
M. S. AL-ISA
PH. D

PH. D.

PH. D.

This is to certify that the

dissertation entitled

Developing a Methodology to Predict High Accident Locations on Rural Highways in Saudi Arabia Using Speed Distribution Characteristics

presented by

Muhammad S. Alisa

has been accepted towards fulfillment of the requirements for

Ph.D. degree in Civil Engineering

William C. Taylor
Major professor

Date August 8, 1984

DEVELOPING A METHODOLOGY TO PREDICT HIGH ACCIDENT LOCATIONS ON RURAL HIGHWAYS IN SAUDI ARABIA USING SPEED DISTRIBUTION CHARACTERISTICS

By

Muhammad S. Al-isa

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Civil and Sanitary Engineering

1984

317184X

ABSTRACT

DEVELOPING A METHODOLOGY TO PREDICT HIGH ACCIDENT LOCATIONS ON RURAL HIGHWAYS IN SAUDI ARABIA USING SPEED DISTRIBUTION CHARACTERISTICS

By

Muhammad S. Al-isa

Traffic accidents and highway fatalities are among the major problems confronting Saudi Arabia. The design and implementation of highway-safety programs and practices in the country are in their infant stages. The experience and practices of developed countries, such as the U.S., in the field of highway safety provide a potentially transferable highway safety technology to Saudi Arabia. Highway safety improvement programs, which proved to significantly reduce the number of accidents on U.S. highways, could be expected to accomplish similar results if implemented in Saudi Arabia.

The absence of an adequate accident recording system in Saudi Arabia, which is an essential tool in highway safety programs, necessitates the use of non-accident measures in the identification of hazardous highway locations. This research has studied speed distribution characteristics, among other traffic performance measures, as a possible

surrogate measure for accident potential. Variations in these characteristics observed on Saudi Arabian rural highways were compared with variations in these same parameters reported for locations with known levels of risk on U.S. rural highways. The statistical tests and comparisons verified the suitability of using the speed distribution skewness index as a surrogate measure for hazardous locations on two-lane rural highways in Saudi Arabia.

ACKNOWLEDGMENTS

The author would like to express his sincere appreciation to those who made the completion of this research possible. Special appreciation is extended to my dissertation advisor, Dr. William Taylor, for suggesting this topic and for his continuous advice and encouragement throughout the work. Thanks and gratitude are also due to other members of my guidance committee: Drs. Thomas Maleck, K. Rajendra, Keith Honey, and John B. Kreer. Also, thanks are due to King Faisal University for supporting this research.

TABLE OF CONTENTS

C

AI

CHAPTER		PAGE

LIST OF TABLES

TABLE		PAGE
14	Spot Speed Distribution Characteristics for Tangent Sections with Marginal Friction . .	29
15	Spot Speed Distribution Characteristics on Curves and Their Approaches	91
16	Comparison of Mean Speeds (mph) for the Curve and Its Approach	93
17	Comparison of Standard Deviations for Curves and Their Approaches	94
18	Spot Speed Distribution Characteristics for Curves	96
19	Empirical Speed-Curvature Relationships . .	100
20	Workload Potential Ratings (R_C) of Horizontal Curves	112
21	Spot Speed Distribution Characteristics for Flat Curves	113
22	Modified Spot Speed Distribution Characteristics for Flat Curves Below 2°	116
23	Spot Speed Distribution Characteristics for Sharp Curves	117
24	Spot Speed Distribution Characteristics for Sharp Curves that are Rated Normal	120
25	Speed Distribution Characteristics for Reverse Curves	124
26	Summary of Results	127
27	Normality Test Results Using Kurtosis . . .	131
28	Empirical Skewness Index-Curvature Relationships	132
29	Variation in Mean Speed with Direction of Traffic	136
30	Comparison of Skewness Index for Different Traffic Direction	137

LIST OF FIGURES

FIGURE		PAGE

MAP

MAP		PAGE

CHAPTER 1

INTRODUCTION AND BACKGROUND

In contrast to many developing countries, Saudi Arabia is a rich country. The sudden rise in the national income is producing challenges which are different from those of other developing countries. Saudi Arabia is changing rapidly from a pre-industrial country to a modern industrialized society. This rapid development exerts pressure on all public utilities and facilities, including the transportation system.

The vehicular population reached 2,467,903 by the end of 1981. This is an increase of 1705 percent within the eleven years from 1970 to 1981 (Traffic Statistics, 1981). This expansion in vehicular population was paralleled by the construction of 20,238 km of main roads and 24,186 km of agricultural roads (116), since most of the initial main road networks consisted of single, undivided two-lane roads.

The development and construction of the road network and the significant increase in automobile ownership are accompanied by a high incidence of traffic accidents. As shown in Table 1, in 1982 traffic accidents injured 15,872

Y

1

1

1

1

1

1

1

1

1

1

1

T
S

TABLE 1

NUMBER OF TRAFFIC ACCIDENTS, INJURED AND FATALITIES IN SAUDI ARABIA AT THE END OF EACH YEAR FROM 1972 TO 1982

Year	Number of Vehicle Accidents	Number of People Injured	Number of Deaths
1972	4,147	4,583	570
1973	7,197	6,530	834
1974	9,808	7,901	1,058
1975	10,897	8,771	1,154
1976	13,475	10,532	1,594
1977	15,709	11,606	1,975
1978	15,785	11,413	2,033
1979	18,051	14,824	2,378
1980	17,743	16,832	2,871
1981	18,748	16,218	2,731
1982	17,897	15,872	2,427

SOURCE: Traffic Statistics, General Department of Traffic, Ministry of Interior-Public Security, Kingdom of Saudi Arabia.

persons and killed 2,427 people. This is a relatively high death rate compared to developed countries, such as the U.K. and the U.S.A. (see Fig. 1) (51). As in any other developing country, traffic accidents are among the leading causes of death and crippling injuries.

Highway Safety Practices in Saudi Arabia

Safety experts agree only on the complexity of the problem of transportation safety. The current strategy of transportation safety has been classified into two basic approaches:

1. The preventive engineering approach, where accidents are reduced or minimized by two general methods: (a) countermeasuring highway malfunctions or failure; and (b) considering safe design measures for new highways (127).

2. The human engineering approach, which seeks to discover the limitations of man performing within the complexity of the automotive transportation system. The results of this type of research are then used to redesign the system so that the system fits the needs and capabilities of the road users (106, 114, 115).

In Saudi Arabia, the highway-safety authorities still hold the traditional "violation-error" attitude toward accidents. This is reflected in the traffic statistics book, where accidents are classified by cause rather than by location (see Table 2). Therefore, safety programs are

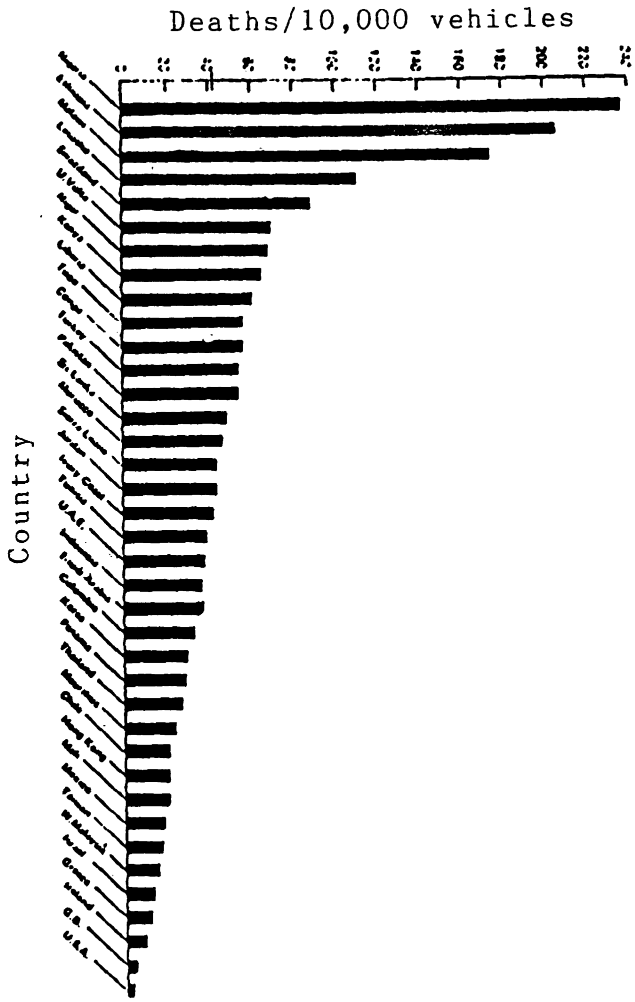


Fig. 1. Fatalities in various developing countries, 1978.

SOURCE: G. D. Jacob and I. Sayer, "Road Accidents in Developing Countries," <u>Accident Analysis and Prevention</u> 15(5) (October 1983):337-69.

TABLE 2

TABLE 2

TRAFFIC ACCIDENTS IN SAUDI ARABIA DURING 1982 BY REGION AND CAUSE

TRAFFIC REGIONS	مجموع TOTAL	اسباب اخرى OTHER	السياقة تحت تأثير مخدر أو مسكر ALCOHOL OR DRUGS	السرعة الزائدة HIGH SPEED	عدم التقيد باشارات المرور TRAFFIC VIOLATION	تجاوز غير نظامي OUTRE-ACH	دوران غير نظامي CIRCU-LATION	توقف غير نظامي STOP	المناطق
RIYADH	10761	537	25	8394	957	467	143	238	الرياض
JEDDAH	3309	401	13	2375	284	91	113	32	جدة
MECCA	1159	368	25	438	99	129	68	32	مكة
MEDINA	1033	478	12	415	43	47	32	6	المدينة
TAIF	2065	261	5	1117	202	332	83	65	الطائف
EASTERN	1161	146	35	692	164	56	45	23	الشرقية
QASEEM	1009	164	29	679	102	28	5	2	القصيم
TABOUK	909	161	2	537	77	43	44	45	تبوك
HA'IL	116	16	1	56	25	8	10	-	حائل
ABHA	652	-	6	548	63	16	12	7	أبها
QURAYYAT	191	48	1	69	33	21	14	5	القريات
ARAR	157	20	-	95	28	5	9	-	عرعر
NAJRAN	297	43	10	125	46	40	20	13	نجران
AL-JOUF	313	29	8	146	89	14	23	4	الجوف
JIZAN	883	111	12	334	219	109	43	55	جيزان
AL-BAHA	269	23	-	148	44	49	5	-	الباحة
TOTAL	24284	2806	184	16168	2475	1455	669	527	المجموع

SOURCE: Traffic Statistics Book, Ministry of Interior-Public Safety, p. 234.

directed toward changing the behavior of violator drivers by imprisonment or fines. On the other hand, preventative measures, such as driver education for the non-accident involved driver and the treatment of design and operational deficiencies in the highway system, are often overlooked.

Recently, in recognition of the safety problems on two-lane, undivided highways, Saudi Arabia has launched a program to build 4,000 km of expressways (70). This undoubtedly will have a positive effect on highway accidents. However, since most of the kingdom's highway network consists of undivided two-lane highways, it is not practical to consider only this extreme approach and not design and/or control hazardous locations on the remainder of the highway system. Work by Jorgensen and Westat (1966) in the U.S. indicated clearly the high benefit-to-cost ratios that could be obtained from "spot" improvements as compared with continuous widening or overall modernization projects (137).

In spite of the complexity of the safety problem, safety measures adopted in Saudi Arabia are often one-dimensional, emphasizing only one aspect of the safety problem: either the driver, or the highway system. The countermeasures adopted in each case are too often extreme, either placing full blame on the driver or adopting the highest design standards and technology for highway improvements. Wallen (132) argues that this is inefficient. Blaming the crash victim does not reduce future accidents,

and it is not possible to rebuild all roadways to the highest current standards.

Instead, the existing and the proposed highway system in the country should continuously be subjected to safety improvements and evaluation. Developed countries such as the U.S. have established highway-safety programs which continuously check and improve hazardous locations on their highway systems. A similar highway safety improvement program is needed to resolve part of the safety problem in the highway system in Saudi Arabia.

Highway Safety Improvement Program

An effective highway safety program in Saudi Arabia needs to apply scientific and quantitative methods to the study of accidents and the selection of countermeasures to improve existing highways. The research and experience in this field from developed countries may be utilized in developing such a system.

Safety-improvement programs have received increased attention in most of the developed countries. Within the past decade, the U.S. federal government and various state highway and transportation agencies have allocated substantial funds for safety improvements of various types (122). Implicit in all these programs is the need for a systematic process for identifying hazardous locations, establishing a method for assigning priorities to the treatment of high-hazard locations which are identified,

and the evaluation of countermeasure safety effectiveness (see Figs. 2 and 3).

The processes currently in use are based on computerized accident record systems. These systems consist of the following elements, which individually or collectively delineate traffic safety problems and are used to rank hazardous locations and develop solutions:

1. accident reporting and accident forms;
2. accident records and data processing;
3. accident location system; and
4. accident classification.

In Saudi Arabia, none of these elements is readily available to the researcher. The accident data are usually collected by police in the form of a descriptive documentation of the accident written in an accident booklet. The information recorded often does not contain the information necessary for accident analysis because it is intended mainly for legal purposes.

Another major drawback of accident records in Saudi Arabia is the absence of a procedure for identifying accident locations on the road network. This is due to the following reasons:

1. the lack of engineering expertise in the local police, which results in the underestimation of the part played by the road environment;

2. the lack of accident recording forms which provide space for this type of information; and

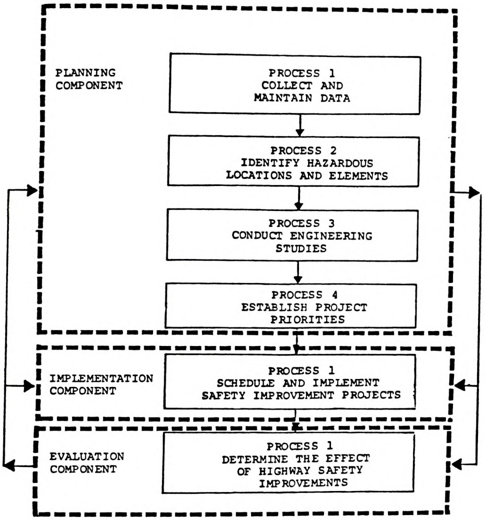


Fig. 2. Highway safety improvement program at the process level.

SOURCE: Goodell-Grivas, Inc., Highway Safety Engineering Studies: Procedural Guide (Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, June 1981), p. 3.

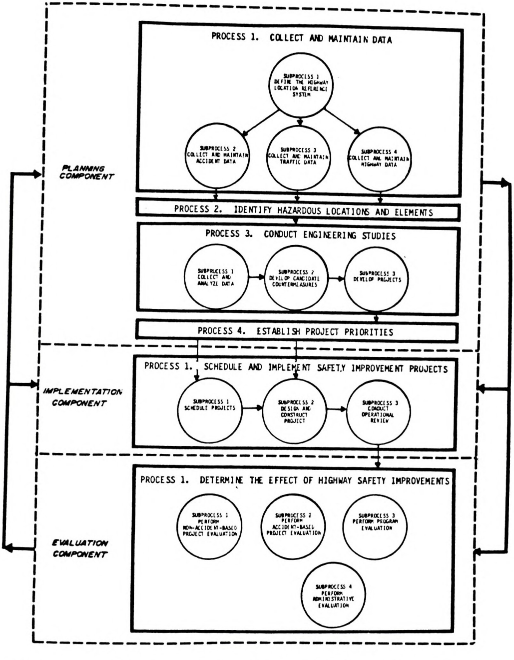


Fig. 3. Highway safety improvement program subprocess.

SOURCE: Goodell-Grivas, Inc., Highway Safety Engineering Studies: Procedural Guide (Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, June 1981), p. 3.

3. the absence of highway records to identify the location of geometric features for use in coding accident locations.

In addition to these deficiencies in accident and highway records, the use of accident records in the development of a highway safety program in Saudi Arabia may be constrained by the following factors:

1. the general official tendency not to release information;

2. the refusal by the people to allow public officials to keep their accident records or any records of their bad conduct;

3. the absence of manpower skilled in accident investigations; and

4. the rapid change in the highway system, which complicates the task of maintaining highway records.

The above discussion points out some constraints that must be overcome in establishing a highway safety program. In addition, a better understanding of the transferability of safety technology developed in the industrial world to developing countries such as Saudi Arabia is essential.

Transferability of Safety Technology

The scientific and quantitative methods of highway safety studies imply the following reasoning:

> If the accident history of a site is found to deviate from the norm for its class, there surely is some reason for it. If so, a

> responsible agency and its professionals should examine the cause for this deviation and if a cost-effective remedy can be found should remove the cause of substandard performance. (44)

Application of this reasoning to developing countries may not be possible because of differences between selected locations in (41, 51):

1. the road users involved;
2. data collection and analysis in various regions;
3. driver behavior;
4. road-user knowledge;
5. traffic-law enforcement practices;
6. vehicle safety measures; and
7. highway engineering practices.

Since the nature of the road safety problem is different in developing countries, Haight suggests that "the lessons to be learned should not be regarded as 'technology transfer.' In fact, many of the 'truths' about traffic safety in developed countries may be untrue in developing countries." For example, Robinson suggests that the application of geometric standards developed for highly motorized countries to low-volume roads in developing countries leads to designs which are uneconomical and technically inappropriate. He also points out that "more research is needed to determine whether geometric design standards have a different influence on road safety in developing countries from that observed in industrial countries" (102). Jacobs and Sayer conclude that "although

1

(

t

n

c

f

h

t

m

o

research findings from developed countries can provide some guidance, the inevitable uncertainties surrounding their transfer to developing countries emphasize the need for caution in their application" (51).

These concerns apply to the situation in Saudi Arabia as well as to any developing country. But while other developing countries suffer from a lack of financial ability to spend on road-safety improvements, Saudi Arabia has the financial ability to adopt the latest tchnology. This is evident from the road network currently under development, where high standards are incorporated in the highways now being built to connect major cities.

However, there are disadvantages to this approach:

1. The geometric standards adopted may have a different influence on road safety in Saudi Arabia from that observed in industrial countries.

2. The low-volume roads and highways connecting non-major cities will not receive sufficient safety consideration, as they are not likely to be upgraded to freeway standards.

3. Accidents which do occur on highways with these high standards will strengthen the traditional attitude that all accidents are due to driver failure.

4. Safety concerns become only part of the modernization projects, rather than being the primary objective.

5. Highway safety may not be institutionalized properly in the official government bodies, but considered only as an offset of the design function.

6. The local agencies will miss the learning experience which results only by local in-depth studies of road layout, vehicle design and road-user behavior.

Therefore, the creation of a highway-safety program in Saudi Arabia requires research to overcome these constraints and verify the suitability of alternative methods and tools. For example, the deficiency of accident records, which is the main tool in highway safety programs, may suggest the use of non-accident measures.

The Use of Non-Accident Measures

Accident history is widely accepted as a primary determinant of hazardous locations. Several methods (144) are now used for identifying hazardous highway spots based on accident histories:

1. number-of-accidents method;

2. accident-rate method;

3. number of equivalent property damage only accidents (EPDO method);

4. equivalent property damage only accident rate (EPDO rate method);

5. rate-quality control method; and

6. various combinations of one or more of the above methods.

Ordinarily, the accident histories of highway locations for certain periods of time (usually three years) are used to screen high-hazard spots on the highway system and to devise cost-effective remedial safety projects. However, the traditional measurements of the various methods have been criticized (44, 70, 92, 96, 117, 122, 128) for the following shortcomings:

1. No agreement has been reached on measures of accident exposure.

2. There are imperfections in rcording accidents.

3. The time period and number of accidents required to obtain statistically significant results are undesirably large.

4. Past accident experience is invalidated with any major changes in the transportation system.

5. The accident histories of locations are subject to random fluctuations, which brings into question the assumption that the number of accidents on a system in the period before treatment is an unbiased estimate of what should be expected to occur on the system during an equivalent "after" period had treatment not been applied.

These shortcomings have brought criticism to safety programs in developed countries (41). Haight stated:

> In developed countries the choice of countermeasures, the design of programs and projects, and administration and final evaluation of these programs are often thought to be on reliable statistical evidence. Unfortunately, the reliability of the evidence is often exaggerated, sometimes grossly (41).

Some researchers, such as Whitelegg (138), propose that researchers and practitioners put road traffic accidents into a wider context of societal development, and use long-term policy objectives as opposed to emphasizing traffic accident performance measures. Other researchers (92, 123) suggest the use of non-accident measures to circumvent the aforementioned shortcomings of accident measures.

This research addresses the possibility of using non-accident measures for ranking hazardous locations and the evaluation of remedial safety projects in Saudi Arabia. A specific research program is proposed to explore the potential of using available non-accident measures.

Research Problem

The determination of reliable non-accident indicators of traffic safety on a given highway section is quite problematic, to date. Among the non-accident measures suggested are various traffic-performance measures.

A traffic-performance measure is defined as any measurable parameter that describes the flow of traffic at a certain point or over a particular section of highway. This category contains all measures that are based on quantifying other traffic characteristics, such as quality of flow. The value of any of these measures depends on the additional knowledge of its quantitative correlation to one of the direct accident measures. Without this correlation,

it cannot be considered a measure of accident potential (42).

Some of the literature (33, 34, 56, 75, 95, 113, 119, 123, 125) reported the following traffic performance measures as potential surrogate safety indicators:

-speed

-speed variance

-speed distribution skewness

-acceleration noise

-headway distribution

-traffic conflicts

-erratic maneuvers

-lateral placement

-brake applications

The basic advantage of these indirect measures over the direct ones is the frequency with which these indirect measures occur, which means a statistically reliable sample can be obtained in a relatively short time interval. But, since conditions prevailing during the short period of measurement are not necessarily representative of the variable conditions over a longer time period, there is no assurance that the measured value will be representative for the longer time period. Therefore, after each design change in existing conditions or for a new highway site, the characteristics of the traffic performance measure have to be determined to check the safety level and evaluate any

improvements.

