBE of 25%. If the system is split, sufficient braking must remain after failure to affect two wheels with a TBE of 25%.

Vehicles registered prior to January 1, 1968, must provide a TBE, as applied by one means of operation, of at least 40%, and a second means of operation must provide a TBE of at least 15%. In the event that the vehicle has a split system the service brakes should provide a TBE of at least 45%, except in case of failure, when 15% is acceptable.

No braking system should become ineffective because of nonrotation of the engine.

No provisions are made for testing procedures or specifications, nor is any reference made to such specifications.

Other Specifications. Pneumatic tires with no regrooves or recuts are required on all passenger cars.

All steering gear fitted to a vehicle must be maintained in good and efficient working order and be properly adjusted.

Every motor vehicle and every trailer shall be equipped with suitable and sufficient springs between each wheel and the frame of the vehicle.

FRANCE

The regulations that apply to vehicles in France appear to be a series of ordinances that are issued periodically. None could be found relating to steering or acceleration requirements; however, ordinances that apply to compliance monitoring and brakes are as follows:

Type Approval. A series of ordinances appeared from 1955 to 1965 that were included under the statute "Code de la Route" [5]. Article 106 of the statute states that every vehicle weighing more than 750 kg (2250 lb) must be approved by the Minister of Public Works, Transport, and Tourism before the vehicle is allowed on the road. The approval can be granted for types of vehicle upon request by the manufacturer, and for single vehicles by request of the driver. Vehicles not manufactured in France may not be admitted by type unless the manufacturer is represented in France by an agent especially licensed by the Ministry. The producer of a series that has received type approval provides every buyer with a copy of the certificate of approval.

Brake Specifications. An ordinance dated August 18, 1955, [6] contains the following information relating to vehicle brake performance requirements:

1. Every vehicle must be equipped with a service brake and an emergency brake which apply forces equally on the wheels in relation to the plane of symmetry.

2. The service brake must be applied to all wheels without requiring the driver to remove his hands from the steering wheel.

3. Passenger cars must have emergency brakes capable of applying a drag on the wheels equal to 45% of the weight.

4. Dual master cylinders, or equivalent, are required.

5. A parking brake is required that is capable of holding the vehicle on a slope of 18% on dry road in neutral, and can be combined with the other brakes.

6. Brake tests should be conducted on a street comparable to a dry street, with no wind and brake lining temperature normal, at starting speed as near as possible to 50 km/hr (31 mph). Requirements below are for normal effort by the driver, normal driving conditions, normal load, without moderation of direction or jerking of the wheels. The stopping distance includes distance from when the signal to stop is given to driver to the point at which the vehicle comes to a complete stop. For action brakes, or service brakes, stopping distance should be no greater than:

$$S = 0.6V^2 + 2.5V \quad \text{(S in meters)}$$

$$V = \frac{\text{km/hr}}{10}$$

This corresponds to an overall deceleration rate of 35%. If only the first term of the equation is used, which omits driver reaction time and slack in system, the deceleration rate is 64%. The stopping distance for the emergency brake is no more than the service brake stopping distance multiplied by 1.8. A passenger vehicle will also pass the braking tests if the braking deceleration rate is 6.5 m/sec^2 (21.4 fpsps) using the service brake and 2.75 m/sec^2 (9.1 fpsps) using the emergency brake.

GERMANY

The following information is condensed from the StVZO, Statute Concerning the Admittance of Vehicles to the Roads [7], a book of 550 pages with statutes and ordinances applying to drivers, vehicle construction and operation, and manufacturers type approval of vehicle components.

Seventy-two of the ordinances are concerned with drivers, vehicles, and conditions under which vehicles may be operated, and thirty-eight of the ordinances describe the design, tests, and acceptable levels of performance of vehicle components. A separate 67-page section deals with type approval of vehicles.

Type Approval. Every mass-produced vehicle intended for use in Germany must conform to governmental requirements specified in StVZO before the vehicle is sold. These requirements apply to components that are included in the design of a particular model of automobile, such as lights, glass, turn signals, seat belts, brakes, etc. Any changes in the original components of an automobile require an additional approval for the special component.