Among the above transportation performance measures, traffic speed has received the most attention in safety research. It is easily observed and measured with little expertise, and spot-speed distribution characteristics have been found to correlate with hazardous locations.

In Saudi Arabia, speed is the only recognized traffic performance measure identified as a factor in traffic safety (see Table 2). Although speed characteristics are not as stringent a screening device as traffic accidents, the financial ability of Saudi Arabia allows the use of less tight screens than traffic accidents in the safety-improvement programs.

As suggested before, the difference in traffic conditions in Saudi Arabia may alter the nature of safeyt problems from that in developed countries. This implies possible differences in traffic-performance measures, especially the ones pertaining to safety. For example, the differences in traffic enforcement, driver behavior and drivers' knowledge may affect the traffic speed behavior, and thus the traffic speed characteristics.

In this research, a methodology is developed for identifying high accident risk locations on rural Saudi highways. A model is developed based on measured characteristics of traffic speeds and statistical parameters derived from these measurements. Variations in these characteristics observed on Saudi Arabian rural

highways are compared with variations in these same parameters reported for locations with known levels of risk on U.S. rural highways. A statistical comparison is then made to determine the potential of using these parameters to predict high accident locations in Saudi Arabia.

Objectives of this Research

In an effort to develop a surrogate safety measure and demonstrate its potential in the identification of high-hazard locations, this research will consider the following objectives:

1. A review of the literature, to demonstrate the relationship between traffic speed characteristics and safety in the United States. This will include empirical evidence as well as theoretical verification.

2. Development of a general approach that utilizes spot speed characteristics and serves as a guideline for highway safety improvement programs.

3. A study of the suitability of this approach for application in Saudi Arabia.

4. The development of an experimental design for field measurements of traffic speed characteristics on Saudi Arabian highways.

5. An analysis of similarities and differences between the U.S. and Saudi Arabia in traffic speed patterns.

6. A discussion of the potential application of speed characteristics as a surrogate measure for highway safety in Saudi Arabia.

CHAPTER 2

LITERATURE REVIEW AND CONCEPTUALIZATION

The research on traffic flow indices for the detection of high accident potential highway sections and roadway locations has received extensive attention from professionals and academicians. Speed-distribution characteristics are among the driving-performance measures which show the influence of both driver and road conditions (1, 14, 46, 48, 60, 70, 75, 80, 92, 115, 117, 119, 121, 122, 123, 125, 131, 141). The speed distribution skewness measure is of special importance because of its sensitivity and potential to be a surrogate indicator of hazardous locations. This chapter will review the literature, trace the theoretical evidence, and integrate the available facts to build a rational formulation of the suggested relationship between the skewness index and hazard in roadway locations. Finally, it will present an approach for a highway safety program, and discuss its application in Saudi Arabia.

Conceptualization

In the United States, there has been a tendency to overestimate the extent to which speed contributes to traffic accidents. Steward stated that "considerable emphasis is directed today toward fast driving and speeding as a major cause of automobile accidents." He explained that the reasons behind this tendency are:

> a) a knowledge of certain statistics which seems to indicate that speed violations are frequently involved in automobile accidents;
> b) a desire by safety officials and other interested individuals to find a satisfactory and feasible solution for the nationwide problem of accidents. (118)

In the search for a more definitive relationship, several researchers (32, 39, 52, 53, 97, 115) have conducted studies regarding the relation of different characteristics of speed to safety. The findings reported by Solomon indicate the following:

> 1. The accident involvement, injury, and property damage rates were highest at very low speeds, lowest at about the average speed of all traffic, and increased at very high speeds, particularly at night. Thus, the greater the variation in speed of any vehicle from the average speed of all traffic, the greater the chance of being involved.
> 2. The severity of accidents increased as speed increased, especially at speeds exceeding 60 mph.
> 3. The fatality rate was highest at very high speeds and lowest at about the average speed. (115)

Based on the findings of several studies, Warren (134) developed a graphical relationship between accident

invo
(see
dayt
U-sha

absol
strea
conce
speed

speed
achie
of in
concl
have

accid
that
to co
actio

the c
proba
to th
lower
the lo
limit,

involvement rate and deviation from average traffic speed (see Fig. 4). This figure shows the relationship for both daytime and nighttime accident rates in the form of a U-shaped curve.

At that time, accidents appeared to depend less on absolute and more on the variation of speeds in the traffic stream. However, the cited research did not provide conceptual or theoretical explanations underlying the speed-safety relationships.

Marsh and Carson (64) concluded that motor vehicle speed control is an extremely important element in achieving safe and efficient traffic movement. In a review of international speed regulation experiences, Smeed concluded "that the imposition of speed limits seemed to have had a favorable effect" (113).

Wilson (139) also wrote that speed zoning reduces accidents, but he attributed accident reduction to the fact that drivers would be more alert and therefore better able to control their cars to avoid the necessity of emergency actions.

Haur (43) explained the role of speed regulation in the context that on rural roads between intersections, the probability of an accident involvement was closely related to the rate at which overtaking took place. When upper and lower speed limits were imposed, slow drivers traveled at the lower speed limit and fast drivers at the upper speed limit. Consequently, the uniformity of traffic speed would

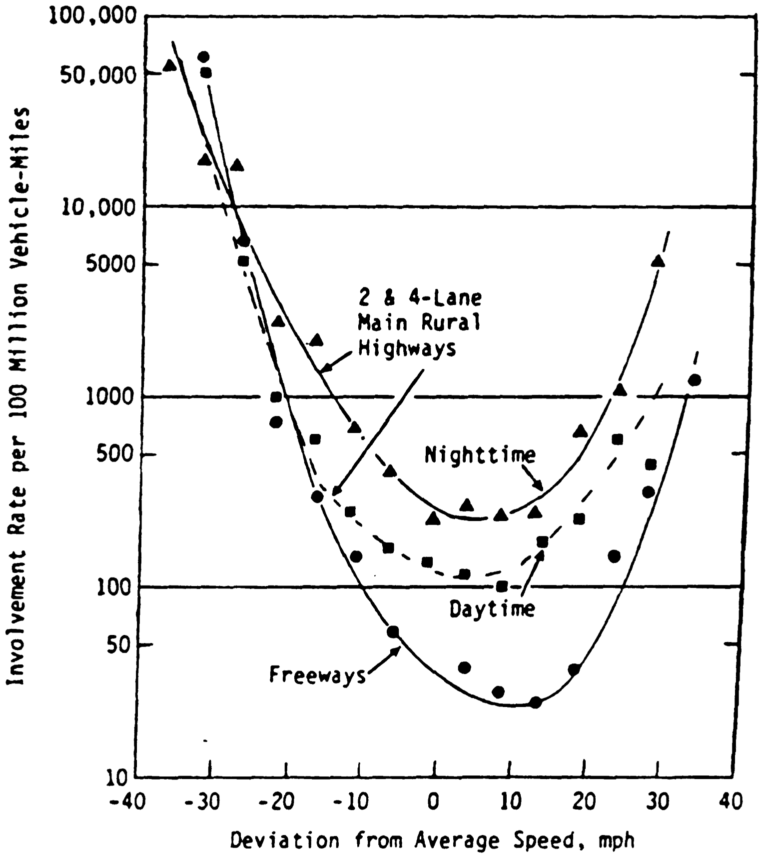


Fig. 4. Accident involvement rate by deviation from average traffic speed.

limi

repo

redu

of h

them

acci

traf

acci

cont

spee

125,

a re

occ

By

jus

is

the

acc

whe

con

the

and

is

and

limit the desire of a driver to overtake. Therefore, as reported by Lam, the greater uniformity of speeds leads to reduced accidents. (58)

The research above presented some logical explanations of how speed zoning reduced accidents, with the general theme that traffic-speed variation was correlated with accidents. However, these studies did not explain how traffic-speed variation took place, nor how it caused accidents.

One of the significant works in speed zoning that contributed to the explanation and verification of a speed-safety relationship was undertaken by Taylor (124, 125, 126). He developed a new theory using the concept that a relationship exists between the rate of accident occurrence and the distribution of speed on rural highways. By studying many Ohio speed zone sites (124), he found that just lowering the higher speeds and raising the lower ones is not sufficient to cause accident reductions, and that the normality of the speed distribution must be taken into account.

His theory is based on the fact that in situations where all drivers are able to determine and evaluate the conditions that exist at that time and at that location, the resulting speed distribution is normal with no skewness and with normal kurtosis. The normality of the distribution is explained by the fact that the driver is a human being and he has to evaluate nontangible associated costs with travel

variat

sectio

inabil

Accord

parame

conclu

r
d

n
r
a

d
i

work o

of haz

explan

approa

108, 1

explan

of the

and th

most i

drivin

strong

This i

traveling, such as comfort, convenience, or service. The variation in the distribution which occurs on certain sections of highway is attributed to various drivers' inability to properly evaluate the same situation. Accordingly, Taylor proposed utilizing speed-distribution parameters to determine unsafe highway sections. The conclusion drawn from this research is as follows:

> -There is a strong relationship between the rate of occurrence of accidents and speed distribution on rural state highways.
>
> -Changing the speed distribution from non-normal to normal results in an accident rate reduction which is twice that found under any other set of "before and after" conditions.
>
> -The best parameter to use in determining non-normality of speed distribution is the skewness of the distribution.

While this research sets the stage for further work on traffic-speed characteristics as surrogate measures of hazardous locations, it does not offer theoretical explanations. The literature on human engineering approaches (7, 19, 24, 27, 28, 29, 30, 36, 57, 63, 73, 100, 108, 109, 132) provides deeper and more comprehensive explanations.

This approach looks upon the three basic components of the transportation system -- the driver, the vehicle, and the environment -- and considers the driver to be the most important part of the highway-traffic system. In the driving situation, the three components are coupled strongly through informational and mechanical links (57). This informational and mechanical flow between the driver, the ve

attrib

r

t

b

I

may be

the af

inters

enviro

indivi

percep

drivin

132).

T
s
f
s
s
h

T

demand

that:

respon

making

T

compre

qualit

the vehicle, and the environment requires the following attributes of the driving tasks (90).

1. Perception (sensing the information)
2. Comprehension (understanding or recognizing the information)
3. Decision (making a decision based upon the information)
4. Action (performing some physical action based on the decision)

In a traffic situation, motor-vehicle accidents may be attributed to a variety of failure modes affecting the aforementioned informational and mechanical intersections linking the driver, the vehicle, and the environment. The three components act collectively or individually to degrade the speed and accuracy of perception, comprehension, decision, and action by placing driving demands beyond the limit the driver can handle (28, 132). Wallen stated that:

> The human error identified in accident causation studies is frequently related to information failure (including recognition error) strongly suggest[ing] that the demands of the driving situation may be more than the driver can handle. (132)

The direct effect of increasing the driving demand is to increase the reaction time. Forbes stated that: "As the complexity of the task increases the required response time also increases. In addition, the chance of making an error increases." (28)

Thus, we see that the time required for perception, comprehension, decision, and action is a very critical quality in highway driving and highway accidents. Forbes expl

how

cri

vol

rel

mor

com

exp

(er

In

anc

gec

po

en

ca

st

a

e

i

explained that in high driving and high accidents it is not how fast the driver is, but how the driver stops that is critical. In addition, he pointed out that the increased volume and pace of traffic and the more efficient and reliable performance of vehicles make driver reaction time more important and more critical (28).

Therefore, it is possible to analyze the various components of the driving task and to measure experimentally the effect of different factors (environment, drivers, and vehicle) on the human reaction. In the case of the roadway environment, the driving demand and thus the reaction time increase with increasing geometric complexity of those highway features perceived as potentially hazardous situations in the driving environment. Versace, recognizing the complex factors causing accidents, used factor-analysis technique in studying roadway and accident data (130). He wrote:

> Only a single factor emerged from a vast amount of data in this analysis which explained where accidents occurred. Although only highway variables were included in the analysis this one factor conveys the psychological.
>
> There are more accidents at those places where the situation places greater demands on the momentary perception-decision motor capacities of the driver.

For further conceptualization, Messer, Mounce, and Brackett, in a recent study, offered a thorough explanation of how a highway geometric failure may influence an accident event. They attribute a failure sit

inc

rel

fol

ah

"e

re

ac

wh

su

th

re

situation to the existence of geometeric design inconsistency, which is defined as

> a change of such magnitude and unexpected nature in the physical dimensions and appearance in the roadway geometry between adjacent sections that unfamiliar or moderately inattentive drivers may be surprised, confused, and misled into making potentially unsafe driving decisions. (76)

The likelihood of inconsistency occurring in relation to the driver's expectancy is explained by the following assumptions:

-Drivers require accurate information about the road ahead to safely control their vehicles.

-Drivers generally "see what they expect to see" and "expect to see" what they have been seeing along their recent driving experiences.

In a study of decision making in a hazardous activity, Cownip found that:

> The subjects tend to adjust their behavior so that their level of risk taking is more or less independent of the severity of hazards they encounter, but their decisions are influenced by their experience of the results of previous decisions, since no other information of the stochastic properties of hazards is accessible to them. (19)

Therefore, when the road ahead disagrees with what is expected, the driver experiences some level of surprise, conflict, and associated uncertainty. The greater the uncertainty, the greater the information required to resolve the uncertainty and the longer the response to wh

un

of

Th

pr

(7

te

dr

ta

a

ha

hi

we

sl

i

p

s

a

d

c

p

whatever situation lies ahead of the driver. Thus, the unexpected geometric design feature may lead to any or all of the following driving-control responses:

1. a design-correct response
2. an incorrect response
3. no response

The last two of these response outcomes would increase the probability of an unsafe driving situation.

Messer and his colleagues Mounce, Brackett, and Wenton (76) operationalized the previous notion and introduced the term of driver workload, which is the time rate at which drivers must perform a given amount of work or driving tasks, based on driver-expectancy considerations and using a subjective rating scale developed for identification of hazardous locations (see Fig. 5). A group of 21 experienced highway-design engineers and research engineers rated the workload associated with several geometric features as shown in Table 3.

The above discussion explains how road geometry may influence the occurrence of accidents. Kontaratos (57) pointed out that their effects come primarily through the sensory pathway reaching the driver, such as visual, auditory, and tactile perceptions. However, the way the driver sees and analyzes the situation ahead of him also can determine the likelihood of an accident occurring. The process of speed perception is defined by Krzeminski as "the awareness of elements of the environment through

DRIVER EXPECTANCY PROBLEMS RATING FORM

Ratings:

0 -- Nothing unexpected or unusual at this location.

Actions required (if any) entirely consistent with criving strategy on approach.

Standard geometry, with pathway(s) for intended movement(s) clearly evident.

No interferences by other traffic likely.

1 --

2 --

3 -- Situation somewhat unexpected.

Driver must be alert, but should be able to respond adequately at "last minute" to most combinations of adverse circumstances.

Some initial confusion on intended path(s) or movement(s).

Interference from other traffic may create some degree of confusion or uncertainty for average driver.

4 --

5 --

6 -- Very unusual situation; will "surprise" many unfamiliar drivers.

Driver required to make major change in driving tactics from those employed over past few miles.

At least a "near accident" almost expected if driver is even moderately inattentive; evasive actions likely to be required.

Intended pathway(s) confusing under fairly normal traffic or lighting conditions.

Other traffic, or lack of it, aggravates situation and misleads driver or deprives him of important cues.

Approach	Rating						
	0	1	2	3	4	5	6
A							
B							

Fig. 5. Driver expectancy problems rating form.

SUMM

tre
lan
lan
ime

TABLE 3

SUMMARY OF GEOMETRIC FEATURE RATINGS FOR AVERAGE CONDITIONS ON VARIOUS CLASSES OF RURAL NON-FREEWAY HIGHWAYS

Geometric Feature	2-lane		4-lane	
	High	Mediocre	Divided	Undivided
• Bridge				
Narrow Width, No Shoulder	5.4	5.4	5.4	5.4
Full Width, No Shoulder	2.5	2.5	2.5	2.5
Full Width, With Shoulders*	1.0	1.0	1.0	1.0
• Divided Highway Transition				
4-lane to 2-lane	—	—	4.0	—
4-lane to 4-lane	—	—	1.8	—
• Lane Drop (4-2 lanes)	—	—	—	3.9
• Intersection				
Unchannelized	3.7	2.8	2.4	2.1
Channelized	3.3	2.5	2.1	2.4
• Railroad Grade Crossing	3.7	3.7	3.7	3.7
• Shoulder Width Change				
Full Drop	3.2	2.4	2.1	2.1
Shoulder Width Reduction	1.6	1.2	1.0	1.0
• Alignment				
Reverse Horizontal Curve	3.1	2.3	2.0	2.0
Horizontal Curve	2.3	1.7	1.5	1.5
Crest Vertical Curve	1.9	1.4	1.2	1.2
• Lane Width Reduction	3.1	2.3	2.0	2.0
• Cross Road Overpass	1.3	1.0	0.8	0.8
• Level Tangent Section*	0.0	0.0	0.0	0.0

*Assumed

NOTE: Ratings of two-lane mediocre road (i.e., surface treatment pavement without paved shoulders) and all four-lane highways usually assumed to equal 0.75 and 0.65 of two-lane high-type highway ratings based on results of Experiment II described in Chapter VI of Volume II.

Value system of ratings described in Fig. 2.

physical sensation" (56). If the driver analyzes the situation properly and makes necessary adjustments in direction and speed, he will properly avoid accidents; if not, he may be "overcommitted" and an accident will result.

The human-engineeering explanation relates the hazardous locations on the highway to the occurrence of accidents. It implies that when drivers traverse or pass through a hazardous location, they will encounter increased driving demands and experience slower reaction times, which affect their driving performance and may result in accidents or hazardous maneuvers.

Therefore, hazardous driving situations, which are partially affected by the roadway environment, may be investigated to uncover hazardous locations. MacDonald (63) reported several experimental measures which can be used to investigate the task of driving demands experienced by drivers. These measures include:

1. subjective estimate of driving-task difficulty;

2. calculation of the complexity of attentional demands of the road-traffic environment, based on observation of "events";

3. indices of drivers' physiological arousal;

4. performance by the drivers of various tasks; and

5. performance of the driving task itself.

In a paper explaining how drivers responded to highway hazards, DeWitt stated that:

s

S

t

r

e

i

s

b

c

a

c

s

> Driver performance measurement rates the combination of decisions the driver makes in determining how and when to make use of manual driving skills as they relate to basic driving knowledge needed to prevent accidents, in spite of adverse conditions and the errors of other drivers. (24)

In a study involving the field evaluation of selected delineation treatments on two-lane rural highways, Stimson and Kittelson explored the relationship between traffic performance and accident probability on two-lane rural highways, based on the general hypothesis that:

> Each of several traffic performance measures and geometric variables could be used to independently predict a portion of the accident potential. The traffic performance measures would indicate the manner in which drivers traverse a given section of roadway, and the geometric variables would in effect define the available factor of safety inherent in the roadway design. Extreme values of traffic performance measures in combination with a limited factor of safety would be expected to result in above average accidents. (119)

This hypothesis summed up the previous explanations in a practical manner which explains the interaction between the driver and the roadway. It suggested that the researcher observe and analyze driver behavior as a means of evaluating adverse roadway conditions. It also adopted an engineering approach to the accident problem by considering failure in the highway design as the starting point of an unsafe situation.

As far as driver behavior in traversing a hazardous section of a roadway, DeWitt quoted Vansodall, a traffic

saf
vel
(24

pa
sa
ha
ad
fi
"a
ne
ve
ma
re
th
wh

dr
Ho
mo
fr
in
di
up
or
a
a

safety specialist, "that you can do two things with a motor vehicle: you can change its speed or change its direction" (24).

Usually, drivers judge speed in part by vision and in part by tactile sensations, and select a reasonable and safe speed for prevailing conditions. Actually, drivers have the ability to make unique and sometimes surprising adjustments (27,36). MacDonald reported that in a detailed field analysis, Curry found that velocity and an "attentional" demand rating of traffic complexity were negatively correlated because drivers typically decrease velocity as traffic complexity increases in an attempt to maintain task demand. Or, as explained by Bakove, the reduction in vehicle speed enables the driver to adjust to the volume of increasing visual information relative to what can be mentally processed effectively (75).

The above behavior is expected from most of the driving population who traverse a hazardous location. However, subjective variations in perceptual abilities, motor skills, and mental disposition prevent all drivers from driving equally well at any one time, or the same individual at different times. Thickry found personality differences associated with either the tendency to "freeze up" when suddenly confronted with a high-stress situation or rise up to an emergency with superior performance. But as a whole, it can be assumed that a driver probably does about as well as can be expected "given the circumstances"

(57

exp

dri

one

tra

ob

Wh

si

di

di

th

wi

sa

sk

hi

re

Co

ve

pa

ar

ap

b

(57, 132). On the other hand, misjudgments of speed are expected from unfamiliar, risk-taking, and inexperienced drivers who fail to evaluate the conditions of the road for one reason or another.

The collective speed perception of all the traffic traveling a certain section of a road can be measured by observing the distribution of individual vehicular speeds. When drivers are able to determine and evaluate the local situation under free-flow conditions, the resulting speed distribution will be normal and show no skewness. The distribution will skew to the left when drivers perceive the area to be more dangerous than it actually is, and it will skew to the right when drivers perceive the area to be safer than it actually is.

This phenomenon of traffic speed distribution skewness, as explained previously, may be used to identify high-hazard locations. This notion was mentioned in a report published by the Minnesota Mining and Manufacturing Company, saying that: "Monitoring the distribution of vehicle speeds to predict accidents is like taking a patient's temperature or blood pressure" (79).

With this background review of empirical verification and theoretical explanation, we can suggest the following approach for a highway safety improvement program, beginning with the identification of hazardous locations.

Approach Framework

The approach presented here is based on findings and practices of previous research, and suits the conditions of Saudi Arabia.

The basic hypothesis of this approach is that speed-distribution skewness can be used to independently predict a portion of the accident potential. The speed distribution would indicate the manner in which drivers travel a given section of a roadway, and the geometric variables would, in effect, define the available factor of safety inherent in the road design. Extreme values of skewness index, in combination with a limited factor of safety, would be expected to result in an above-average accident rate.

A highway safety program based on this concept would consist of the following steps:

Determining suspected locations. Any route chosen for safety inspection would be divided into subsections. From the original roadway design drawings and field observations, suspected high hazard highway locations can be identified using the following information:

1. Any previous accident history taken from police reports, reports from local people, or personal observation or experiences.

2. The reported research findings which correlate accidents with individual design elements (15, 53, 94, 105) (See Table 4).

el

th

cr

th

si

wi

vi

gr

de

fe

lo

di

di

Ha

i

l

s

c

c

m

d

3. The reported research findings regarding the design elements and combination of elements (geometric features) that might lead to violations of driver expectancy and create a geometric design inconsistency (75) (See Table 4).

4. The rating of driver-expectancy tests which measure the readiness of the driver to respond to events, situations, or the presentation of information. The rating will be carried on by a diagnostic expert team who will visit the site. Using a seven-point scale, the diagnostic group (highway design engineers having expertise in highway design, traffic engineering, and human factors) will rate features of the roadway.

<u>Spot-speed studies.</u> At each selected suspected location, a spot-speed study is conducted to obtain a speed distribution for each site.

<u>Statistical analysis.</u> The resultant spot-speed distribution would be checked for skewness.

<u>Classification of safety level of the section.</u> Hazardous or safe sections are designated by the skewness index. Parameters can be compared to the same parameters at locations with known levels of risk to determine the skewness value at which a location is hazardous.

<u>Countermeasures.</u> When extreme values are found to be critical, indicating a safety problem, research is conducted to arrive at the most suitable countermeasures.

<u>Evaluation.</u> Safety improvement of highway geometrics may be evaluated by measuring changes in the speed distribution skewness parameter.

TABLE 4

ROADWAY GEOMETRIC EXPECTANCY FAILURE MODE ANALYSIS BASED ON LITERATURE

GEOMETRIC FEATURE	CRITERIA FOR DESIGN CONSISTENCY			FAILURE		STRATEGIES FOR CORRECTING EXPECTATIONS	
	GENERAL	SPECIFIC		OF EXPECTANCY	CONSEQUENT BEHAVIOR	STRATEGY	RESEARCH QUESTIONS
		FROM ACCIDENTS	FROM PERFORMANCE				
1. HORIZONTAL ALIGNMENT							
Superelevation (e)	Do not use max but vary 0.00-0.06 (89) Flat curves on long fills (89)	Provision of superelevation on flat curves reduced injury accidents 70% (90)	If superelevation = .005 ft/ft/°, curve safe speeds do not change appreciably after curve entered - adjustment made on approach. (77) Superelevation has little effect on operating speeds. (77)	Curve tighter if e too low $\leq$ 0 Curve wider if e too high $\geq$ .10	Understeer and goes to outside Oversteer and goes to inside Brake application and drift	Consistency with similar appearing curves and design speed Upper bound = 0.10	Does perception of e influence entering speed? Lower bound?
Curvature	Compound curves of different radii should be avoided Direct Reverse curves should be avoided Avoid max curvature Sharp curves at end of long tangents or long flat curves should be avoided Short length curves should be avoided (89)	Low freq. of curves associated with increased accident rate (25, 27) Longer radius curves associated with lower accident rates (26) Shorter radius curves (<580') associated with higher accident rates (24)	Geometrics have little to do with driver response. (57) Speeds do not change after entering curve. (77) Drivers position vehicles on center of both 2 - and 4 - lane roads. (91)	If sight distance 400 ft - Curve not consistent with rest of roadway Curve discontinuous Curve reverses Max lat acceleration exceeds (f = 0.12 at 60mph)	Wrong speed on entering - brake/ acceleration in curve Placement incorrect for lanes; an oversteer situation	Provide sight distance 400-600 ft Make curvatures consistent throughout section Radius $\geq$580 ft Number of curves/ unit distance = R	What is minimum with respect to speed? How much can distance (d) and/or e distance vary and still preserve consistency? Variance and number of curves/ unit distance
Transitions	Design to provide proper balance between operating speed on approach and on curve (81)		Adjustment for speed made on approach (77)	Design speed of curve ≠ approach speed Same as curvature	Same as curvature	Provide sight distance Adjust superevaluation (within limits) Traffic control devices	Can driver estimate correct speed in approach? What will work?
2. VERTICAL ALIGNMENT							
Upgrades	AASHTO Design "Heavy Truck" (98) L = KA A = alg. diff. in grades K = design constant Smooth grade lines, gradual changes Avoid sudden changes in grade (89)	Rate of change of grade (>4% change) leads to more accidents (44) Grade no problem on 2 lane or 4 lane undivided roadway (24) No relationship between percent grade and accident (24) Marked relationship between percent grade and accidents (29)	Speed changes occur on steep grades (>6%) (57) Speed changes do not correlate with grade (57)	Grade steeper than perception Shortened sight distance	Slows down - a problem when passing	Traffic control devices Passing lanes on grade Make grades less than 6%	
Downgrade	Same as upgrade	Grades not a problem 2 lanes & 4 lanes undivided (24) Curved downgrade highest accident source - Straight downgrade 3rd lowest accident source (90)	Same as above	Grade steeper than perception	Speed gain Too close following Enter curve at wrong speed affecting placement	Build runaway lanes Traffic control	Estimate of required vehicle speed from grade appearance?
Crest Curves Sag Curves	Same as upgrade Avoid roller coaster and hidden dip effects (89)	Sight distance restrictions associated with higher accident rates than all highway segments considered together (26) Comparative accident rates (30) Tangents - 5.1 Crest - 10.7 Sag - 12.8	On average, drivers position vehicles on center of both 2 and 4 lane roads (91)	Hidden dip (loss of sight distance)	Wrong placement (passing maneuver)	Eliminate by reconstruction Traffic control devices (warning, no passing) Pavement texture enhancement	Thresholds of detection of gradient change?

TABLE 4--continued

GEOMETRIC FEATURE	CRITERIA FOR DESIGN CONSISTENCY			FAILURE		STRATEGIES FOR CORRECTING EXPECTATIONS	
	GENERAL	SPECIFIC: FROM ACCIDENTS	SPECIFIC: FROM PERFORMANCE	OF EXPECTANCY	CONSEQUENT BEHAVIOR	STRATEGY	RESEARCH QUESTIONS
3. INTERSECTIONS AND OTHER DISCONTINUITIES							
Intersections	Intersections should have adequate sight distance (89) Provide greater than minimum sight distance for approaching traffic (81) Separate conflict points 90° cross angle (89)	Accident rates 3 x rates on pure segments (44) Number of intersections per mile highest correlation with accident frequencies (35) Access points good predictor of accident rates at all ADT's (32) Exposure to accidents at intersection is proportional to the product of number of vehicles in merging traffic stream (90) Accident rate increases with increase of conflict mile (35) Access control has most powerful accident reducing effect (44)	Speed changes do not correlate with intersections (57) Approaching a cross traffic point causes a lateral displacement on the pavement (92)*	Sight distance inadequate - no expectation Slow traffic (entering or crossing stream) Class of roadway intersection frequently violated	Abrupt braking Change of pavement position Inappropriate speed	Eliminate intersections by above/below grade crossings Add transition lanes Traffic control devices	Sight distance for intersections?
Merges	Converging Y has low relative design speed, low angle of convergence (89) Drop lanes only at locations with excellent sight distance (89) Points of access and egress located in areas with good sight distances and away from sight - restricting features (10) Create lane drops on better side of roadway Coordinate visual and operational lane drop Provide adequate lane drop escape areas (26) Minor roads should join major roads with T - intersection (81)	Some left hand exit ramps violate expectancy but work OK Accident rate at drops 3 x that of lane adds (90) Increase in accident rates associated with shorter lengths of both acceleration and deceleration lanes (50)		If sight distance inadequate - no expectation Main route not obvious at diverging routes or roadway	Speed inappropriate Brake applications Sudden lane change Loss of time on wrong road	Provide adequate sight distance Minor route T Delineate diverging minor route from major route Traffic control devices Eliminate left side off ramps	What is proper taper dimension envelope? Adequate cues for lane drop?
4. CROSS SECTIONS							
Lane widths	No width changes on Structures (e.g. bridges) (89) Provide adequate sight distance where transitions can't be provided between two sections of different cross sectional design (10) 9-11 ft lane widths narrow depending on volume and truck traffic (89)	Lane width poor predictor of accidents (32) High accident rate correlation with reduced lane width (25, 26) Lane width some correlation with accident frequencies (35) Pavement width not correlated with accident rates (24) Lane width more critical on bridges in wet weather (28) Accident rates on wider 2 lane roads less than on narrow (90) Drivers stayed on center of both 2 and 4 lane roads (91)		Only an expectancy violation if: abrupt transition to different width too narrow to remain in lane	Speed inappropriate Brake application Driver workload increases (tighten dead band)	Provide sight distance and visible transition Wider lanes	Transition visibility?

TABLE 4--continued

GEOMETRIC FEATURE	CRITERIA FOR DESIGN CONSISTENCY: GENERAL	CRITERIA FOR DESIGN CONSISTENCY: SPECIFIC: FROM ACCIDENTS	CRITERIA FOR DESIGN CONSISTENCY: SPECIFIC: FROM PERFORMANCE	FAILURE: OF EXPECTANCY	FAILURE: CONSEQUENT BEHAVIOR	STRATEGIES FOR CORRECTING EXPECTATIONS: STRATEGY	STRATEGIES FOR CORRECTING EXPECTATIONS: RESEARCH QUESTIONS
4. CROSS SECTIONS (continued) Shoulder Widths	Vary depending on type of highway (89)	Narrow shoulder roads had lower accident rates than roads with wide shoulders (90) Shoulder width not good predictor of accidents (32) Small correlation between shoulder width and accidents (35) Positive relationship between shoulder width and accident reduction (38, 37) No relationship or inconclusive relationship between accidents and shoulder width (24, 34) Accident rate decreases as shoulder width increases on horizontal curves (39) The accident rate increases as the shoulder width increases on tangents for selected volumes (41)		Violates expectancy if: Perceived as lane width reduction	Lateral displacement in lane Brake application	Provide below threshold (Gradual) reduction of shoulder width	Threshold of perceived reduction?
Shoulder Slopes	Roadside slopes should be 4 to 1 or less (86)	Steep (4:1) slopes cause driver overreaction and vehicle control problems resulting in accidents (48)					
Roadside Environment	Eliminate roadside structures or make them breakaway Provide guardrails where warranted Protect against abuttments and barriers (89)	Obstacles adjacent to roadways increase fatalities (49, 93)	Objects adjacent to roadway cause lateral displacements which occur as much as 110' prior to the object (92, 94)	Violates expectancy by causing: Perceived lane width narrowing Loss of sight distance	Lateral Displacement Brake application	Clear 30' - 50' sections either side of roadway	Threshold of perceived reduction? Perception of threat of slope or obstacle?
Shoulder Type		Paved shoulders Lower Accident Rate (43)					
Cross-Slope		Flatten the X-slope Higher Accident Rate (35)					
Medians	Put impact attenuators on median barriers Medians should be 2' to 100' wide on highways with 4 or more lanes (89)	Medians tend to decrease the number of accidents (44) Highways with traversible medians-good correlation between crossed median accidents and median width (47)					
Median Openings		Positive correlation between injury accidents and number of openings - 25% of all accidents on rural, non-controlled access, four-lane divided (46)					
General		Number of accidents increase with number of situations presenting a change in conditions necessitating a decision by the driver (32)					

SOURCE: C. J. Messer, J. M. Mounce, and R. Q. Brackett, Highway Geometric Design Consistency Related to Driver Expectancy, Vol. III, "Procedures for Determining Geometric Design Consistency" (Report No. FHWA-RD-81-037).

de
pr
im
ca
pr
hi
mo

us
Or
ne
va
pe
th
Ho
we
b
n
p
s
r
p
h

Application to the Case of Saudi Arabia

As explained previously, it will be necessary to depend on indirect measures to predict highway-safety problems in Saudi Arabia or to evaluate safety improvements, until there are complete records and adequate capabilities to utilize them. The methodology presented provides a simple and fast technique to identify high-hazard locations. The following discussion will offer more reasons for using this methodology in Saudi Arabia.

In reviewing road-network development in Saudi Arabia using a study prepared by the Central Planning Organization, it is discovered that the present road network is built with various design standards and with various construction practices. At the beginning of petroleum production, roads were built by Aramco to follow the terrain and to serve a light volume of traffic. Horizontal and vertical alignments for high-speed traffic were of no major concern. At the same time, the government built a number of roads with various standards which are not in accordance with modern road design and construction procedures. Road geometrics were sub-standard, and pavement strength varied. However, some of the roads were rebuilt or rehabilitated when the government launched its first 5-year program to develop a major network of modern two-lane highways connecting all the centers of population.

Because Saudi Arabia lacked skilled manpower, foreign co

co

ac

Mi

de

ha

re

ar

co

4,

st

l

n

p

h

c

c

s

v

consultants were engaged to design and supervise the construction of a 4,000-km program. The program actually accomplished 8,027 km by mid-1970! By the end of 1970, the Ministry had standardized its methods for selecting and dealing with foreign consultants. Technical experience that has been gained since the early days of the program resulted in the 1971 revision of the general specification and design standards. Since most of the main road network consists of two-lane roads, the need to launch a program of 4,000 km of divided highways and expressways with higher standards of geometric design and safety was apparent (78, 104).

The above discussion reveals that the rural road network in Saudi Arabia has the potential of having problems of inconsistency, because:

1. Even though sections of the old, low-standard roads have been improved, the remaining sections are still in operation and are connected to higher-standard roads.

2. The road network in Saudi Arabia is built with different design standards. The variation in design standards comes from the variation of foreign consultants who practice different design standards than those of other foreign contractors.

3. Some roads are built with inexperienced contractors who rush the job and do not comply with <u>any</u> design standards. Thus, compound geometrics, poor visibility, and lack of transitions are common geometric features on the

tw

su

us

on

in

co

ch

qu

ab

un

s

c

i

t

v

m

i

a

o

t

S

U

i

two-lane rural roads in Saudi Arabia.

4. Finally, the lack of adequate positive guidance, such as warning signs and advisory speeds or the improper use of such signs, increases the problem of inconsistency on the two-lane roads in Saudi Arabia.

Drivers in Saudi Arabia, therefore, face problems of inconsistency in the rural roadway network. They are confronted with two types of inconsistencies: from abrupt changes in design and from various changes in roadway quality. This situation is made worse because of the absence of roadway information, which adds to the uncertainty and brings about unsafe driving situations.

The problem of roadway inconsistency may be substantiated when it is pointed out that non-Saudi drivers constitute approximately one-third the number of drivers involved in traffic accidents (see Table 5). Apparently, they have less experience with the roadway system and the variations in roadway design standards, which makes them more prone to accidents resulting from these inconsistencies. If further analysis could be done on the available accident data, we may find that a major portion of the Saudi drivers who get involved in accidents are traveling outside their familiar residential region.

A solution to the accident prone roadway system of Saudi Arabia needs to be undertaken immediately. In the United States, a very strict screening process is used to identify high-hazard locations, because the U.S. faces

Ye

19

19

19

19

P

TABLE 5

DRIVERS INVOLVED IN ACCIDENTS, BY NATIONALITY

Year	Saudi Drivers	Non-Saudi Drivers
1979	20,765	8,783
1980	17,740	10,531
1981	18,451	11,905
1982	18,096	10,922

SOURCE: Traffic Statistics Book, Ministry of Interior-Public Safety, General Department of Traffic, pp. 251-4.

sev

acc

yea

hig

imp

le

me

pr

es

ca

st

fa

pr

al

b

s

f

t

severe financial limitations. Detailed records are kept of accidents over a period of at least three consecutive years. Then, only those sections of highways with the highest incidence of accidents get money allocated for the implimentation of further safety features. Saudi Arabia has less severe financial limitations; therefore, indirect methodology provides an acceptable alternative to predicting highway safety problems in that country, especially when the paucity of data and lack of skilled capabilities to carry on accident analyses is noted. Speed studies are easy to conduct and analyze, and will facilitate and expedite any highway-safety program.

These conditions encourage the utilization of the proposed methodology. Because of time limitations and absence of adequate local capabilities, this research will be concerned only with the potential application of traffic speed distribution characteristics as a surrogate measure for high-hazard locations in Saudi Arabia. The next step is to design an experiment to explore this potential.

ap
ex
Sa
di
Sa
ex
co
lo
ba
sh
th
sy
t
b
u
r

a
i
t

CHAPTER 3

EXPERIMENTAL DESIGN

To explore the potential of utilizing the proposed approach and to assure the transferability of the U.S. experience of speed distribution and safety relations to Saudi Arabia, it is necessary to discover similarities or differences in the traffic speed behavior between U.S. and Saudi Arabia rural highways. The hypothesis used in the experimental design is that this can be accomplished by conducting spot speed studies on suspected high-hazard locations and classifying them as hazardous or as safe based on the speed distribution. If the speed distribution skewness agrees with the findings in similar situations in the U.S., then the degree of risk reflected by the speed-distribution skewness index may be attributed to the tested section in Saudi Arabia. Similarities in speed behavior and degree of hazard will encourage the utilization of the technique for the evaluation of Saudi rural highways.

This experimental design will be based on the available literature and past experiences. Field investigations and pilot spot speed studies were utilized to identify constraints, limitations, and particular

at
Sa
in
tw

me
st
to
si
Ar
co
t
a

e

b
i
l
p

S
e

attributes in the study area or the study procedures in Saudi Arabia. This experiment, in addition to the field investigations and pilot studies, consists of the following two major tasks:

1. site selection and description; and
2. spot speed studies.

It is important to note that this experiment is not a mere spot speed study; rather, it is conducting a speed study in particular settings and special traffic conditions to develop a sensitive surrogate measure of a hazardous situation. Spot speed studies are a new experience in Saudi Arabia. Therefore, it is necessary to be familiar with constraints, limitations, assumptions, and conditions of the experiment to come up with results that are accurate and reliable.

Constraints and Limitations of the Experiment

The factors that constitute limitations to the experiment are the following constraints:

1. Lack of accident data (especially accident records by location) made it compulsory to use indirect means of identifying sites with potential hazards, such as using the literature on accidents related to roadway geometrics and physical characteristics of the highway.

2. Absence of any spot speed studies and data from Saudi Arabia made it necessary to depend on past experiences from the United States in choosing the sample

dat

sys

mea

stu

wo

sp

lo

th

ac

im

ph

in

He

di

o

h

o

d

i

data.

3. Paucity of engineering information about the road system made it necessary to make extensive field measurements.

4. Time limitations dictated the need for limiting the study area and sample of locations.

5. Shortage of skilled manpower made the researcher work by himself, which increased the time of the study.

Assumptions and Conditions

As explained in the second chapter, the concept of speed-distribution skewness as an indicator of hazardous location is founded on an implicitly rational assumption that some correlation exists between the skewness index and accident experience at a particular location. It also implies that as individual drivers interact with the physical characteristics of the roadway, they make an individual evaluation of the adverse roadway conditions. Hence, the observed spot-speed distribution reflects the drivers' behavior when traversing a hazardous location.

Since this experiment is dealing with a problem of observing and measuring driver behavior when facing a hazardous situation, it is necessary to avoid, eliminate, or control unknown or undesired factors that may influence driver behavior. These factors are many and diverse, and include volume as a major factor influencing speed choice.

Vehicular speeds are controlled to various degrees by th

to

on

vo

av

tw

li

in

wh

b

t

c

n

h

f

t

a

c

c

the traffic stream and by traffic-control devices designed to regulate traffic flows. Volume has a pronounced effect on speed, particularly on two-lane rural highways where volumes as low as 700 vph (high for rural roads) reduce the average spot speed (90). It has also been found that on two-lane rural highways, the average spot speed decreases linearly with the increase in volume (18, 66, 90).

To avoid this effect of volume, the spot speed studies in this study were carried out in free-flow conditions, where drivers are free or virtually free from interference by other vehicles (140). In this way, the speed measured is the speed which reflects the drivers' interpretation of the conditions over the observed locations. The rural road network in the study area, as well as most of the rural highways in Saudi Arabia, carry very light traffic and have free-flow traffic most of the time.

The free speed will then be a function of the drivers, their vehicle characteristics, the highway characteristics, and the environment. To further isolate the highway characteristics from other influences, the factors controlled by the environment, such as light, pavement wetness, visibility, etc. were kept constant for all vehicles.

The absence of any speed control (speed limits, advisory speeds) or speed enforcement gives drivers more freedom to assume a speed which they think suits the prevailing conditions. However, this situation may increase the

a s

as

pre

rea

cha

phy

the

con

pro

ins

rou

whi

spe

sec

App

fol

the variation of individual drivers' speeds as compared to a situation with strict speed control and enforcement, such as in the U.S.

Site Selection and Description

The study sites were chosen using the procedures presented in the prescribed approach. For statistical reasons, at least two highway sections with similar characteristics were selected for each test. Sites whose physical characteristics or previous accident history met the criteria for suspected hazardous locations were considered for the test.

As the last step in selecting a field study site, each prospective site was inspected personally. This field inspection included the following items:

-checking roadway geometrics for consistency over the route

-locating geometrically appropriate subsections at which to observe traffic speed

-marking the locations where the spot speed-distribution studies were to be conducted

-obtaining all pertinent information about the roadway section using the information sheet shown in Fig. 1, Appendix A

The process of locating the study consisted of the following steps.