Design approval is given when it is determined that the vehicle conforms to the requirements either by a test at a government test site (University, Institute, etc.) or by furnishing adequate proof that the vehicle has passed the tests at the manufacturer's facilities.

The design approval provides for a booklet (KFZ-Brief) to be issued with each vehicle that is sold, and without this booklet no auto license will be issued. (The booklet also contains information regarding tire sizes and pressure, maximum vehicle weight and horsepower, and is also the vehicle title to be transferred from owner to owner when the car is sold.) A tag is attached to the license plate indicating that the vehicle has been approved and the date of inspection.

The Federal Government maintains records of vehicle inspections and appropriate action is taken against vehicle owners who do not have their cars inspected as required. A person who is guilty of driving a vehicle that does not conform to inspection regulations is subject to a maximum fine of $125.00. A further means of enforcing compliance is provided by insurance companies, which require proof each year that the inspections are up-to-date.

Brake Specifications. All vehicles having service brakes that control four wheels must be designed so that two wheels, not on the same side, can be braked in case of failure. In the event that the brakes do not control all four wheels, then two independent systems or one system with two means of actuation must be provided.

For used vehicles, brakes may be tested by stopping from a speed of 45 to 50 km/hr (28 to 31 mph), with engine in neutral and brake drum temperature under 100°C, with vehicle in loaded and unloaded conditions, on a maximum road incline less than ±1%, and with no wind. The brake pedal force should not exceed 80 kg (176 lb), and the minimum deceleration should be 40% [(total drag force ÷ weight of vehicle) x 100]. If it is desired, the vehicle can be tested on a brake test stand without meeting the speed requirements above; however, for a rolling test stand, deviations in the braking forces for the two wheels on an axle may not be more than 30% of the greater value, or, for a stationary test stand, more than 20% of the greater value.

Brake tests on new vehicles being tested for type approval are more detailed. The tests are outlined below:

1. A cold brake test (drum temperature <100°C) is made in which deceleration is measured for five graduated stages of braking force up to the point of wheel lock. The total deceleration should be at least 45% for a maximum pedal force of 80 kg (176 lbs).

2. Vehicles with self-actuating, load-controlled brake regulators must attain the same deceleration on dry pavement with no wheels skidding, regardless of the load condition.

3. For vehicles with dual master cylinders a deceleration of 15% must be attained for each cylinder with 80 kg (176 lbs) of pedal force applied.

4. The parking brake must hold the vehicle on a 25% grade, or whatever grade the vehicle can climb if less than 25%. This requirement will also be fulfilled if the emergency brake is capable of providing a deceleration of 20% on level ground.

5. Heat fade tests are conducted by driving the vehicle at 40 km/hr (25 mph) over a course 1700 meterslong (1.05 miles) while brakes are continuously applied with a pedal force determined for the weight of the vehicle. The vehicle is then accelerated to a speed of 45 to 50 km/hr and a braking test is made. The deceleration values should be at least 60% of the cold brake tests.

6. Speed fade tests are specified for vehicles with a maximum speed of 140 km/hr (87 mph) by driving the vehicle at 110 km/hr (68 mph) and braking with a force that would provide a cold brake deceleration of 45%. The resultant deceleration should be equal to or greater than 36%.

7. Allowable limits of both service and hand-brake pedal actuation distance are provided for both manual and power assist brakes. These are provided for both cold braking tests and fade tests.

Other Specifications. Trucks and buses are required to have a minimum power output of 6 hp per ton of permissible loaded weight and potential trailer load. No power requirements are applied to vehicles.

No performance requirements were found in StVZO relating to acceleration or steering except for a brief statement that the vehicle must guarantee easy and safe steering, and must be steerable if the power assist fails.

All tires must have at least 1 mm of tread at any point on the rolling surface. Regrooving can only be performed once and must have at least 2 mm of rubber between the bottom of the groove and the undergroove.

IRELAND

The Road Traffic Section of the Department of Local Government in Dublin states that it is their intention to adopt generally the recommendations specified in W/TRANS/WP29/257/Rev. 2 of the Economic Commission for Europe Regulations [2].