1. deciding on the general study area;

to
Pr
be
en
ne
vi
ma
in
go
wh

wi
on
be

re

ar

2. choosing the rural network; and

3. selecting the study locations.

Deciding on the General Study Area

Given limited resources and time, this research had to be conducted in one area of the country. The Eastern Province was chosen to be the general area of the study because it is one of the first areas in the country to enjoy a road system (see Map 1). It also features old and new highway facilities. Two-lane roads serve most of the villages and cities in the area. This area attracts many people from other parts of the country and also includes a big foreign labor community, which makes it a good representative of the population of drivers in the whole country.

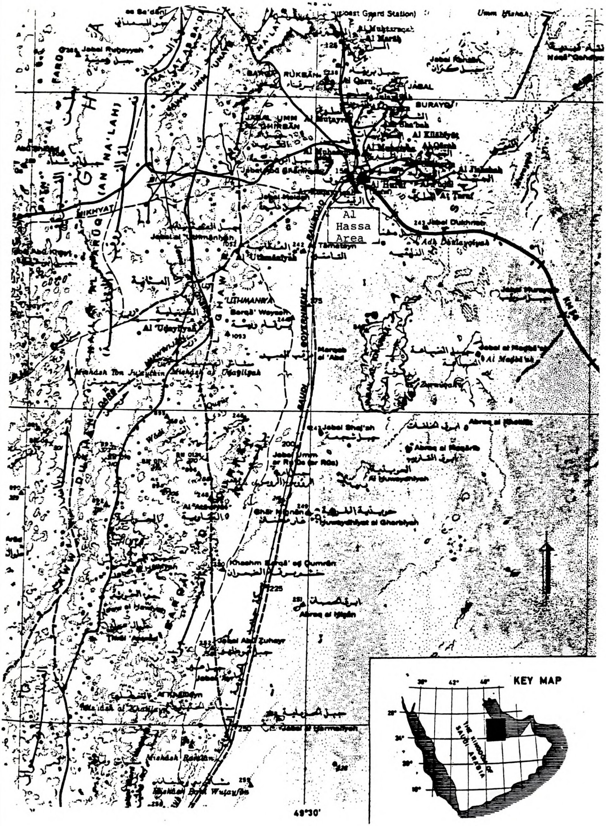
Choosing the Two-Lane Network

After a preliminary field investigation and consulting with the roadway department, it was decided to concentrate on the two-lane network in Alhassa area (see Map 1), because:

1. it carries sufficient traffic to obtain the required sample in a reasonable time;

2. it contains roads with both good and poor design; and

3. it is accessible and familiar to the researcher.



Map 1

loc

obs

con

int

net

loc

of

cho

pos

and

hor

doc

cur

res

res

rat

sha

cur

if

Selecting Study Locations

Rather than identifying potentially hazardous locations using local police information or citizen observations, this research was left to choose among conventional hazardous highway locations, such as curves or intersections (17, 75). Curves on the two-lane rural network were selected as the study population of hazardous locations.

Limiting the study to curves has many advantages, one of which is elimination of any bias coming from subjective choices of potentially hazardous locations. Also, it is possible to compare results in Saudi Arabia with findings and trends in the U.S. This is because the hazard on horizontal curves is empirically and theoretically documented (5, 53, 54, 98, 99). Also, speed behavior on curves is well reported (49, 72, 100).

Potential Hazard of Curves

Curve hazardousness is well documented in the research, both empirically and theoretically, Many researchers (5, 53, 54, 98, 99) have found that accident rates vary with the sharpness of the curvature and that sharp curves have a higher incidence of accidents than flat curves. Moreover, the hazardousness of the curve increases if it is unexpected or associated with other hazardous ele

wit

th

ve

th

si

to

c

s

a

ents. In general, the hazard of the curve increases the increase in curve sharpness (49, 72, 100).

Driver Behavior on Curves

In relation to driver behavior on curves, a study by)epartment of Main Roads, N.S.W. (22) observed that :les generally decelerated through the approach half of :urve, reaching their minimum speed on the departure of the curve center. And while passenger cars tended :celerate through the remainder of the curve, ercial vehicles maintained minimum speed.

As an explanation for this behavior, Ritchie found a ıg inverse relationship between speed and lateral .eration for speeds above 20 mph.

> This means that drivers negotiate a curve and select their speeds according to a velocity lateral acceleration relationship. Therefore, if speed is considered a manifestation of drivers' desire or utility for expedience, lateral acceleration may be viewed as a comfort index or safety criterion. (100)

This behavior was also operationally explained by in, who concluded that:

> a) operating speeds on curves are linearly related
> b) sight distance also affects operating speeds on a curve, but to a lesser extent than curvature
> c) curve super-elevation has no effect on vehicle speeds. (121)

The above discussion on vehicle speed behavior rves conforms with the expected behavior of drivers rsing a hazardous situation. It also shows that speed stribution characteristics may be a suitable check for zardous situations.

Sample of Potentially Hazardous Locations

To explore the general speed behavior of Saudi drivers d to study the trend of skewness index with various grees of hazard, it is necessary to choose a wide ectrum of hazardous situations. Since the hazard reases with the sharpness of the curve, tangent tions, plus a sample of curves with a wide range of ii and several reverse curves, were chosen to provide desired spectrum.

Previous studies of driver behavior on curves used ferent sample sizes of locations. Taragin (121) measured eds of passenger cars at the point of minimum sight tance for the inside and outside lanes of 35 curves on -lane rural roads in the U.S. Emmerson (25) measured eds for 12 curves on two-lane rural roads in England, n curve radii ranging from 21 to 460 m. In a study of measurement of vehicle free speeds, Both (12) selected rural locations. Finally, in a study of using skewed ed distributions to locate points of high accident ential on low-volume, two-lane highways, Krzeminiski ected 12 sites to conduct his study.

In general, if the locations are considered vidually, then the emphasis on the sample of vehicles an

re

va

sh

te

ex

as

va

lo

wi

al

le

or

g

m

t

r

t

i

t

t

s

l the sample of locations would depend on the available sources of the experiment. But if the effect of location riation is to be considered, then the sample of locations uld be 30 and above, depending on the statistical ting to be done and the available resources of the eriment. Since this research is considering the curves separate treatments, but is also interested in the iation of their effects, a sample of 30 or more ations was required.

The sample of locations selected included 61 curves h radii ranging from 120 m to 5000 m. The study sample o included 12 reverse curves. For comparison with s-complex situations, speed studies were also attained 12 tangent sections.

Site Description

The absence of engineering information on local road netrics made it necessary to make extensive field urements to obtain information on the curves. Some of information -- like curve length, cross-section, and side characteristics -- were obtained at the time of study. To obtain the radius or the degree of curvature, as necessary to conduct some surveying using a dolite.

Knowing the curve length, it is possible to determine degree of curvature and thus the curve radius. As n in Fig. 6, the angle may be measured by placing a

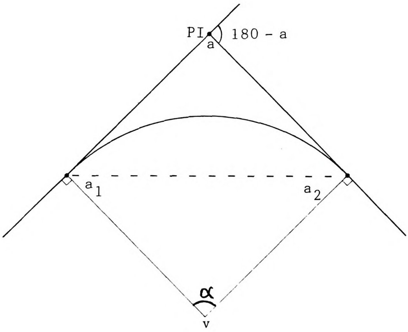


Fig. 6. Measurement of the angle by placing a
dolite on point PI.

th

in

fo

tr

ce

va

fo

su

wh

sp

cu

ev

la

ob

as

ob

lo

eodolite on point PI, which is the point of tangent
tersection.

The intersection angle α may be found using the
lowing equation:

$\alpha = (a_1 + a_2) - 180 = 180 - a.$

Using the arc definition of degree of curve, which has
ditionally been defined as the angle subtended at the
ter of the curve by an arc 100 ft. long, the degree of cur-
ure and the radius may be computed using these equations:

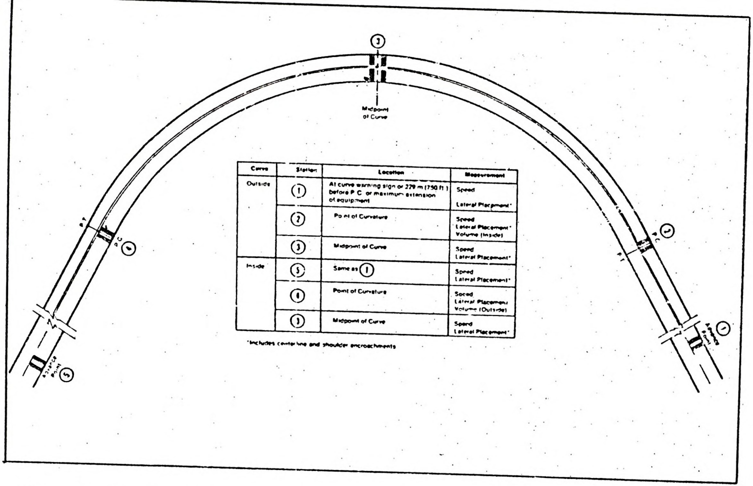
1. $D_a = \frac{\alpha}{100L}$

2. $R = \frac{5729.578}{D_a}$

In Table 14, all geometric information is tabulated
each curve.

Configuration of Monitoring Site

Each study section must contain a particular type of
ection (i.e., test site) a few hundred feet long over
h traffic speed is to be monitored. In this experiment,
d monitoring was conducted at about the midpoint of the
e, which is the prescribed practice in a study of field
uation used in selecting delineation treatments on two-
rural highways (see Fig. 7). For reverse curves, speed
rvations were made at the midpoint between two curves,
rescribed in Fig. 8. In the case of tangents, the
rvation was taken on a flat section in the middle of a
tangent, as prescribed in Fig. 9.

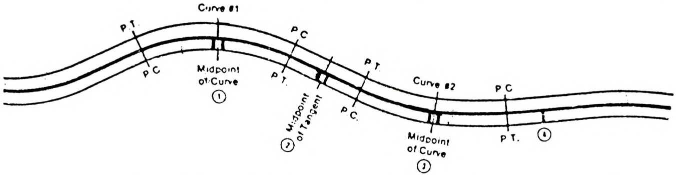


Curve	Station	Location	Measurement
Outside	1	At curve warning sign or 229 m (750 ft) before P.C. or maximum extension of equipment	Speed Lateral Placement*
	2	Point of Curvature	Speed Lateral Placement* Volume (Inside)
	3	Midpoint of Curve	Speed Lateral Placement*
Inside	5	Same as 1	Speed Lateral Placement*
	4	Point of Curvature	Speed Lateral Placement Volume (Outside)
	3	Midpoint of Curve	Speed Lateral Placement*

*Includes centerline and shoulder encroachments

Fig. 7. Configuration of measurement apparatus for horizontal curve.

SOURCE: 119, p. 43.

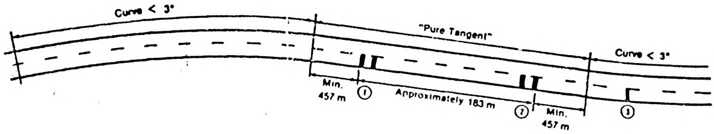


Station	Location	Measurement
1	Midpoint Curve #1	Speed Lateral Placement*
2	Midpoint of Tangent	Speed Lateral Placement*
3	Midpoint Curve #2	Speed Lateral Placement*
4	Any point beyond Station 3	Volume

*Includes centerline and shoulder encroachments.

Fig. 8. Configuration of measurement apparatus for winding situation.

SOURCE: 119, p. 42.



Station	Location	Measurement
1 & 2	Points on tangent section no closer than 457 m (1,500 ft.) from nearest curve	Speed Lateral Placement*
3	Any point beyond Station 2	Volume

*Includes centerline and shoulder encroachments.

Fig. 9. Configurations of measurement apparatus for tangent situation.

SOURCE: 119, p. 41.

Spot Speed Studies

The second major task in this research is conducting
d studies at the selected sites. This part
isted of:

-Pilot speed studies to observe the nature of traffic,
liarize the researcher with the speed-measurement
ce, and identify any peculiar criteria for speed
urement in Saudi Arabia.

-Verifying speed studies. A few sites were chosen to
ure the approach speed along with the speed in the
le of the curve, to verify the assumption that vehicles
erate when they enter the curve.

-Actual speed studies conducted on the selected
tially hazardous curves, along with the reverse curves
angent sections.

Conduct of the Studies

The actual collection of data at the selected
ions was made during a period of four months between
ry 10, 1983 and May 10, 1983. To assure a sufficient
e of vehicles in each location, the speed studies were
cted in the daytime for a period of four hours --
n 9:00 a.m. and 1:00 p.m.

Because drivers are influenced in their choice of
lar speed by many variables (9, 31), it is necessary
e sure that the effects of variables other than

lway characteristics are eliminated or decreased. The
st controlled variables are the environmental variables,
use they are random in nature. However, in this study,
hose not to obtain data when it was raining or dusty,
use adverse weather conditions tend to lower spot speed
. Also, the speed studies were only conducted in the
ime of weekdays, to avoid any possible differences
een weekdays and weekends (90) and to eliminate the
cts of nighttime driving, because low luminance levels
e the driver to travel at slower speeds and to be more
ious (65). Even though the influence of the hour of the
on speed patterns is subject to disagreement, the
ce of morning hours, 9:00 a.m. to 1:00 p.m., eased any
of the influence of this effect, especially when it
eported that speeds are slightly higher around 3:00 to
p.m. than during other hours (18).

The distribution of road-user characteristics is a
ficant variable in this experiment, because the
ved parameter (speed) is a result of the drivers
acting with the roadway characteristics. The variation
eed distribution has been correlated with variations
road-user abilities and characteristics such as age,
residence, trip distance, and experience (40, 90,
In this study, the assumption is made that driver
cteristics are uniform across all samples obtained.
that women do not drive in Saudi Arabia, one of the
variables is eliminated; and there is no reason to

.ieve the remaining characteristics would vary ;nificantly among the sites chosen for data collection.

Another factor which influences speed is the roadway racteristics. In this experiment, the effect of facility e on speed is eliminated, because all sites are located the two-lane rural network (90). In addition, a check made to be sure that the pavement surface of the ected sections was in good condition, because rough ement surfaces require a reduction in speed and cause ed to be influenced by comfort criteria rather than ety criteria (81).

The influence of the motor vehicle on spot-speed acteristics is related to the performance capabilities he vehicle. Generally, motor vehicles can be grouped passenger cars and light trucks, and heavy vehicles 18, 31, 90). Because heavy vehicles' free-flow speed ffected more by the vehicle capabilities (which could be controlled) than the road characteristics (12), it decided to consider speed measurements for passenger and light trucks only.

Because traffic volume is a major factor influencing speed, it received considerable attention in this iment. Free flow traffic speed is the data needed to the hypotheses in this study. Consequently, only le free speeds -- i.e., the speeds adopted by drivers uninfluenced by the presence of other traffic -- were red during the study. In this way, the speed measured

the speed which reflects the driver's interpretation of roadway characteristics. The assessment of whether a icle was traveling at its free speed was a matter of gment by the observer. Consequently, speeds were not orded if there was any doubt whether a vehicle was eling at its free speed.

As for the effects of interaction with other vehicles, as found that moving in platoons caused speed ctions, especially when heavy vehicles move as platoon ers or constitute a high proportion of the traffic am (141). Therefore, to obtain a more representative le of free-flowing vehicles, speed measurement was ded when there were platoons of vehicles or heavy cles in the observed direction or in the opposite lane.

Although speed enforcement is lacking in Saudi Arabia, rivers are not familiar with radar speedometers, it ecided that the observer and the radar meter should be aled in a small passenger car throughout the study.

The accuracy of speed measurements also depends on the r use and operation of the radar meter. For accurate rement, the observer must associate a specific vehicle ing at a specific speed, make a positive fication of the vehicle, and assure minimum effect of vehicles (142, 143). The fact that speed measurement s experiment was conducted by one person eliminates ions due to human factors. More important to the y of speed measurement is the proper location and

rection of the radar. Usually, radar meters measure the eeds of both approaching and receding vehicles. In this eriment, the radar meter was portable and set up inside mall passenger car, so that it was possible to align the trument correctly with respect to the line of travel of vehicles.

Finally, decreasing the variation due to ed-measurement errors was accomplished by selecting an quate size and representative sample. This is discussed the following section.

Sample Requirements

The choice of the sample size to be used in conducting data-collection effort is one of the more important sions to be made in the planning phase of any research.

The exact sample size required in any statistical ysis is dependent upon the size of the interval and the l of confidence which is desired. It is also dependent the particular parameter being estimated.

Walpole and Meyers (133) stated if the sample mean used as an estimate of the population mean, we e $(1-\alpha)$ 100% confident that the error will be less a specified amount e, when the sample size is given

$$= \frac{Z/2\sigma}{e}$$

e Z is a normal random variable with mean zero and ance one and σ is the standard deviation of the lation.

Walpole and Meyers (133) stated that the sample dard deviation "s" can be used as an estimate of the lation standard deviation if the sample size is equal r greater than 30. This sample standard deviation can btained by taking a small set of observations, or it be estimated from past studies. Oppenlander (87) found a standard deviation of 4-5 mph can be used as a "rule humb" in minimum sample size determination, as shown in 6.

Webster and Gruen (136) offered the following ssion for determining the minimum number of vations to predict the properties of a normal ibution by a sampling procedure.

$$N = \frac{V^2 S^2 (S + u^2)}{2d^2}$$

= minimum sample size

= normal deviate to the desired confidence level

= standard deviation of the sample

= normal deviate corresponding to the percentile stimated

= permitted error in the estimate

series of graphic solutions to the above theoretical ns were developed by Oppenlander, Bunte, and Kadakia

TABLE 6

STANDARD DEVIATIONS OF SPOT SPEEDS
FOR SAMPLE SIZE DETERMINATION

ic Area	Highway Type	Average Standard Deviation	Standard Error of Estimate
	Two-Lane	5.31	0.41
	Four-Lane	4.16	0.38

SOURCE: Oppenlander, J. C., "Sample Size Determination
pot Speed Studies at Rural, Intermediate, and Urban
ions," Highway Research Board Record No. 35, 1963,
8-80.

1) (see Appendix A).

Using the "rule of thumb" value for the sample
andard deviation, the minimum size can be determined from
g. A-1 in Appendix A.

for s = 5

and confidence level = 95%

N = 150 vehicles

Past studies on vehicular speeds have shown that a
nple size of 150 vehicles would be an adequate size for
determination of mean spot speed at each study site
, 87). This sample size was based on a desired accuracy
less than 2 mph.

Another approach was used by Shumate and Crowther
0), in which they sampled all vehicles that passed in a
en two-hour period. Both (12) reported that on the most
hly traveled roads, observations for at least two-hour
iods were required to obtain a satisfactory sample, but
less heavily traveled roads a considerably longer period
required.

Given the conditions of low traffic on Saudi rural
ways and the fact that the speed variance on Saudi
ways may be greater than on U.S. highways, it was
ded to increase the sample size to 200 vehicles. A
-hour period was sufficient to obtain the required
le size at all locations, and the sample size exceeded
vehicles at some locations.

Data Collection

Recognizing that measurement techniques may produce a ificant bias in data, the author took all measurements ehicular speeds with the radar meter. When the data ection was completed for several sites, the raw data each site was input into the computer using a -sharing terminal. (The computer facility at King al University was used for this purpose.) By the end of data-collection phase, the raw data for all sites were rded on magnetic tape.

Statistical Analysis

After recording the data on magnetic tape, the data processed using the statistical methods in the SPSS to the following statistics:

$\bar{x}$ = mean value of the spot speed distribution

S = the standard deviation of the distribution

μ_3 = skewness index

μ_4 = kurtosis

The statistical tests are based on the general ption that spot speed distribution characteristics in Arabia are similar to those in the U.S., and more cularly that the spot speeds on a particular roadway ion from which a sample is drawn are normally ibuted. The statistical tests include the following.

Normality of the spot speed distributions are checked Tables F and G of Appendix B (2), which give 0.05 and

l points of the sampling distributions of μ_3 and If a given sample has a value of μ_3 beyond 0.05 point for that statistic, the population may be ned to be non-normal. A more strict test would use 0.01 its.

Those tables are used for any normal distribution uation, but they provide a very strict test of nificance for spot speed distribution normality at ident-prone locations. Krzeminiski, in his study, ermined that the boundary point separating normal from -normal or skewed distributions is a value of Y_1 al to 0.1. Consequently, if the skewness index found for ertain spot speed distribution is greater than 0.1, then distribution is deemed to be non-normal.

Similarities and differences in spot speed ribution characteristics between Saudi Arabia and the are explored by comparing the statistics found in i Arabia with the ones in the U.S.

Trends in speed behavior on curves, and also trends in ness index with curvature degree, are explored using ession analysis.

For comparison purposes, the Gosset "student-t" ribution was used to check any significant differences.

CHAPTER 4

DATA ANALYSIS

The review of the literature has established onclusively that curves on two-lane rural roads have a gher accident potential than tangent sections. Based on eeds observed in Saudi Arabia, there is no reason to pect a different pattern in this study. The main purpose this analysis is to find out whether the skewness index the speed distributions on curved sections reflects the ticipated hazard.

Since the ultimate goal of this study is to determine the skewness index can be used as a predictive tool thin a general highway safety program for Saudi Arabia, is necessary not only to verify the transferability of e hazard surrogate measure, but also to establish its nitations, strengths, and weaknesses.

Spot speed studies were conducted on a wide spectrum situations, ranging from least hazardous (tangent tions) to most hazardous (reverse curves), to obtain a for the following analyses:

-analysis of the speed-distribution characteristics to

dentify similarities and differences between driving ehavior in Saudi Arabia and driving behavior in the U.S.

-verification of the skewness index as a surrogate easure for hazardous locations in Saudi Arabia.

-exploration of any variational or trend haracteristics of the skewness index to establish imitations and criteria for its use.

Statistical Results

The speed data were processed in the computer using ne statistical methods in the SPSS to obtain the following peed-distribution parameters.

$\bar{x}$ = mean value of speed distribution

s = standard deviation of the speed distribution

μ_3 = skewness index

μ_4 = kurtosis

Normality Tests

The normality of a distribution is used not as a ntinuous variable, but as a classification variable. The o classes are normal and non-normal (skewed) as termined at the 0.05 percent level of analysis of the efficient of skewness. The skewness-index value for each eed distribution was checked against the 0.05 percent gnificance limits as shown in Appendix B (Table F).

For comparison purposes, normality of the speed stribution was also determined at the 0.05 percent level

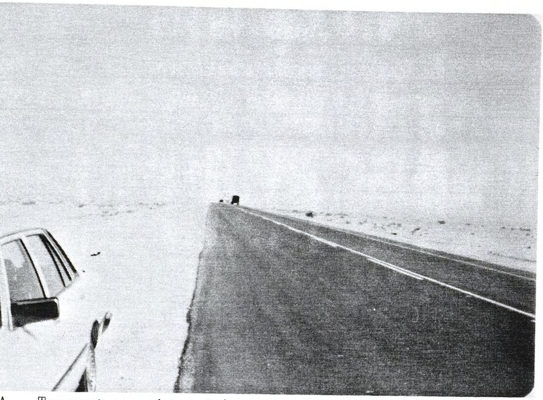
by the analysis of the coefficient of kurtosis, as prescribed in Appendix B (Table G).

Speed and Speed Distribution Characteristics

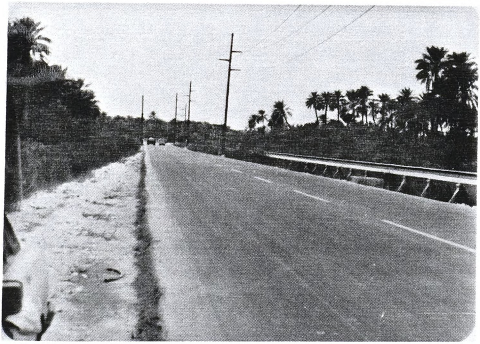
One hypothesis in this research is that drivers in Saudi Arabia are similar to drivers in the U.S. However, the absence of speed control (speed limits, speed zoning, advisory speeds, and speed enforcement), and the lack of positive guidance in the traffic operation on two-lane rural roads in Saudi Arabia, suggest that traffic-stream characteristics including the spot speed distribution may possess some differences and variations from similar spot speed distributions in the U.S. Therefore, it is necessary to identify these differences (if any) and study their possible effects on the use of the skewness index.

Tangent sections with minimum marginal friction were chosen to observe the Saudi driver's behavior under roadway conditions where the physical characteristics (road geometrics, roadside development) as displayed in Fig. 10-A impose no perceptual difficulties. The parameters of the spot speed distribution for five straight and level tangent sections with paved shoulders, minimum off-road objects, and adequate lateral clearance are tabulated in Table 7.

For the mean speeds, Saudi drivers are shown to approach an overall average speed of 62 mph on two-lane tangent sections, as compared to an overall average of 53 mph reported in Table 8 for U.S. drivers.



A. Tangent section without marginal friction.



. Tangent section with marginal friction.

ig. 10. Roadside development conditions.

TABLE 7

SPOT SPEED DISTRIBUTION CHARACTERISTICS
FOR TANGENT SECTIONS WITH
MINIMUM MARGINAL FRICTION

e	Mean mph $\bar{x}$	Standard Deviation s	Kurtosis	Skewness Index	Normality Test
	60	9	0.210	-0.179	Normal
	64	11	-0.004	0.496	Skewed
	64	12	-0.517	0.517	Skewed
	61	10	-0.154	0.685	Skewed
	60	9	-0.277	0.305	Skewed

Overall Average Mean Speed = 62 mph

Overall Average Standard Deviation = 10.20

TABLE 8

SPEED DATA FOR TANGENT SECTIONS
ON TWO-LANE RURAL HIGHWAYS

Site Number	Speed Limit (mph)	Mean Speed (mph)			
		Day		Night	
		Upstream Station 1	Downstream Station 2	Upstream Station 1	Downstream Station 2
A 56	55	49.2	49.8	50.6	51.2
A 32	55	55.5	55.2	56.3	56.6
LA 7	55	57.5	57.4	56.9	56.9
A 50	40	47.6	46.3	52.6	51.1
A 29	55	54.9	54.4	56.7	55.5
D 60	50	51.3	51.0	52.4	52.6
A 13	55	56.7	55.8	57.2	57.8
A 16	55	56.9	56.6	57.3	57.1
106	50	47.9	48.2	48.3	46.6
A 25	55	55.9	55.0	56.1	55.1
T 19	55	49.6	49.0	49.8	43.7
T 30	55	52.4	52.6	53.5	53.5
		Speed Variance $(mph)^2$			
56	55	72.0	72.3	72.5	68.1
32	55	65.7	81.0	100.6	92.5
A 7	55	77.8	81.1	93.5	103.7
50	40	61.5	69.6	57.0	56.3
29	55	60.7	55.3	68.1	77.5
60	50	98.9	90.0	112.2	96.4
13	55	59.5	62.0	52.7	51.5
16	55	47.6	47.1	65.4	65.6
06	50	77.5	74.8	55.8	39.7
25	55	41.5	51.3	45.0	59.5
19	55	59.6	57.4	53.2	57.8
30	55	57.0	59.2	63.5	64.7

OURCE: W. H. Stimpson, H. W. McGee, and W. K.
son, "Field Evaluation of Selected Delineation
ents on Two-Lane Rural Highways: Final Report"
ngton, D.C.: U.S. Department of Transportation,
l Highway Administration, October 1977), p. 206.

For speed variation around the mean, the speed distribution registered an overall average standard deviation of 10.20, as compared to an overall average standard deviation of 8.09 for tangent sections on two-lane rural highways in the U.S., obtained from Table 8 (119). This relatively high average speed and standard deviation underline an excessive speeding habit for many Saudi drivers.

This excessive speeding habit is better displayed in Table 9, which indicates that on the average about 87 percent of Saudi drivers exceed 50 mph, and about 50 percent of them exceed 60 mph, as compared to 75 percent exceeding 50 mph and 36 percent exceeding 60 mph reported for drivers in the U.S. (135).

Speeding on two-lane rural roads in Saudi Arabia was reported in 67 percent of all the accidents which took place in the country during 1980 (see Table 2). Although the report probably overemphasized speed as an accident cause, it still reflects a long-time observation of aggressive driving and excessive speeding of many drivers in Saudi Arabia.

In explanation of the excessive speeding problem on the two-lane rural roads, Knell (55) reported that on two-lane carriageways or motorways in the United Kingdom, drivers are inclined to take greater risks, and usually exceed speed limits despite the risk of fines. The absence of speed control, which is known to have a marked effect in

TABLE 9

PERCENTAGE OF VEHICLES (PASSENGER CARS AND LIGHT VEHICLES) EXCEEDING 50 MPH AND 60 MPH

Site No.	Percentage of Vehicles Exceeding 50 mph	Percentage of Vehicles Exceeding 60 mph
50	90.00%	59.00%
52	85.50%	56.00%
46	88.70%	46.90%
82	82.70%	44.40%
83	87.80%	45.30%

reducing extreme and average speeds and consequently decreasing the variation around the mean (50, 64, 112), makes the situation on the two-lane rural roads of Saudi Arabia worse. Without enforcement, aggressive drivers are left free to decide their own speed, which is most often higher than the safe speed.

The fact that men constitute the total driving population in Saudi Arabia, and young drivers form the highest proportion of that population, may also partially explain the problem of excessive speeding. Higher speeds and higher-risk driving have been associated with men and young drivers (90).

Moreover, the survey published by The Ministry of Transportation (see Table 10) indicates that new cars (which are increasingly imported to the country) constitute the highest portion of the vehicle population. These cars are driven faster than older ones because they ride more comfortably, travel more smoothly and quietly, handle better, and are generally in better mechanical condition (90) than the older cars.

At the same time, the driver population in Saudi Arabia also contains some excessively slow drivers, as evidenced by the observed wide range of speeds shown in Table 11. The average minimum speed at the five tangent sections was 38 mph, as compared to an average maximum speed of 90 mph at the same locations.

This problem may be attributed to the fact that each

TABLE 10

VEHICLE AGE DISTRIBUTION

Average age of vehicle (year)	Percentage of vehicles							
	Private passenger car	Taxi	Pick-up	Bus	2-axle truck	3-axle truck	Truck-trailer	Tractor-semi-trailer
0 - 2	38.6	13.6	57.6	21.7	19.6	48.0	17.2	36.8
3 - 4	15.3	23.0	14.3	3.8	13.4	26.6	10.3	17.9
5 - 7	24.8	45.2	11.0	12.8	35.1	21.5	25.1	22.8
8 - 10	14.2	11.6	11.6	40.8	21.7	2.1	17.2	9.5
11 - 15	4.7	5.8	3.5	18.3	6.2	0.9	17.2	4.3
> 15	2.4	0.8	2.0	2.6	4.0	0.9	13.0	8.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Average age	4.9	5.7	3.8	7.5	6.4	3.4	8.8	5.5

SOURCE: National Transportation Survey, Volume 11L: "Roads and Road Transport" (Kingdom of Saudi Arabia, Central Planning Organization, 1975), pp. 5-14.

TABLE 11

OBSERVED SPEED RANGES ON TANGENT SECTIONS
ON TWO-LANE ROADS IN SAUDI ARABIA

Site No.	Speed Range
46	34 ——— 80
50	38 ——— 97
52	39 ——— 99
82	43 ——— 90
83	40 ——— 85

year many new drivers, with little training and short driving experience, are licensed (see Table 12). Those inexperienced drivers often drive cautiously and maintain their cars at very low speeds (90). The lack of speed limits, which are reported to bring lower speeds closer to the mean (56), contributes to this wide variation in speed.

In summary, the absence of speed control, combined with certain driver and vehicle characteristics in Saudi Arabia, partially explain the high incidence of excessive speeding. However, the same combination of factors on U.S. highways would probably not result in the same speed distribution, as the higher speeds stem also from the aggressive driving attitudes of many Saudi Arabian drivers.

The lack of adequate driver education and the absence of stringent licensing tests allow many inexperienced drivers to drive in the roadway system. These drivers often travel at excessively low speeds. Therefore, the spot speed distributions in Saudi Arabia would feature relatively higher means and standard deviations than similar speed distributions in the U.S. The distribution often contains extreme high and low speeds on one or both ends, which increase the variance, the skewness, and the kurtosis.

Normality of Spot Speed Distributions on Tangent Sections

The distribution of individual speeds for all drivers on tangent highway sections was found to be normal in the U.S. (55). However, the normality test in Table 7 shows

TABLE 12

INDEX OF DRIVING LICENSES ISSUED IN SAUDI ARABIA
DURING THE YEARS 1972-1982 ACCORDING TO TYPE

TYPE \ YEARS	1982		1981		1980		1979		1978		1977		1976		1975		1974		1973		1972	
	Index	No.	Index	No	Index	No	Index	No	Index	No	Index	No	Index	No	Index	No	Index	No	Index	No	Index	No
PRIVATE	514	123662	718	172818	849	204321	925	222685	620	149166	436	104959	371	89238	217	52322	170	40868	109	26203	100	24064
PUBLIC	383	23320	538	32835	582	35476	544	33203	374	22765	179	10869	128	7802	72	4390	81	4938	92	5617	100	6093
MECHA – NICAL	180	2490	13	174	98	1356	93	1288	133	1837	149	2063	124	1718	87	1199	102	1403	111	1538	100	1385
MOTOR – CYCLES	-	698	–	722	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
TOTAL	476	150178	655	206549	765	241153	815	257176	551	173788	374	117911	313	98758	184	57911	150	47209	106	33358	100	31542

INDEX No. 1391 _ 100 ١٠٠ - ١٣٩١

SOURCE: Traffic Statistics During 11 Years (Ministry of Interior-Public Security, General Department of Traffic, Kingdom of Saudi Arabia), p. 55.

that all but one of the speed distributions are skewed. In the U.S., this would indicate that drivers faced some perceptual difficulties, and thus the site was potentially hazardous. In theory, the higher average speed and standard deviation observed in Saudi Arabia should not change the shape of the speed distribution from normal to non-normal. However, since the coefficient of skewness measures the second moment about the mean, a few drivers who drive with excessive speeds would lead to a distortion of this index (2):

$$\mu_3 = \frac{m_3^{\;2}}{m_2} = \frac{E(x - \bar{x})^3}{E(x - \bar{x})^2} = \text{skewness index}$$

To reduce the effect of those few drivers with extreme speeds, the speeds at both ends of the speed distributions shown in Table 7 were eliminated by only considering speeds within two standard deviations of the mean ($\bar{x} \pm 2\sigma$). With this data modification, the results were as shown in Table 13, and the skewness indexes registered the expected normal speed distribution for all the tangent sections except one. This modification had little effect on the shape of the distribution, as shown in Appendix C.

In addition to the spot speed observations on tangent sections of highway with no roadside interference, another group of tangent sections with more marginal friction on both roadsides (unpaved shoulders, slopes, ditches, and

TABLE 13

RESULTS OF THE MODIFIED SPOT SPEED DISTRIBUTION CHARACTERISTICS FOR TANGENT SECTIONS

Site No.	Mean mph	Standard Deviation	Kurtosis	Skewness Test	Normality Test
46	60	7.435	0.311	-0.154	Normal
50	63	9.779	0.635	0.227	Normal
52	63	10.482	-0.620	0.280	Normal
82	59	8.744	0.418	0.658	Skewed
83	59	7.993	0.671	0.129	Normal

Overall average speed = 61 mph

Overall average standard deviation = 8.89

less lateral clearance, as displayed in Fig. 10-B) were selected and spot speed data obtained. As shown in Table 14, the presence of roadside friction resulted in a speed distribution with both a lower mean speed and less speed variation. Consequently, the skewness indexes indicate a normal speed distribution for all these tangent sections with no modification of the raw data. Since this level of roadside development is commonly found in the United States, this result tends to verify the relationship between sites with relatively low hazard and a non-skewed speed distribution.

The skewness index is very sensitive to traffic operational characteristics as well as to the physical conditions of the roadway (125, 126). This sensitivity may lead to unrealistic results because of the complexity of the factors influencing spot speed characteristics. In the absence of speed control measures in Saudi Arabia, the variables influencing speed choices increase and are even more complex than in the U.S. Human factors, which are more complex and random in nature than the physical factors, assume a more significant role in speed choices.

Even with the Saudi attitudes of aggressive driving, the lack of speed control, and different driver and vehicle characteristics, the drivers' speed behavior on tangent sections with some side friction proved to be normal, which is similar to the drivers' behavior in the U.S. Where there is no side friction to restrict very fast drivers, when

TABLE 14

SPOT SPEED DISTRIBUTION CHARACTERISTICS FOR TANGENT SECTIONS WITH MARGINAL FRICTION

ite No.	Mean mph	Standard Deviation	Kurtosis	Skewness Test	Normality Test
5	51	8.364	-0.312	0.133	Normal
3	54	9.447	-0.187	0.193	Normal
6	46	7.565	-0.435	0.227	Normal
8	53	6.29	-0.230	0.062	Normal
5	47	7.619	-0.297	0.130	Normal
6	47	7.233	-0.823	0.204	Normal

Overall average speed = 50 m.p.h.

Overall average standard deviation = 7.75

eeds which exceeded two standard deviations beyond the an were eliminated, the skewness indexes registered rmal.

This conclusion sets the stage for testing the pothesis that speed-distribution characteristics can be ed to identify operational deficiencies and thus zardous situations.

Speed Behavior When Negotiating Curves

Since spot speeds are to be observed only at the nter of the horizontal curve, it is necessary to termine whether driver behavior when traversing a curve similar in the United States and Saudi Arabia. In the S., when traversing a horizontal curve, drivers celerate to a constant speed, then accelerate when erging from the curve. This speed behavior is a measure the interaction of the individual drivers with the anging roadway conditions (46).

This behavior was checked by observing speeds on eight ves and their respective approaches, the results of ch are shown in Table 15. On tangent open sections of a d, a driver's choice of free speed is determined by his ired speed and vehicle capability. However, on curves, speed is limited by the road geometry, a restriction h applies to all drivers. Therfore, the mean and dard deviation of the speed distribution on the curve d be expected to be less than on tangent sections.

TABLE 15

SPOT SPEED DISTRIBUTION CHARACTERISTICS ON CURVES AND THEIR APPROACHES

Approach		Curve	
Mean mph	Standard Deviation	Mean mph	Standard Deviation
44	6.719	43	5.697
46	8.835	45	6.261
41	7.698	37	7.0741
45	6.447	39	5.730
46	8.165	41	6.511
51	8.364	33	5.608
53	6.290	34	4.318
47	7.619	41	6.511

When comparing the parameters of mean speeds and tandard deviations of the curves and their approaches sing the Gosset "student" distribution, as shown in Tables 6 and 17, the differences proved to be significant. This eans that drivers, when confronted with a curve, changed heir speed to suit the new conditions, and they also drove loser to the mean.

The fact that the speed changes when moving from a angent section to a curve section verifies the assumption iat the speed the driver assumes on the road is related to is expectancy. Drivers select a reasonable and safe speed or prevailing conditions, and change this speed when the pectancy is altered.

The observation that there is a lower standard viation means that the geometric complexity of the curve, ich is more restrictive than the tangent section, has fluenced all drivers to drive slower and closer to the an. This tends to eliminate extreme speeds, and speeds ken at the center of the curve may not require dification before testing the skewness index. The ysical conditions of the curve rather than the driver aracteristics determine the speed of traffic.

It is a common observation that drivers slow down when ey encounter a horizontal curve on a rural highway (121). e extent to which they slow down appears to be related imarily to the degree of curvature. Taragin (121) ported an average speed change of 0.7 mph for each

TABLE 16

COMPARISON OF MEAN SPEEDS (MPH) FOR THE CURVE AND ITS APPROACH

Approach Mean	Curve Mean	Difference
44	43	1
46	45	1
41	37	4
45	39	6
46	41	5
51	33	18
53	34	19
47	41	6

$\mu = 0$

$\mu \neq 0$

$x_i - \bar{x}$	$(x_i - \bar{x})^2$
-6.5	42.25
-6.5	42.25
-3.5	12.25
-1.5	2.25
-2.5	6.25
10.5	110.25
11.5	132.25
-1.5	2.25
	350

$$S = \frac{350}{7} = 7.07$$

$$t = \frac{7.50 - 0}{7.07} \sqrt{8} = 3.00$$

$$t_{0.05} = 2.365 \ F_0$$

D.F = 7

$$t = 3.0 > t_{0.05} = 2.365$$

7.50

reject the null hypothesis

TABLE 17

COMPARISON OF STANDARD DEVIATIONS
FOR CURVES AND THEIR APPROACHES

Approach Standard Deviation	Curve Standard Deviation	Difference
6.719	5.697	1.02
8.835	6.261	2.57
7.698	7.074	0.62
6.447	6.730	0.75
8.165	6.511	1.67
8.364	5.608	2.76
6.290	4.318	1.97
7.619	6.511	1.11

$\Delta = 0$

$\Delta \neq 0$

$x_i - \bar{x}$	$(x_i - \bar{x})^2$
-0.54	0.29
1.01	1.02
-0.94	0.88
-0.81	0.66
0.11	0.01
1.20	1.44
0.41	0.17
-0.45	0.20
	4.67

$S = \frac{4.67}{7} = 0.82$

$t = \frac{1.56 - 0}{0.82} \sqrt{8} = 5.38$

$t_{0.05} = 2.365 \ F_m D \qquad F = 7$

$t = 5.38 > t_{0.05} = 2.365$

1.56

reject the null hypothesis

ree change in curvature. This implies that the tighter urve, the greater will be the influence of road try on drivers' choice of speed. That is obvious when ean speed and standard deviations of the individual distributions for the curve sections in Table 18 are ssed with the radius of the curves and their degrees rvature. (See Appendix E.)