The regulations in use at present are the Road Traffic (Construction, Equipment and Use of Vehicles) Regulations, 1963 [8]. The pertinent parts of these regulations are summarized as follows:

Brake Specifications. For passenger vehicles weighing less than 2 tons the vehicle must be capable of stopping with service brakes in 160 ft or less, from a speed of 50 mph with no more than 100 lb of pedal force. The emergency brake specifications are identical except that the stopping distance is not to exceed 320 ft.

For vehicles weighing over two tons the tests are made at 25 mph with a pedal force not exceeding 150 lbs. The stopping distance must not exceed 66 ft using the service brake and 122 ft using the emergency brake.

In addition, the service brake is required to develop a braking force of at least 55% of the weight of the vehicle and must decelerate the vehicle at a rate not less than 17.75 fpsps.

The emergency brake is required to develop a braking force at least half that of the service brake and to decelerate the vehicle at a rate not less than 8.87 fpsps.

The parking brake must hold the vehicle on a gradient of at least 16%.

Other Specifications. Their regulations state that "every vehicle must be equipped with a strong and efficient steering mechanism which enables a vehicle to be turned easily, quickly and with certainty, and which is so constructed and arranged that no overlock is possible and that the wheels will not under any circumstances foul any part of the vehicle."

ITALY

The following information is from the Testo Unico (dated 1959), the ordinances in Italy that relate to braking and compliance monitoring [9]. No specifications could be found relating to steering or acceleration requirements.

Type Approval. Type approval is included in the Testo Unico by requiring every manufacturer to submit a sample to the Minister of Transport and to supply the buyer with a formal certificate stating that the car is similar to the sample. Vehicles that do not belong to a certified series require that tests be made to determine if the vehicle conforms to existing regulations. It is the responsibility of the owner of the vehicle to have the vehicle tested by an engineer of the Traffic Agency.

Every vehicle must be inspected every year, but a vehicle can be inspected anytime there is a suspicion that it no longer meets the standards required by law. The driver of a vehicle that has not been presented for the required yearly inspection will be fined from 4,000 to 10,000 lire and the certificate allowing the vehicle to operate on the road will be revoked until the vehicle has been inspected and found to conform to existing regulations.

Brake Specifications. An ordinance became effective in 1959, supplementing the Testo Unico, that established the level of performance of the braking system.

The stopping distance, with 60 kg (132 lbs) or less applied to the brake pedal, must be less than or equal to $V^2/130$, where V = km/hr and the stopping distance is in meters. This corresponds to a deceleration rate of 0.51 g. The distance is measured from the time the brake pedal is actuated until the vehicle comes to a complete stop.

For determining the fade characteristics of brakes the vehicle is tested on a course 1 km in length with a 10% gradient. The vehicle travels downhill at 40 km/hr using the brakes to maintain a constant speed and is braked to a stop at the end of the course. The braking efficiency must not be less than 80% of that obtained from the formula $S \leqq V^3/130$, nor less than 75% of that measured with cold brakes.

The emergency brake must stop the vehicle in a distance no greater than twice that of the service brake stopping distance. The parking brake must keep the vehicle stopped on grades not exceeding 16%.

SWEDEN

The following information results from a translation of pertinent sections of Vagtrafikforordning, Sweden's ordinances that apply to operation of vehicles on roads, with amendments to December 1966 [10]:

Every vehicle in Sweden must be inspected before the vehicle can be registered. Registering requires that the owner of the vehicle pay taxes and obtain insurance prior to operating the vehicle on the roads. If the vehicle is in proper condition and passes the inspection, a certificate is issued to the owner which must be shown at the time of registration.

Vehicles produced in Sweden or imported by a licensed agent will receive a type approval which provides that purchasers of the vehicle will be given a certificate at the time of sale.

The county administration can call any vehicle, or group of vehicles, in for inspection and if the owner does not appear within a reasonable time the vehicle certificate will be suspended until the vehicle is inspected. Policemen of the county administration are authorized to inspect vehicles at any time or place and withdraw the certificate of any vehicle that is deemed unsafe for operation on the roads.