For the mean speed, the curvature radius produced stically significant effects at a significance level < 0.05. This equation shows the speed increases as adius increases.

$$\bar{v} = 36.67 + 0.0023R$$

$$r^2 = 0.57650$$

$\bar{v}$ = mean speed (mph)

R = Radius (feet)

r^2 = proportion of variance of the independent variable explained by the regression

The same trend found in this study is supported by the ical speed curvature relationship reported by McLean in Table 19, which shows the 90th percentile speed, percentile speed, and median speed as curve radius ses.

sing the radius as the measure of the curve, Fig. 11 ys graphically the relationship between the mean and curvature radius, which is comparable with the

SPOT SPEED DISTRIBUTION CHARACTERISTICS FOR CURVES

Site No.	Radius ft	Degree of Curvature	Length of Curve ft	Mean Speed mph	Standard Deviation	Kurtosis	Skewness Index
1	763'	7.50°	200'	39.285	6.407	0.109	0.224
2	498'	11.50°	200'	39.773	6.226	0.164	0.009
3	498'	11.50°	200'	39.317	6.386	0.587	0.427
4	1145'	5.00°	267'	41.215	7.604	-0.059	0.411
5	1145'	5.00°	267'	43.035	7.796	2.910	0.275
7	655'	8.75°	400'	43.484	8.497	0.548	0.614
8	655'	8.75°	400'	42.720	7.591	0.171	0.491
11	607'	9.44°	233'	43.625	8.345	0.135	0.389
12	607'	9.44°	233'	43.110	7.528	-0.374	0.183
88	405'	14.16°	233'	36.125	6.179	0.137	0.474
15	405'	14.16°	233'	35.916	4.730	0.687	0.340
20	460'	12.45°	233'	37.660	5.852	0.192	0.356
21	460'	12.45°	233'	38.025	5.734	0.293	0.333
16	135'	42.50°	200'	22.160	3.987	0.023	0.547
17	135'	42.50°	200'	20.123	3.053	-0.204	0.547
18	382'	15.00°	599'	32.769	4.884	-0.266	0.161

Site No.	Radius ft	Degree of Curvature	Length of Curve ft	Mean Speed mph	Standard Deviation	Kurtosis	Skewness Index
19	382'	15.00°	599'	33.055	4.577	-0.072	0.358
44	637'	9.00°	433'	36.229	6.337	0.384	0.568
22	637'	9.00°	433'	40.571	6.511	-0.146	0.250
24	400'	14.40°	333'	35.460	5.938	-0.111	0.420
40	955'	6.00°	267'	44.436	7.637	1.099	0.859
41	955'	6.00°	267'	45.858	8.867	0.833	0.658
78	1146'	5.00°	666'	40.410	7.062	-0.178	0.394
84	1146'	5.00°	666'	41.634	7.362	-0.194	0.352
85	907'	6.31°	666'	35.121	6.087	0.435	0.531
80	907'	6.31°	666'	34.040	6.087	0.342	0.669
81	818'	7.00°	333'	42.965	5.697	-0.413	0.371
87	818'	7.00°	333'	44.860	6.261	-0.489	0.311
47	8325'	0.69°	386'	53.651	9.980	0.167	0.385
48	9990'	0.57°	559'	54.625	11.069	-0.228	0.209
51	16660'	0.34°	786'	60.087	10.706	-0.498	0.145
53	9990'	0.57°	1236'	58.245	12.486	-0.178	0.378
57	6660'	0.86°	1181'	57.593	11.741	-0.153	0.519
58	6660'	0.86°	406'	50.316	11.833	-0.305	0.255

Site No.	Radius ft	Degree of Curvature	Length of Curve ft	Mean Speed mph	Standard Deviation	Kurtosis	Skewness Index
54	3330'	1.72°	704'	63.285	11.957	-0.487	0.156
55	6660'	0.86°	494'	63.355	11.967	-0.717	0.187
56	6660'	0.86°	876'	62.769	12.363	-0.758	0.283
23	498'	11.50°	367'	32.498	4.411	0.474	0.438
39	498'	11.50°	367'	31.880	4.913	1.140	0.568
25	466'	11.00°	467'	36.843	5.635	0.720	0.563
26	466'	11.00°	467'	34.951	4.754	0.351	0.513
27	881'	6.50°	400'	38.644	5.730	0.092	0.398
28	881'	6.50°	400'	41.275	6.460	0.024	0.493
37	674'	8.50°	667'	37.218	7.074	1.301	0.041
38	674'	8.50°	667'	37.564	6.333	0.102	0.491
43	1720'	3.33°	300'	46.569	7.929	0.154	0.597
32	1720'	3.33°	300'	46.430	8.228	3.035	0.119
60	333'	17.00°	351'	31.971	5.226	0.968	0.737
61	333'	17.00°	351'	33.320	5.608	4.073	1.128
62	3330'	2.00°	1262'	48.496	9.220	0.417	0.059
63	3330'	0.20°	1262'	46.365	8.710	-0.364	0.202
64	818'	7.00°	523'	38.325	5.335	-0.260	0.115

Site No.	Radius ft	Degree of Curvature	Length of Curve ft	Mean Speed mph	Standard Deviation	Kurtosis	Skewness Index
65	818'	7.00°	523'	40.808	6.360	-0.086	0.509
66	487'	12.00°	226'	35.076	5.182	0.640	0.764
67	487'	12.00°	226'	33.933	4.318	0.534	0.568
69	1117'	5.00°	987'	42.276	7.801	-0.049	0.462
70	1117'	5.00°	987'	42.070	8.060	-0.314	0.456
71	477'	12.00°	667'	28.340	3.931	0.173	0.748
72	477'	12.00°	667'	28.951	3.348	0.290	0.348
76	440'	13.00°	355'	34.745	5.983	0.077	0.202
77	440'	13.00°	355'	35.275	6.623	0.725	0.783

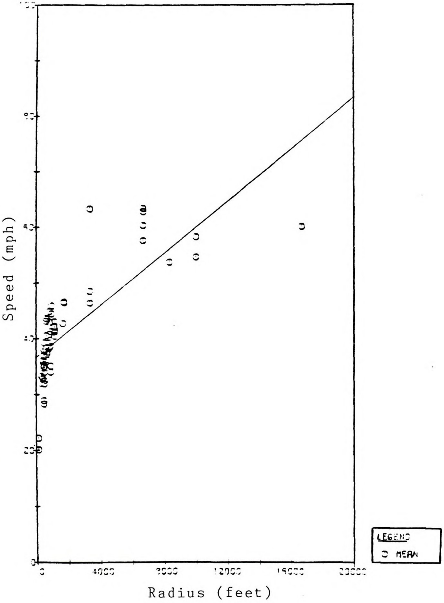
TABLE 19

EMPIRICAL SPEED-CURVATURE RELATIONSHIPS

Independent variable	Dependent variable		
	Taragin, 90th percentile speed (km/h)	DMR, 85th percentile speed (km/h)	Emmerson, median speed (km/h)
Curve radius R (m)	$59.1 + 0.065R$ $r^2 = 0.59$	$52.3 + 0.009R$ $r^2 = 0.91$	$40.6 + 0.037R$ $r^2 = 0.77$
$\sqrt{R}$	$43.2 + 2.10\sqrt{R}$ $r^2 = 0.67$	$31.7 + 2.05\sqrt{R}$ $r^2 = 0.90$	$25.9 + 2.62\sqrt{R}$ $r^2 = 0.68$
Curvature C (deg/100m)	$89.4 - 0.45C$ $r^2 = 0.74$	$93.1 - 0.55C$ $r^2 = 0.73$	$73.7 - 0.19C$ $r^2 = 0.87$
Exponential* $V_o(1 - e^{-BR})$	$63(1 - e^{-0.014R})$ $r^2 = 0.73$	$89(1 - e^{-0.01R})$ $r^2 = 0.71$	$74(1 - e^{-0.017R})$ $r^2 = 0.95$

* An iterative procedure was used for the exponential model so that the parameters for this model may be sub-optimal

SOURCE: J. R. McLean, "Driver Behavior on Curves: view," ARRB Proceedings 7 (Pt. 5) (1974):135.



ig. 11. Empirical speed-curvature radius relationship
ed for the data collected in Saudi Arabia.

eed-curvature relationship obtained for Taragin's (121) 54 data, as shown in Fig. 12.

The regression equation is:

$$\bar{v} = 49.731 - 0.949D_a$$

$$r^2 = 0.60410$$

$\bar{v}$ = mean speed

D_a = degree of curvature

This equation says that as the degree of curvature creases, the mean speed decreases. This trend is also pported by the speed-curvature relationships reported in ble 19, which shows the 90th percentile speed, the 85th rcentile speed, and the median speed decreasing with the crease of the degree of curvature. More specifically, it similar to the trend displayed by the Taragin equation 3):

$$V_a = 46.26 - 0.746D_a$$

Fig. 13 displays graphically the relationship between speed and degree of curvature. This is also comparable h the empirical speed-degree of curvature relationship nd by Taragin (121), as shown in Fig. 14.

For the standard deviation, the effects of the radius found to be statistically significant at $\rho < 0.05$. The ression equation is:

$$S_d = 5.953 + 0.0005R$$

$$r^2 = 0.57061$$

S_d = standard deviation

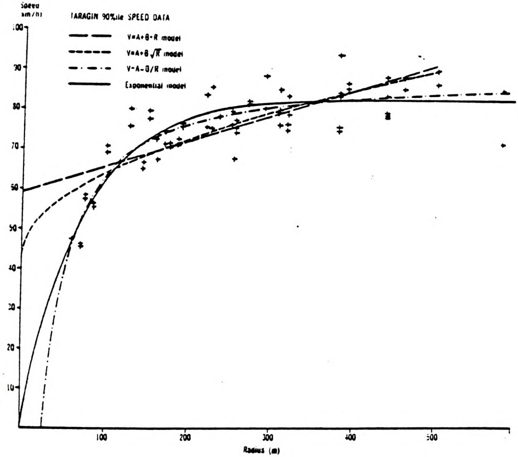
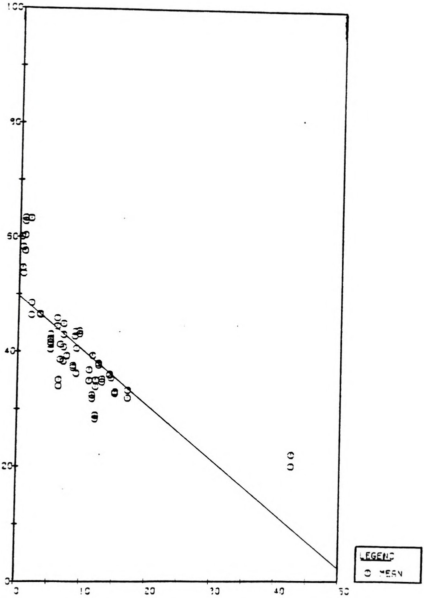
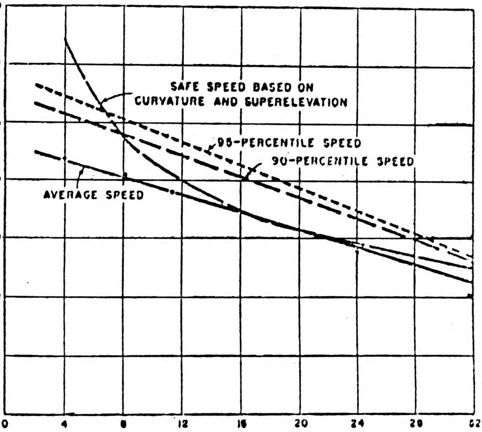


Fig. 12. Empirical speed-curvature relationship
ained for the Taragin (1954) data.

SOURCE: J. R. McLean, "Driver Behavior on Curves--A
iew," <u>AARB Proceedings</u> 7 (Pt. 5) (1974):135.



ig. 13. Empirical speed-degree of curvature
onship obtained for the data collected in Saudi
.



ig. 14. Empirical speed-curvature degree onship.

OURCE: A. Taragin, "Driver Performance on Horizontal ," Proc. 4RB 33 (1954):452.

R = curve radius

This equation indicates that the standard deviation
eases as the radius increases. This rising trend is
displayed graphically in Fig. 15.

Using the degree of curvature, this regression
tion is

$$S_d = 8.967 - 0.2112D_a$$

$$r^2 = 0.48602$$

S_d = standard deviation

D_a = degree of curvature

This equation indicates that the standard deviation
eases as the degree of curvature increases. This
ning relationship is displayed graphically in Fig. 16.

These models confirm the assumption that as the curve
es tighter, the drivers decrease their speed and drive
r to the mean, and thus the mean speed and the
ard deviation decrease. A better fit of the data may
tained with a non-linear equation, but the
ionship is significant even with a linear
ximation. Since these equations are being used not to
ct behavior but only to demonstrate a phenomenon,
inear equations are not tested.

The findings confirm the notion that the influence of
sive speeds on the skewness index will decrease as the
tric complexity increases. This should increase
dence in the skewness index results, as data
ications will not be necessary.

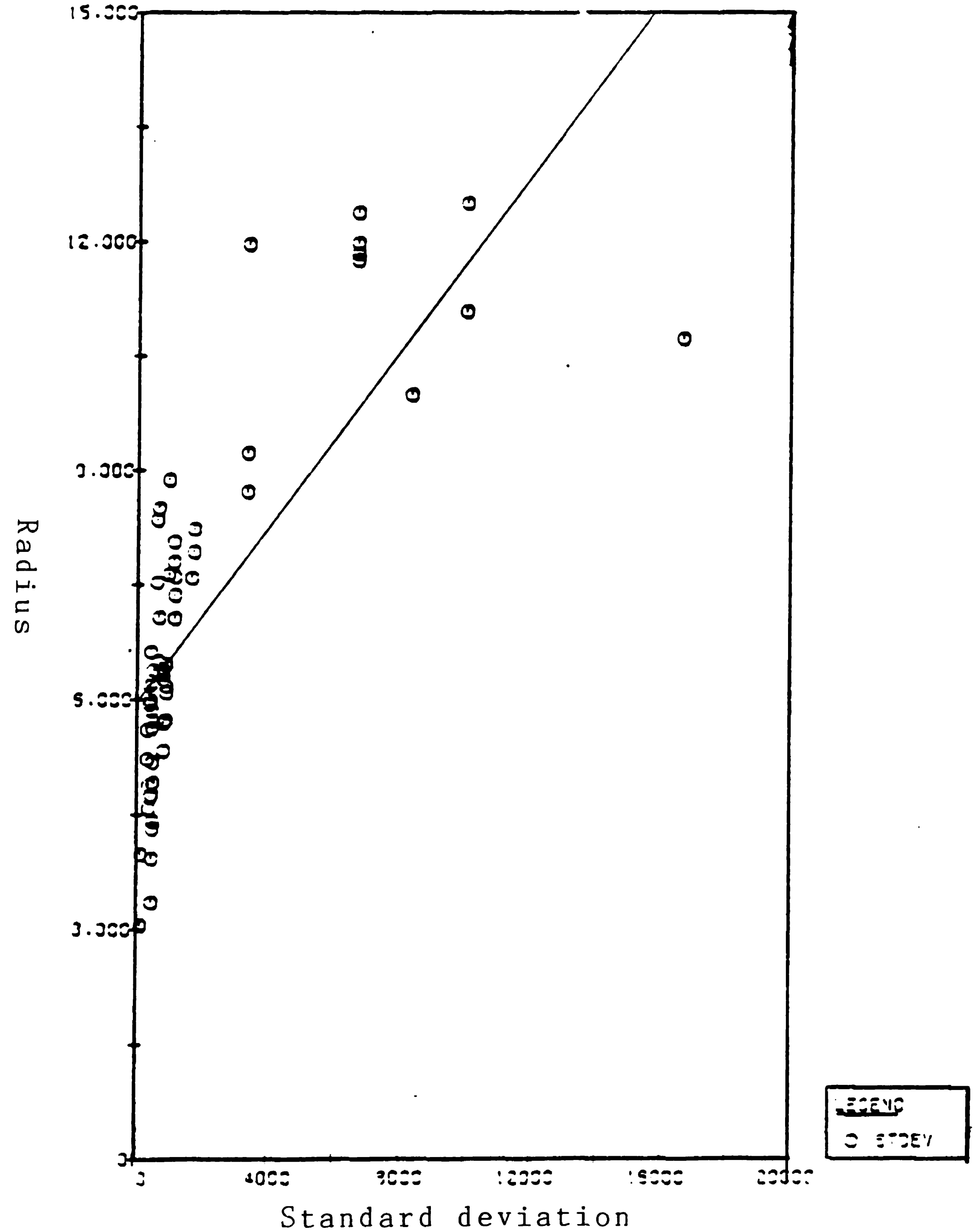


Fig. 15. Empirical standard deviation-curvature
.us relationship obtained for the data collected in
li Arabia.

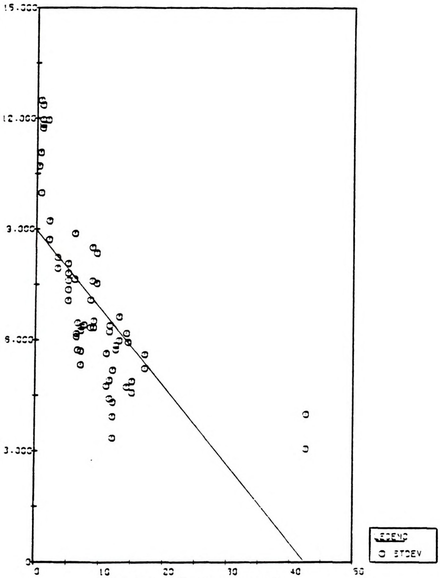


Fig. 16. Empirical standard deviation-degree of
ture relationship obtained for the data collected in
Arabia.

The fact that Saudi drivers perceive, evaluate, and espond to conditions on tangent setions in the same manner s do U.S. drivers allows the testing of the hypothesis hat they perceive and evaluate the adverse roadway onditions imposed by curve sections similarly to U.S. rivers. The general speed behavior found for Saudi drivers s similar to that of U.S. drivers. However, this general peed behavior has not yet been related to the perceptual ifficulties associated with traversing each individual urve, which is the main theme of this research.

Normality of the Speed Distribution on Curves

The speed distribution skewness index is the tatistical parameter used to register those perceptual ifficulties associated with traversing a curve. While the peed distribution of Saudi drivers on tangent sections evealed a normal spot speed distribution, the speed istribution on individual curve sections is hypothesized become skewed depending on the severity of the curve.

According to AASHTO practice, curves may be classified flat or sharp. "Flat" horizontal alignment is considered be 3 degrees or less, which is the maximum curvature gree recommended by AASHTO and the limit adopted by many ates (45). A "sharp" curve is any curve with a degree of rvature greater than 3. As shown in the relationship in g. 17, which was developed by Babkov (5), alignments with ad curvatures flatter than about 3 degrees or with an R

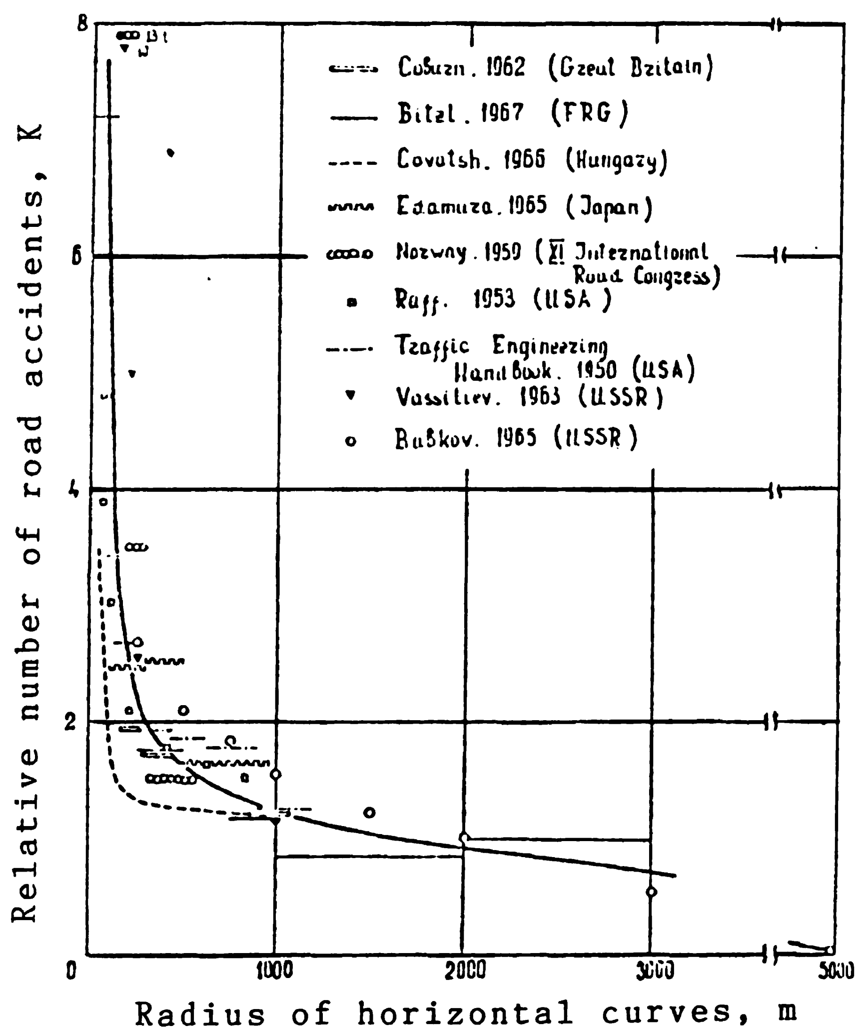


Fig. 17. Relative number of road accidents versus 'adius of horizontal curves in meters.

SOURCE: V. F. Babkov, "Road Design and Traffic afety," Traffic Engineering and Control (September 1968): 37.

of 2000 ft. produce a relatively small decrease in accidents, while alignments with road curvature sharper than 3 degrees produce a rapid increase in accidents. This is in agreement with Messer's rating of the potential workloads associated with traversing different curves, as indicated in Table 20. He found that curves of 3 degrees or less produce less geometric inconsistency than curves of more than 3 degrees. However, excessively long curves were rated proportionatey higher.

Using 3 degrees as the dividing line, this research dealt with 13 flat curves and 48 sharp curves. A separate analysis for each of these two curve groups is presented in the following discussion.

Most of the flat curves would not be expected to represent a particularly hazardous location, and according to the hypothesis being tested, the spot speeds in those curves would be expected to remain normally distributed. However, as shown in Table 18 and reproduced in Table 21, there is no consistent trend in their rating of normal or non-normal. There are three curves rated normal and 10 curves rated non-normal. Curves with similar or equal degrees of curvature varied in their rating from normal to non-normal.

These results might be explained by the fact that drivers in Saudi Arabia approach curves at a higher rate of speed than do U.S. drivers, and thus, while a flat curve is not hazardous in the U.S., it may be a hazardous location

TABLE 20

WORKLOAD POTENTIAL RATINGS (R_C) OF HORIZONTAL CURVES

Degree of Curvature D°	Deflection Angle, Δ°				
	10°	20°	40°	80°	120°
1°	0.5	1.0	2.1	4.1	6.2
2°	1.2	1.5	2.0	3.0	4.1
3°	2.1	2.3	2.6	3.3	4.0
4°	3.1	3.2	3.5	4.0	4.5
5°	4.0	4.1	4.3	4.7	5.2
6°	5.0	5.1	5.3	5.6	6.0
7°	6.0	6.1	6.2	6.5	6.8
8°	7.0	7.0	7.1	7.4	7.7

NOTE: All ratings are for two-lane, high-type highways. Ratings for two-lane mediocre roads (i.e., surface treatment pavement without paved shoulders) equal 0.75 of rating shown. Ratings for all four-lane highways equal 0.65 rating shown.