No information was found describing the methods of testing or levels or performance relating to acceleration, braking, or steering.

Appendix I

REFERENCES

1. Bundesgesetzblatt Fur Die Republik Osterreich, Part 62, Number 267, 1967, pp. 1501-1503, 1516-1525.

2. Braking Regulations for Motor Vechiles, Trailers, and Mopeds; Economic Commission for Europe Inland Transport Committee; W/Trans/WP29/157/Rev. 2 dated May 25, 1967.

3. The Road Traffic Act of 1960, from Halsbury's Statutes of England, Second Ed., Vol. 40, 1960, pp. 762-777.

4. The Motor Vehicles (Construction and Use) Regulations 1966, from Statutory Instruments 1966, part 2, sectionl, Nr. 1098 1471, pp. 3493-3571.

5. Code de la Route, Dalloz; Bulletin Legislatif, Vol. 41, 1958, Articles 106, 107, 108.

6. Ordinance of Aug. 18, 1955, issued by the Ministry of Public Work, Transport, and Tourism of Grance, Articles 2-12, 30 and 31.

7. Strassenverkehrs-Zulassungs-Ordnung, Liegel and Bosselmann, May 1965, Ordnance Nos. 30, 31, 35, 36, and 41, and pages 458-537, published by Kirshbaum Verlag, Bad Godesber, Germany.

8. Road Traffic (Construction, Equipment and Use of Vehicles) Regulations, 1963, Statutory Instrument No. 190, pages 24, 31-43, issued by the Minister for Local Government, Ireland. Available through Government Publications Sales Office, G.P.O. Arcade, Dublin 1, Ireland.

9. Testo Unico Delle Norne Sulla Circolazione Stradala, Lex Legislazione Italiano, 1959, Vol. I, p. 760 ff, Vol. II, p. 1073 ff.

10. Vagtrafikforordning, ordinance issued by the government of Sweden dated Sept. 28, 1951, Part II, sections 3, 14, 15, 22, 23, and 23a.

Appendix II

A LISTING AND EVALUATION OF EXISTING DATA SOURCES

Existing sources of quick-access data relating accident involvement to vehicle characteristics are limited to motor vehicle or comparable departments in about half of the states of the United States. Comparable data are not available from most of the automobile companies. However, the state data are fairly complete and uniform in format so that they constitute a valuable source in terms of consistency in large samples. In 1964, the American Association of Motor Vehicle Administrators conducted a survey of the accident data compiled in the several states, part of which is applicable to the correlation between accident involvement and vehicle type, make and year. The pertinent results are given in Table II-I. This table indicates which states provide quick-access data storage in various forms. Although other states require accident reporting, these data are not readily accessible.

Data recorded on magnetic tape and/or punch cards would be processed in digital computer programs which would generate listings of the numbers of vehicles involved in accidents according to specific program instructions. Because the tapes and cards have different formats and codings, translation programs would be required to implement a correlation program.

It is important to note distinctions between motorist reports and police reports produced in the various states. All states require motorists involved in accidents to submit an accident report, but in some cases the reports are never forwarded to a central records bureau. No more than 20 percent of accidents are reported by police agencies. The police reports are usually more accurate and complete than motorists' reports, and hence, for compiling accident statistics, police reports are favored in several states. Inconsistencies are frequently produced, however, when the states combine motorist and police reports in an attempt to obtain more complete coverage. For the sake of efficiency it is desireable that both types of reports be in the same form. Only in Connecticut, New York, and Oregon are both motorist and police reports on tape. The records produced in Idaho, Montana, Tennessee, Virginia, and Washington contain vehicle-type, make, and year information on punched cards.