TABLE 21

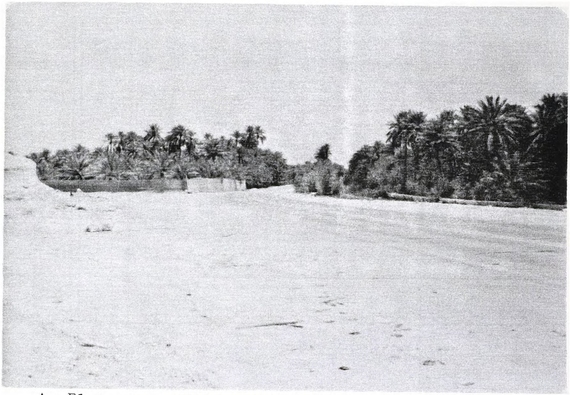
SPOT SPEED DISTRIBUTION CHARACTERISTICS FOR FLAT CURVES

Site No.	Degree of Curvature	Mean mph	Standard Deviation	Speed Range	Kurtosis	Skewness Index	Normality Test
43	3.33	46	7.929	(30-75)	0.154	0.597	Skewed
32	3.33	46	8.228	(30-70)	3.035	0.119	Normal
62	2.00	48	9.220	(30-80)	0.417	0.528	Skewed
63	2.00	46	8.710	(25-69)	-0.364	0.202	Normal
54	1.72	64	13.142	(32-96)	-0.487	0.261	Normal
55	0.86	64	12.713	(44-98)	-0.717	0.350	Skewed
56	0.86	64	13.434	(42-97)	-0.758	0.413	Skewed
57	0.86	60	13.839	(35-95)	-0.153	0.716	Skewed
58	0.86	61	13.103	(37-99)	-0.305	0.419	Skewed
47	0.69	55	11.817	(31-91)	0.167	0.711	Skewed
48	0.57	56	12.600	(30-75)	-0.228	0.465	Skewed
53	0.57	59	13.874	(30-99)	-0.178	0.597	Skewed
51	0.34	61	11.572	(38-94)	-0.498	0.356	Skewed

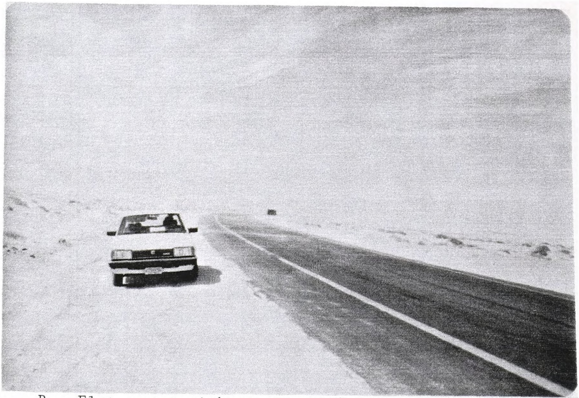
on Saudi highways. The skewness index measure is sensitive to a small number of drivers who misperceive the adverse roadway conditions and thus distort the speed behavior. This fluctuation may also be representative of other factors (like roadside development), as some of these flat curves had some type of marginal friction (as displayed in Fig. 18-A), while others had minimum marginal friction (as displayed in Fig. 18-B). Thus, it is not clear that the sample location successfully eliminates all factors other than the curve geometrics.

Furthermore, as suggested by the speed ranges shown in Table 21, the skewness index on curves below 2 degrees is influenced by those individual drivers exceeding two standard deviations above the mean. Thus, these data points should be eliminated to compare the data with tangent sections. When this is done, as shown in Table 22, six of nine sections lie within the normal range for the coefficient of skewness.

For sharp curves, the results in Table 18 and reproduced in Table 23 show that 39 of the 48 curves are skewed, reflecting the workload and the potential hazard associated with traversing sharp curves. This result complements the previous findings that Saudi drivers' speed behavior, and thus their speed distribution characteristics, trends in mean speeds, and the reduction in standard deviation reflect driver interaction with adverse roadway conditions. The sample of curves included a



A. Flat curve with marginal friction.



B. Flat curve without marginal friction.

Fig. 18. Roadside development condition.

TABLE 22

MODIFIED SPOT SPEED DISTRIBUTION CHARACTERISTICS FOR FLAT CURVES BELOW 2°

Site No.	Degree of Curvature	Mean mph	Standard Deviation	Speed Range	Skewness Index	Normality Test
54	1.72	63	11.957	(36-90)	0.156	Normal
55	0.86	63	11.967	(44-85)	0.187	Normal
56	0.86	63	12.363	(42-89)	0.293	Normal
57	0.86	58	11.741	(35-87)	0.519	Skewed
58	0.86	60	11.833	(37-87)	0.255	Normal
47	0.69	54	9.980	(31-91)	0.385	Skewed
48	0.57	55	11.069	(31-79)	0.209	Normal
53	0.57	58	17.468	(32-86)	0.378	Skewed
51	0.34	60	10.706	(38-84)	0.145	Normal

TABLE 23

SPOT SPEED DISTRIBUTION CHARACTERISTICS
FOR SHARP CURVES

Site No.	Degree of Curvature	Mean mph	Standard Deviation	Speed Range	Skewness Index	Normality Test
4	5.00°	41	7.604	(27-62)	0.411	skewed
5	5.00°	43	7.796	(27-62)	-0.275	normal
69	5.00°	42	7.801	(24-63)	0.462	skewed
70	5.00°	43	8.060	(28-67)	0.456	skewed
78	5.00°	40	7.062	(26-60)	0.394	skewed
84	5.00°	42	7.362	(27-66)	0.352	skewed
40	6.00°	44	7.637	(31-69)	0.859	skewed
41	6.00°	45	8.876	(31-85)	0.658	skewed
85	6.31°	35	6.087	(23-60)	0.531	skewed
80	6.31°	34	6.170	(22-54)	0.669	skewed
27	6.50°	39	5.730	(27-55)	0.398	skewed
28	6.50°	41	6.460	(28-61)	0.493	skewed
81	7.00°	43	5.697	(30-60)	0.669	skewed
87	7.00°	45	6.261	(24-57)	0.371	skewed
64	7.00°	38	5.335	(25-52)	0.115	skewed
65	7.00°	41	6.360	(28-60)	0.509	skewed
1	7.50°	39	6.407	(24-59)	0.224	normal
37	8.50°	37	7.074	(26-56)	-0.014	normal
38	8.50°	38	6.333	(23-55)	0.491	skewed
7	8.75°	43	7.796	(22-71)	0.614	skewed
8	8.75°	43	7.796	(21-62)	0.491	skewed
44	9.00°	36	6.337	(22-57)	0.568	skewed
22	9.00°	41	6.511	(25-60)	0.250	normal
11	9.44°	44	8.345	(25-59)	0.389	skewed
12	9.44°	43	7.528	(27-60)	0.183	normal
25	11.00°	37	5.635	(25-60)	0.563	skewed
26	11.00°	35	4.754	(25-50)	0.513	skewed
23	11.50°	32	4.411	(22-47)	0.438	skewed
39	11.50°	32	4.913	(20-52)	0.568	skewed

TABLE 23--continued

Site No.	Degree of Curvature	Mean mph	Standard Deviation	Speed Range	Skewness Index	Normality Index
2	11.50°	39	6.226	(21-58)	-0.009	normal
3	11.50°	39	6.380	(24-62)	0.427	skewed
66	12.00°	35	5.182	(25-55)	0.764	skewed
67	12.00°	34	4.318	(25-49)	0.568	skewed
71	12.00°	28	3.931	(20-42)	0.748	skewed
72	12.00°	29	3.348	(22-42)	0.348	skewed
20	17.45°	38	5.852	(23-58)	0.356	skewed
21	12.45°	38	5.734	(23-55)	0.356	skewed
76	13.00°	35	5.983	(22-55)	0.202	normal
77	13.00°	35	6.623	(24-60)	0.783	skewed
15	14.16°	36	4.730	(24-55)	0.340	skewed
88	14.16°	36	6.179	(22-56)	0.474	skewed
24	14.40°	35	5.938	(24-53)	0.420	skewed
18	15.00°	33	4.884	(70-46)	0.161	normal
19	15.00°	33	4.577	(22-47)	0.358	skewed
60	17.00°	32	5.226	(20-52)	0.737	skewed
61	17.00°	33	5.608	(22-63)	1.128	skewed
16	42.50°	22	3.987	(14-35)	0.547	skewed
17	42.50°	20	3.053	(14-29)	0.540	skewed

wide range of geometric complexity and severity. Yet the skewness index appears to be a good surrogate measure of their potential hazard.

The skewness index measure classified 19 percent of the sharp curves as normal. In the absence of historical accident data, it is not possible to tell whether the measure failed to identify locations which are hazardous, or whether these 9 curves are in fact less hazardous than the 38 which have been identified as skewed. If the skewness index is to be a better surrogate than simply using the degree of curvature, then it will have to be shown that these nine sites are less hazardous for some reason.

A close investigation of the normal rated sharp curves shown in Table 24 indicates that the curves vary from 5 degrees to 15 degrees, which covers the range of most of the sharp curves in this study. Their mean speed and standard deviations as shown in Table 23 are similar to the other curves. Moreover, their speed ranges, and the percentage of drivers exceeding 50 mph and 60 mph, do not show a problem of excessive speeding. Therefore, these characteristics of the curves do not help explain the difference in normality. It is noteworthy that three of 48 sites have a negative coefficient, meaning some drivers perceived the area to be more dangerous than it actually is and thus disproportionately influenced the speed distribution by driving slower than the mean.

TABLE 24

SPOT SPEED DISTRIBUTION CHARACTERISTICS FOR SHARP CURVES THAT ARE RATED NORMAL

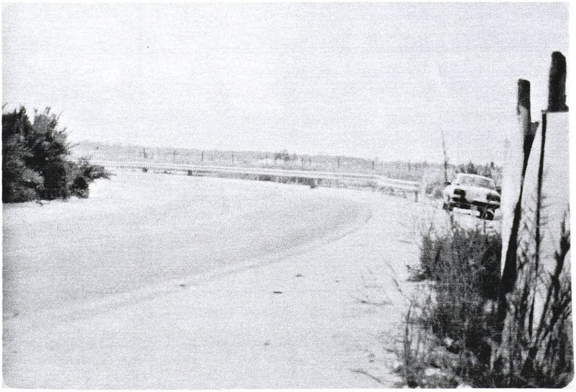
Site No.	Degree of Curvature	Mean mph	Speed Range	% of Vehicles Exceeding 50 mph	% of Vehicles Exceeding 60 mph
1	7.5°	39	(24-59)	6.0%	-0.0%-
2	11.5°	39	(21-58)	3.5%	-0.0%-
5	5.0°	43	(27-71)	15.0%	1.5%
12	9.44°	43	(27-60)	17.0%	1.0%
18	15.0°	33	(20-46)	-0.0%-	-0.0%-
22	9.0°	41	(26-56)	1.9%	-0.0%-
64	7.0°	38	(25-52)	1.5%	-0.0%-
76	13.0°	35	(22-55)	0.5%	-0.0%-

The fact that not all curves produce a high value of the skewness index may be attributed to chance, and the speed distribution did not reflect the true adverse roadway conditions. Another possible explanation is that there is some other factor (e.g., roadside development, prior geometric feature) that results in these locations being less hazardous than the remaining sites, and the index is able to identify this fact. Only a review of future accidents will determine which of these two possibilities is correct.

It is worth noting that most of the sharp curves have agricultural roadside development and marginal friction, as displayed in Fig. 19-A. Some curves even suffer from sight obstruction, as shown in Fig. 19-B. Some curves have some type of positive guidance (delineation treatment, or warning signs), while other curves do not, as displayed in Fig. 20.

A third group of sites with more complex geometrics, and therefore inherently more hazardous than sharp curves, were chosen for analysis. This group consisted of 12 reverse curves. The speed distribution as analyzed by the skewness index registered non-normal for seven of these 12 curves, as shown in Table 25. Again, the mixed results may be attributed to chance, roadside development interference, or traffic operational features. For instance, some reverse curves had adequate sight distance or were preceded by warning signs, as shown in Fig. 21, while others were not.

A. Sharp curve with adequate sight distance.



B. Sharp curve with sight-obstruction problem.

Fig. 19. Sight distance situation at curve locations.

A. Sharp curve with delineation.

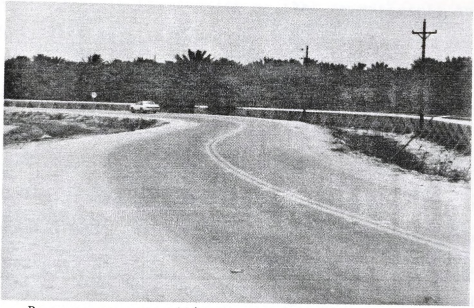
B. Sharp curve without delineation.

Fig. 20. Delineation treatment of curve sections.

TABLE 25

SPEED DISTRIBUTION CHARACTERISTICS
FOR REVERSE CURVES

Site No.	Mean mph	Standard Deviation	Kurtosis	Skewness Index	Normality Test
86	37	6.437	-0.197	0.621	skewed
80	34	6.170	0.342	0.669	skewed
73	42	7.142	0.087	0.345	skewed
74	41	6.725	0.247	0.233	normal
29	33	5.101	-0.312	0.084	normal
30	36	5.255	0.532	0.330	skewed
9	36	5.6	0.083	0.227	normal
10	36	5.389	0.392	0.525	skewed
42	37	6.026	-0.218	0.361	skewed
31	38	6.302	0.075	0.262	normal
33	38	5.173	-0.320	0.027	normal
34	38	6.456	3.281	0.526	skewed



A. Reverse curve without warning sign.

B. Reverse curve with warning sign.

Fig. 21. Positive guidance measure on curve location.

Another possible explanation is that on extremely hazardous highway locations, the hazard is so obvious that drivers are more alert, especially if there are warning signs. For example, on reverse curves, the vehicles entering the site were exiting from another curve, where they had just lowered their speeds. Therefore, the hazard is obvious to all drivers, the probability of driver uncertainty is decreased, and thus the location is likely to be safer than a less complex location. Consequently, if the skewness index is a valid surrogate, we might expect the speed distribution to approach a normal value as the complexity of the curve increases.

According to the previous discussion, the skewness index was associated with accident occurence at hazardous locations in the United States (126). This research has demonstrated, as evidenced by the summary of results in Table 26, that the general pattern of skewness index-roadway hazard relationship also exists in Saudi Arabia.

On tangent sections and flat curves which are geometrically simple and free from hazard, the skewness indexes are 79-percent normal. However, a modification of the data was necessary to obtain reasonable results for tangent sections. On sharp curves, which are geometrically complex and thus hazardous, the majority of skewness indexes (81 percent) were non-normal.

On reverse curves, which are more complex than sharp

TABLE 26

SUMMARY OF RESULTS

	Group I	Group I-A	Group II	Group III	Group III-A	Group IV	Group V
	Tangent Sections Without Friction	Modified Data	Tangent Sections with Friction	Flat Curve	Modified Data for Flat Curves with Excessive Speeds	Sharp Curves	Reverse Curves
No. of Sites	5	5	6	13	9	48	12
Normal	1	4	6	3	6	9	5
Non-Normal	4	1	-0-	10	3	39	7
% Non-Normal	80%	20%	-0%-	77%	33%	81%	58%
% Normal	20%	80%	100%	23%	67%	19%	42%

Overall percentage of normal tangent sections and flat curves after modification equals $\frac{19}{24} = 79\%$.

curves, the skewness index fluctuates between normal and non-normal. The variation in results may be attributed to the fact that the degree of geometric complexity and thus the hazard was so obvious that it was difficult for drivers to misjudge.

Those demonstrated patterns, although not totally consistent, recommend the skewness index as a potential surrogate measure for hazardous highway locations on two-lane roads in Saudi Arabia, as well as an evaluation tool for spot improvements.

Hauer and Persaud demonstrated that using accident history as a measure of potential hazard is also not totally reliable. Using accident history, they found that only a limited number of ramps could be correctly identified as being hazardous for the study period involved. According to their study (Fig. 22), as the number of previous accidents at a ramp increases, the probability that the hazardousness of the ramp will be overestimated increases and the probability of correctly identifying the ramp as hazardous decreases. Using ramps with three accidents in the base year as a definition of hazardous, 92 ramps would be correctly identified, while 184 ramps would be left undetected in the study year. Nearly 100 ramps would be classified as hazardous, which, even though untreated, would experience fewer than three accidents in the study year. Thus, accident history may only produce a surrogate measure with 25-percent accuracy.

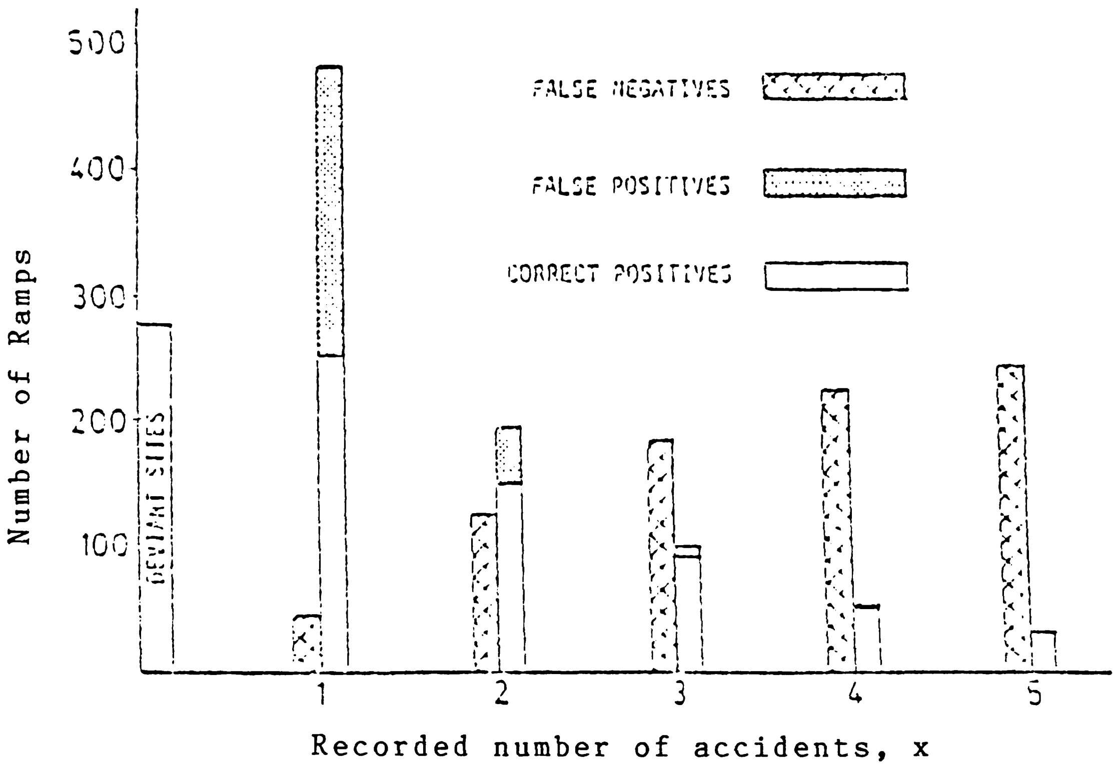


Fig. 22. Recorded Number of Accidents/Number of Ramps.

SOURCE: E. Hauer and B. Persaud, "The Problem of Identifying Hazardous Locations Using Accident Data," paper presented to the 62nd Annual Meeting of the TRB, 1984, p. 10.

Comparison with Other Tests of Normality

Among the tests of normality, kurtosis was found to be an insensitive indication of hazardous locations (124). In this research, as shown in Table 27, it is found to relfect the normal conditions of tangent sections and flat curves with 78-percent accuracy, without modification. However, on sharp and reverse curves, it only produced a 25-percent accuracy.

Trends and Variations Associated with the Use of Skewness Index

The previous section described the normality or non-normality of the skewness index measure as a function of curve geometry at various highway locations. Because the skewness index measure was used as a categorical variable, its variation with the curve characteristics could not be regressed, as was done with the other speed-distribution parameters. Using the skewness index as a continuous variable, the regression equations, shown in Table 28 and displayed graphically in Figs. 23 and 24, were developed to investigate the relationship between degree of curve and the index (see Appendix E). The results show that there is a weak linear and/or curvilinear relationship between this parameter and the radius and degree of curvature, as evidenced by the small values of r^2.

Another possible source of variation that was

TABLE 27

NORMALITY TEST RESULTS USING KURTOSIS

	Group I	Group I-A	Group II	Group III	Group III-A	Group IV	Group V
	Tangent Sections Without Friction	Modified Data	Tangent Sections with Friction	Flat Curve	Modified Data for Flat Curves	Sharp Curves	Reverse Curves
No. of Sites	5	5	6	123	12	48	12
Normal	4	2	5	9	2	34	11
Non-Normal	1	3	1	4	10	14	1
% Non-Normal	20%	40%	17%	33%	83%	29%	8%
% Normal	80%	60%	83%	75%	17%	71%	92%

Overall percentage of normal tangent sections and flat curves without modification equals $\frac{18}{23}$ = 78%.

Overall percentage of non-normal sharp and reverse curves equals $\frac{15}{60}$ = 25%.