TABLE II-I. ACCIDENT DATA (BY STATES) AVAILABLE FOR QUICK ACCESS; VEHICLE TYPE, MAKE, YEAR

	Motorists' Reports		Police Reports	
Tape:	Connecticut(C,F)		California	Kansas(C)
	New York		Colorado(C)	New York
	Oregon		Connecticut(C)	North Dakota
			Iowa(V,C)	Oregon
Punched Cards:	Arizona	Vermont	Alabama	Virginia
	Idaho	Virginia	Idaho	Washington
	Massachusetts(V)	Washinton	Massachusetts(V)	Delaware(F)
	Montana	Wisconsin	Montana	Indiana
	New Jersey(V)	Iowa (V,T)	New Jersey	Michigan
	Ohio(V)	N. Hampshire(M,F)	Ohio	Missouri
	Pennsylvania	Utah(V,F)	Oklahoma	Utah(V)
	Tennessee		Pennsylvania	Hawaii(V,P)
			Tennessee	Maine(P)
			Texas	
Paper File:	Colorado	South Dakota	South Dakota	
	Missouri	West Virginia	West Virginia	
	Rhode Island		Wisconsin	

NOTE:

(V) Vehicle-type data only
(M) Make and year data only
(T) Also on tape
(F) Also on microfilm
(C) Also on punch card
(P) Also on paper file

Appendix III

OBJECTIVE MEASURE (TENTATIVE) OF VEHICLE-HANDLING PROPERTIES

The measures outlined below are applicable primarily to passenger cars. By means of suitable modifications, however, these measures could be made to apply to other vehicle categories. If follows that commercial cargo-carrying vehicles should be loaded to their rated load-carrying capacity in order to establish their full-load test condition. Trunk volume should be interpreted as "enclosed volume available for cargo-carrying purposes" whenever it is intended to apply these measures to the station wagon category. In this instance, it is likely that a different cargo-density factory would be required to determine a representative full-load condition for a wagon in contrast to the factor that would be employed for so-called "trunk" space.

The proposed measures are listed for acceleration, braking, and steering, respectively. Although a measure of braking performance following an energy-absorption process equivalent to maintaining speed on a long downgrade is discussed in the body of the report, this measure of "fade" performance is not included below, since the details of the specific test methodology that would accomplish the desired simulation have not as yet been formulated. It should be noted that this measure must necessarily be formulated to apply, in particular, to evaluating the braking performance of large cargo-carrying vehicles following a descent down a grade.

Finally, it is important to note that these are "new car" performance measures. For example, the tendency of a vehicle to depart from straight-line motion during braking as a result of right/left unbalance in the braking system is, undeniably, an important aspect of braking performance. However, these unbalanced conditions are assumed to derive from degradation processes and thereby represent conditions which, in theory at least, should not exist in the prototype vehicle. Thus for the operating-vehicle population we may postulate a set of performance measures which would include various aspects of behavior that we would exclude in evaluating new-car performance, on the grounds that all components or subsystems should be performing in a non-degraded manner. Where there is reason to believe that quality-control procedures are such as to cause significant scatter in a specific performance measure, this measure should be evaluated on a sample size sufficient to produce a reliable mean and standard deviation.

1.0 ACCELERATION MEASURES

1.1 For Three- and Four-speed Manual Transmissions:

Highest gear

Longitudinal acceleration achieved at 30 + Δ, 40 + Δ, 50 + Δ, and 60 + Δ mph by means of full throttle applied (stepwise) at initial steady velocities of 30, 40, 50, and 60 mph respectively on a level, smooth, dry surface.

(a) For single-passenger capacity (150 lb/passenger), plus trunk space loaded with weights corresponding to trunk volume x cargo-density factor (____lb/ft^3)

Second highest gear

Longitudinal acceleration achieved at 10 + Δ, 20 + Δ, and 30 + Δ mph by means of full throttle applied (stepwise) at initial steady velocities of 10, 20, and 30 mph respectively on a level, smooth, dry surface.

(a) For single-passenger load and zero cargo

(b) For maximum-rated passenger capacity (150 lb/passenger) plus trunk space loaded with weights corresponding to trunk volume x cargo-density factor (____lb/ft^3)

1.2 For Automatic Transmissions:

Longitudinal acceleration achieved at 10 + Δ, 20 + Δ, 30 + Δ, 40 + Δ, 50 + Δ and 60 + Δ mph by means of full throttle applied (stepwise) at initial steady velocities of 10, 20, 30, 40, 50, and 60 mph respectively on a level, smooth, dry surface.

(a) For single-passenger load and zero cargo

(b) For maximum-rated passenger capacity (150 lb/passenger) plus trunk space loaded with weights corresponding to trunk volume x cargo-density factor (____lb/ft^3)

2.0 BRAKING MEASURES

2.1 Deceleration achieved on a smooth, level, dry road (in percent of the friction-coefficient measured on a nonrotating tire which is equivalent to the tires mounted on the test vehicle) at ___percent of the initial speed at which brakes are applied as a function of brake-pedal force, which force is increased (in increments corresponding to ____ percent of the pedal force corresponding to the maximum pedal force that can be applied by the 10th centile woman) until both the front and rear wheels have locked.

(a) For single passenger load and zero cargo

(b) For maximum-rated passenger capacity (150 lb/passenger) plus trunk space loaded with weights corresponding to trunk volume x cargo-density factor (____ lb/ft^3)

(c) For initial, steady veolocites of 80, 70, 50, and 30 mph for vehicles with top speed in excess of 80 mph. For initial velocities of V max, 60, 40, and 30 mph for vehicles whose top speed, V max, falls in the range

$$60 \leq V\ max < 80$$

2.2 The value of braking deceleration at which the rear wheels lock on a dry road surface, for which a test tire will exhibit a locked-wheel friction coefficient of $\mu \geqq 0.7$.

(a) For single-passenger load and zero cargo

(b) For maximum-rated passenger capacity (150 lb/passenger) plus trunk space loaded with weights corresponding to trunk volume x cargo density factor (____ lb/ft^3)

(c) For stops made from an initial velocity of 30 and 60 mph

2.3 The ratio of measured stopping distance to the stopping distance calculated from the steady decelerations achieved at ____ mph as a result of braking forces initiated at the initial speed of 30 mph. The braking input for this test and this calculation should be a pedal displacement which closely approximates a step-function and whose amplitude shall be such as to produce an average deceleration in percent of available friction coefficient equal to 0.4 ($\pm$ 0.05). This test is to be made on a dry clean surface having a locked-wheel friction coefficient $\mu \geqq 0.7$.

3.0 STEERING

3.1 Static path-curvature and lateral-acceleration gain with respect to steering-wheel displacement and steering-wheel torque.

These gains are to be established for steering inputs which do not produce lateral accelerations in excess of 0.3 g. Data should be obtained at a sufficient range of speeds to establish the stability factor, K, and the zero-speed value of path-curvature gain per unit steering-wheel displacement.

(a) For single-passenger load and zero cargo

(b) For maximum-rated passenger capacity (150 lb/passenger) plus trunk space loaded with weights corresponding to trunk volume x cargo-density factor (____ lb/ft^3)

3.2 The amplitude of the hysteresis loop in the yaw velocity response plotted vs. steering-wheel displacement and torque as measured at ____ mph over a range of steering-wheel excursion required to produce 0.15 lateral acceleration in both the right and left directions.

3.3 The ratio of vehicle weight to measured total cornering stiffness of all four tires. Ratio to be computed

(a) For single-passenger load and zero cargo with tires at inflation pressures which exceed the recommended cold inflation pressure settings by 4 pse.

(b) For maximum-rated passenger capacity (150 lb/passenger) plus trunk space loaded with weights corresponding to trunk volume x cargo density factor (____ lb/ft^3)

3.4 Steering-wheel torque versus the lateral acceleration for a vehicle driven around a flat curve of ____ ft. radius at speeds which are slowly increased until the vehicle can no longer maintain the specified curved path.

(a) For single-passenger load and zero cargo

(b) For maximum-rated passenger load (150 lb/passenger) plus trunk load with a weight corresponding to trunk volume x cargo density factor

3.5 The maximum lateral acceleration in g units (ratioed to the friction coefficient measured on an equivalent tire operating at a slip angle above its "stalled" value) which can be maintained by the vehicle in the above test carried out on a flat, dry surface. (This ratio is to be determined in a manner such that driver skill is not introduced as a confounding variable.)

(a) For single-passenger load and zero cargo

(b) For maximum-rated passenger capacity (150 lb/passenger) plus trunk load with a weight corresponding to trunk volume x cargo density factor (____ lb/ft^3)