TABLE 28

EMPIRICAL SKEWNESS INDEX-CURVATURE RELATIONSHIPS

Independent Variable	Dependent Variable: S.I. = Skewness Index
curve radius R(fl)	$.526 - .3275 \times 10^{-4}R$ $r^2 = 0.24319$
Degree of Curvature Da	$.3834 + .887 \times 10^{-2}Da$ $r^2 = .13791$
R,Da	$.473 + .448 \times 10^{-2}Da - .2715 \times 10^{-4}R$ $r^2 = .27126$
R^2	$.4891 - .175 \times 10^{-8}R^2$ $r^2 = .14332$
Da^2	$.4515 + .106 \times 10^{-3}Da^2$ $r^2 = .03606$

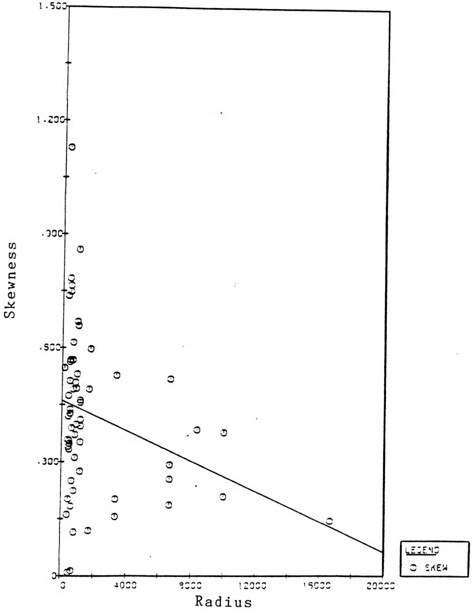


Fig. 23. Empirical skewness index-curvature radius relationship obtained from the data collected in this research.

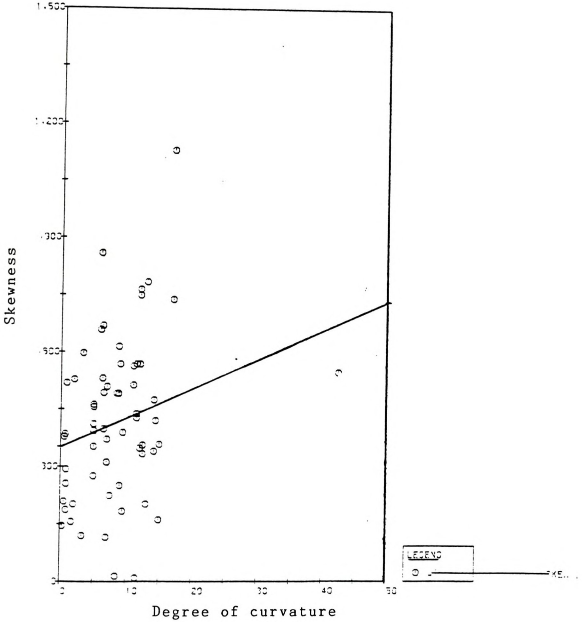


Fig. 24. Empirical skewness index-curvature degree relationship obtained from the data collected in this research.

investigated is the direction of traffic. The purpose was to find out whether conducting the sopt speed study in one direction or the other would make a difference. When the mean speed and the skewness indexes for different directions were compared, as shown in Tables 29 and 30, there was no significant difference at a confidence level of 95 percent.

TABLE 29

VARIATION IN MEAN SPEED WITH DIRECTION OF TRAFFIC

Inbound Traffic	Outbound Traffic	Difference in Mean Speed	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
44	45	-1	-1.29	1.66
41	39	1	0.71	0.50
43	43	-0-	-0.29	0.08
37	35	2	1.71	2.92
32	32	-0-	-0.29	0.08
38	38	-0-	-0.29	0.08
36	36	-0-	-0.29	0.08
		2		5.41

$H_o = 0$ $\qquad \bar{x} = 0.29$

$H_a \neq 0$

$$S = \frac{5.41}{6} = 0.95$$

$$t = \frac{0.29 - 0}{0.95} \sqrt{7} = 0.82$$

$t_{0.05} = 2.447$ f for D.F. = 6

TABLE 30

COMPARISON OF SKEWNESS INDEX FOR DIFFERENT TRAFFIC DIRECTION

Inbound Traffic	Outbound Traffic	Difference	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
0.859	0.658	0.20	0.17	0.03
0.568	0.513	0.05	0.02	0.0004
0.498	0.398	0.10	-0.07	0.0049
0.491	0.614	-0.12	-0.15	0.02
0.563	0.513	0.13	0.10	0.01
0.356	0.356	-0-	-0.03	0.0009
0.340	0.474	-0.13	-0.16	0.03
		0.23		0.10
$H_o = 0$		$\bar{x} = 0.03$		
$H_a \neq 0$				

$$S = \frac{0.10}{7} = 0.14$$

$$t = \frac{0.03 - 0}{0.14} \quad \sqrt{7} = 2.14 \times 2.65 = 5.68$$

$t_{0.05} = 2.447$ for D.F. = 6

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The fact that the accident rate is eight times higher in Saudi Arabia than in the U.S. (51) indicates that there are potentially significant savings in lives and injuries from the implementation of effective highway safety improvement programs. The main hypothesis of this study was that the experience of developed countries such as the U.S. could be transferred and utilized in the development of such safety programs. From among those experiences, this research hypothesized that speed behavior of Saudi drivers resembles that of United States drivers, and thus the skewness index of the spot speed distribution is a potential surrogate measure for the identification of hazardous locations on two-lane rural roads in Saudi Arabia.

In order to develop an experimental design for testing this hypothesis, it was assumed that the spot speed distribution in Saudi Arabia is influenced by the same factors and variables that are found to influence spot speed distribution in the U.S. A wide spectrum of geometric configurations, ranging from tangent sections to reverse curves, were chosen to study the speed behavior of Saudi

drivers, and more specifically to explore the behavior of the skewness index with changing road conditions.

Given that the highway sections studied in this research represented a range of safe and hazardous locations according to their geometric complexity, the skewness index measure was hypothesized to reflect the degree of hazard associated with each location. A normal speed distribution was expected at tangent sections and flat curves, and a non-normal speed distribution was expected at sharp curves.

In the conduct of this study, the following objectives were achieved:

1. Through a literature review, the relationship between traffic speed characteristics and safety in the United States was demonstrated theoretically and empirically.

2. A general approach that utilizes spot speed characteristics was developed which will serve as a guideline for future highway safety inprovement programs in Saudi Arabia.

3. The potential application of spot speed distribution skewness as a surrogate measure for potential hazardous highway locations on two-lane roads in Saude Arabia was verified.

4. Similarities and differences in traffic speed patterns between the U.S. and Saudi Arabia were analyzed.

5. An experimental design for field measurements of

traffic speed characteristics on Saudi Arabian highways was developed.

The results of the study, as evidenced in Table 27, indicated that the skewness of the speed distribution is higher at hazardous highway locations and thus is a potential surrogate measure for the identification of hazardous locations. This same relationship was found to be valid in the United States (56, 126).

Specific Findings

Based on the results of the speed studies, the traffic stream on two-lane rural roads in Saudi Arabia features the following speed characteristics:

1. Relatively higher mean speeds than in the U.S.

2. Excesseve speeding by a significant number of Saudi drivers (50%).

3. Excessive low speed for some drivers.

4. Spot speed distributions with relatively high variance.

5. Normal speed distributions on most tangent sections and flat curves when speeds beyond two standard deviations ($\bar{x} \pm 2\sigma$) were eliminated.

Apparently, the observed higher speeds and standard deviations did not change the shape of the speed distribution on tangent sections and flat curves. Excessive speeds were not found on tangent sections with marginal friction. It is hypothesized that this is because

aggressive drivers were detered from driving too fast by the obvious roadside marginal friction.

The speed behavior on sharp curves revealed the following:

-The mean speed at the center of the curve is significantly lower than the mean speed on the approach.

-The standard deviation at the center of the curve is significantly less than the standard deviation on the approach.

-The mean speed increases as the radius of curve increases (e.g., 5.1).

-The standard deviation increases as radius increases (e.g., 5.3).

Those findings are comparable to similar findings in the U.S., and confirm the assumption that speed behavior of Saudi drivers resembles that found in the U.S. Saudi drivers interact with changing roadway geometrics, and respond in predictable and measurable ways to adverse roadway conditions.

Transferability of Skewness Index

The similarity of Saudi drivers' speed behavior to that in the U.S.; the fact that Saudi drivers interact with favorable as well as adverse roadway conditions; and the normality of their speed distribution on tangent sections and flat curves, suggest the transferability of the skewness index as a surrogate measure for hazardous highway

locations in Saudi Arabia. In this study, the majority of the skewness indexes under adverse roadway conditions were non-normal. These results verified that the speed behavior of a sample of Saudi drivers on individual complex geometric configurations (and thus assumed hazardous locations) such as sharp curves could be analyzed using spot speed distribution parameters, and that the skewness index is a good potential surrogate measure for the identification of hazardous locations.

It is important that there were variations in the skewness index results. Some sharp curves and reverse curves were rated normal, while the majority were non-normal. These results may be attributed to chance, but if the hypothesis put forth in this study is correct, these locations may simply be less hazardous due to some special feature associated with the location, such as adequate positive guidance prior to the location (warning signs, advisory speeds, etc.), adequate sight distance through the location, or obvious complex geometric configuration of the hazardous location.

The regression analysis revealed that there was a weak linear and curvilinear relationship between the skewness index and the radius and degree of curvature. This relationship suggests a potential trend with the degree of hazard, as the skewness index increased from normal levels on tangent sections and flat curves to non-normal levels on sharp curves, and decreased again on reverse curves.

The analysis of variance using a "student-t" test revealed that direction of traffic did not affect the mean speeds or the skewness coefficient, meaning that spot speeds may be conducted on either side of the road at the location of the hazard.

Recommendations

According to the previous discussion, the skewness index measure appears to be a suitable surrogate measure for the identification of hazardous locations. Further verification is desirable, particularly in the quantification of the hazard associated with each specific location. Consideration should be given to increasing the sample size and repeating the spot speed studies at each individual location to minimize the potential of inconsistency caused by chance.

To complement and expand on the findings of this research, the following studies are recommended:

1. A study which includes the roadside development, sight distance, and traffic-control devices (warning signs, etc.) in addition to the geometric characteristics in determining the degree of hazard.

2. A study which would include a subjective hazard evaluation to classify locations by degrees of hazard. Besides considering the documented hazard associated with the physical characteristics of the roadway (roadway geometrics and roadside development), a group of experts

(civil engineers, safety researchers, etc.) should collectively evaluate the hazard associated with the driving task at each location. Similar procedures prescribed by Taylor and Thompson (122) could be used in this research.

3. A study utilizing all available knowledge of accidents in determining potential hazardous locations. This would aid in directly verifying the relationship between the skewness index and accident occurence.

4. A "before" and "after" study involving a highway-improvement program to study the change in skewness index as an evaluation tool.

Because traffic stream characteristics, including speed behavior, in Saudi Arabia evolve and change with time and traffic technology, the findings of this research will serve as a benchmark for further research and comparisons.

This research can be used to improve highway safety in Saudi Arabia by:

-Facilitating the establishment of highway safety improvement programs in Saudi Arabia in advance of a national program to require the use of accident records.

-Promoting the use of spot speed distribution characteristics, including the skewness index, in the evaluation of highway safety improvement programs.

-Providing background information for more research, especially in relation to driver behavior, traffic flow, and highway safety.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Aazis, D. C. "Traffic Science." A Wiley-Interscience Publication. John Wiley and Sons, New York,1974.

2. Acheson, J. Duncan. Quality Control and Industrial Statistics. Fourth Edition. Richard D. Irwin, Inc., Homewood, Illinois, 1974.

3. Agen, Kenneth R., and Dean, Robert C. "Relationships Between Roadway Geometrics and Accidents." TRB, Record 541, 1975, pp. 1-13.

4. American Association of State Highway Officials. "A Policy on Geometric Design of Rural Highways. Washington, D.C., 1965.

5. Babkov, V. F. "Road Design and Traffic Safety Report from USSR," Traffic Engineering and Control 10(5) (Sept. 1968):236-9.

6. Baldwin, David M. "Accident Causes and Countrmeasures," Traffic Engineering 36(5) (March 1966):31-3.

7. Barret, G. V.; Kobay, Ashi; and Fox, B. H. "Driving Requested Speed: Comparison of Projected and Virtual Image Displays," Human Factors 10(3) (1968):259-62.

8. Bearwold, J. E. "Theory of Speed Zones in Developed Areas," Traffic Engineering (Dec. 1957):20-23, 39.

9. Belmont, D. M. "Effect of Average Speed and Volume on Motor Vehicle Accidents on Two-Lane Tangents," Proceedings, HRB 32 (1953):383-413.

10. Blensly, R. C., and Head, J. S. "Statistical Determination of Effect of Paved Shoulder Width on Traffic Accident Frequency," HRB Bulletin 240 (1960):1-16.

11. Blumenthal, M.; Solomon, D.; and Thorp, Kenneth J. "Highway and Safety: A Problem of Definition." North Carolina Symposium on Highway Safety (Raleigh, N.C.), Vol. 2, Spring 1970.

12. Both, G.; Harris, G. S.; and O'Loughlin, G. G. "Measurement of Vehicle Free Speeds at Selected Rural Locations," ARRB Proceedings 6 (Pt. 3), 1972.

13. Bunte, W. F. Methods for Evaluating Highway Features Which Influence Vehicular Speeds. Urbana, Ill.: Department of Civil Engineering, University of Illinois, Sept. 1959.

14. Carroll, P. S. "Classification of Driving Exposure and Accident Rates for Highway Safety Analysis."

15. Cirillo, J. A.; Dietz, S. K.; and Beaty, R. L. Analysis and Modeling of Relationships Between Accidents and the Geometric and Traffic Characteristics of the Interstate System. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, August 1968.

16. Cleveland, Donald E. Traffic Control and Roadway Elements: Their Relationship to Highway Safety. Revised. Ann Arbor, Mich.: Department of Civil Engineering and Highway Safety Research Institute, University of Michigan, 1970.

17. Cleveland, D. and Kostyniuk, L. P. "Geometric Design Element Groups and High Volume Two-Lane Rural Highway Safety." Presented to the Annual Meeting of Transportation Research, Jan. 1984.

18. Coleman, Robert R. "The Effect of Speed Limit Signs," Traffic Engineering (Jan. 1957):176-86.

19. Cownip, A. R. "An Operational Game for the Study of Decision Making in a Hazardous Activity," Accident Analysis and Prevention 2(1) (May 1970):1-10.

20. Davis, Merrill M., and Williams, K. M. Vehicle Operating Characteristics on Outer Loop Deceleration Lanes of Interchanges. O.J.H.R.P. Report No. 43, March 1968.

21. Dearinger, J. A. and Hutchinson, John W. "Traffic Control and Roadway Elements: Their Relationship to Highway Safety, Revised -- Cross Section and Pavement Surface." 1970.

22. Department of Main Roads, N.S.W. "The Behavior on Horizontal Curves," Main Roads 34(4) (1969):127-8.

23. De Silva, Harry R. "Results From Speed Studies in Connecticut and South Carolina," Proc. HRB 20 (1940):702-708.

24. Dewitt, Thomas E. "Testing the Way a Driver Responds to Highway Hazards," Traffic Safety 83(3) (May/June 1983):10-79.

25. Emmerson, J. "Speeds of Cars on Sharp Horizontal Curves," Traffic Engineering and Control (July 1969):135-7.

26. Fell, C. James. "A Motor Vehicle Accident Causal System: The Human Element," Human Factors 18(1) (Feb. 1976).

27. Forbes, T. W. "Driver Behavior Affecting Design, Speed, Capacity Relationships and Accident Patterns on Expressways." East Lansing, Mich.: Highway Traffic Safety Center, Michigan State University, 1960.

28. ________. "Human Factors in Highway Safety." Highway Traffic Safety Center, MSU. For presentation at the Annual Virginia Highway Conference, Lexington, Va., Oct. 30, 1959.

29. ________. "Procedural Task Factors and Performance Decrement in Automobile Driving." East Lansing, Mich.: Highway Traffic Safety Center, Michigan State University.

30. ________. "Psychological Factors in Traffic Accidents on Freeways." East Lansing, Mich.: Highway Traffic Safety Center, Michigan State University, Dec. 9, 1957.

31. Galin, Daniel. "Speeds on Two-Lane Rural Roads: A Multiple Regression Analysis," Traffic Engineering and Control 22(8) (August/Sept. 1981):453-63.

32. Geon, Richard L. Drastic Measures for Reducing Traffic Casualties. Stanford Research Institute, December 1965.

33. Glauz, W. D., and Migletz, D. J. "Application of Traffic Conflict Analysis of Intersections." Final Report, NCHRP Project 17-3, Oct. 1979.

34. Glennon, J. C. "Critique of the Traffic Conflicts Technique." TRR 630 (1977):32-8.

35. Goodell-Grivas, Inc. Highway Safety Engineering Studies: Procedural Guide. Washington, D.C.: U.S. Department of Transportation, Federal Highway Administration, June 1981.

36. Gordon, D. A. "Psychological Contributions to Traffic Flow Theory." Washington, D. C.: Federal Highway Administration, June 1973.

37. Gordon, H. Sheehe. "The Traffic Accident Situation." Presented at the National Home Demonstration Council Conference on Traffic Safety, Michigan State University, East Lansing, Mich., Jan. 13-15, 1960.

38. "The Great Achievement: 19,000 KM -- A Report on the Construction of Saudi Arabia's Highway Network." Ministry of Communication, Kingdom of Saudi Arabia, October 1978.

39. Gupta, R. C. Knorle, Beneler, Stoneanel Associates, Inc.; and Jain, R. P. "Effect of Certain Roadway Characteristics on Accident Rates for Two-Lane, Two-Way Roads in Connecticut," TRB Record 54, pp. 165-71.

40. Hagen, Roger E. "Sex Differences in Driving Performance." Human Factors 17(2) (1975):165-71.

41. Haight, Frank A. "Traffic Safety in Developing Countries." Journal of Safety Research 12(2) (Summer 1980).

42. ________. "A Practical Method for Improving the Accuracy of Vehicular Speed Distribution Measurements." HRB Bulletin 341 (1962):92-5.

43. Hauer, Ezra. "Accidents, Overtaking, and Speed Control," Accident Analysis and Prevention 3(1) (July 1971).

44. ________. Hauer, Ezra, and Persaud, B. "The Problem of Identifying Hazardous Locations Using Accident Data." Department of Civil Engineering, University of Toronto. Paper presented at the 1961 TRB meeting, 1983.

45. Hay, W. W. An Introduction to Transportation Engineering. Second Edition. John Wiley & Sons, New York, 1977.

46. Heimbach, C. L.; Allred, P. W. Jr.; Anderson, P. L.; Atkins, J. R.; and Hooper, J. W. III. "Developing Traffic Flow Indices for the Detection of High Accident Potential Highways in North Carolin." Raleigh, N.C.: Highway Research Program, Civil Engineering Department, North Carolina State University, October 1968.

47. Heimbach, C. L., et al. "Developing Traffic Flow Indices for the Detection of High Accident Potential Highways in North Carolina." Highway Research Program, Civil Engineering Department, North Charolina State University.

48. Heimbach, C. L., and Vick, H. D. "Relating Change of Highway Speed per Unit of Time to Motor Vehicle Accident Rates," Highway Research Record 225, Highway Research Board, 1968, pp. 44-64.

49. Herrin, G. D. "An Empirical Model for Automobile Driver Horizontal Curve Negotiation," Human Factors 16(2) (April 1974).

50. Institute of Transportation Engineers. "Review of Usage and Effectiveness of Advisory Speeds," HE Journal 48(9) (September 1978):43-6.

51. Jacobs, C. D., and Sayer, I. "Road Accidents in Developing Countri," Accident Analysis and Prevention 15(5) (October 1983):337-69.

52. Joksch, H. C. "An Empirical Relation Between Fatal Accident Involvement per Accident Involvement and Speed," Accident Analysis and Prevention 7(2) (June 1975):129-32.

53. Kihlberg, Jaakko K., and Tharp, K. J. "Accident Rates Related to Design Elements of Rural Highways." National Cooperative Highway Research Program, Report 47, 1968.

54. Kip, O. L. "Final Report on the Minnesota Roadside Study, Land Acquisition and Control of Adjacent Areas," HRB Bulletin 55 (1952):33-7.

55. Knell, I. K. "Effectiveness of Speed Limits on Rural Roads in the German Federal Republic." The International Study Week in Traffic and Safety Engineering.

56. Krzeminski, Robert J. "The Use of Skewed Speed Distributions to Locate Points of High Accident Potential on Low Volume Two-Lane Rural Highways." Joint Highway Research Project, Project C-36-59R, File No. 8-5-18, Purdue University, West Lafayette, Indiana, Aug. 13, 1970.

57. Kontaratos, N. Anthony. "A System Analysis of the Problem of Road Casualties in the United States," Accident Analysis and Prevention 6(3/4) (December 1974).

58. Lam, T. M., and Wasielewski, O. "Driver Response to the 55-mph Maximum Speed Limit and Variational Characteristics of Spot Speed," TRB Record 567 (1976):91-7.

59. Leeming, J. J. "Road Accidents, Other Accidents, and Our Laws About Them," Traffic Quarterly (July 19).

60. Lefeve, B. A. "Speed Characteristics on Vertical Curves." Highway Research Board Proceedings 32:395-413.

61. ________. "Speed Habits Observed on a Rural Highway," Highway Research Board Proceedings 33 (1954):409-429.

62. ________. "Relation of Accidents to Speed Habits and Other Driver Characteristics," Highway Research Board Bulletin 120, pp.6-30.

63. MacDonald, Weny A., and Hoffmann, E. R. "Review of Relationship Between Steering Wheel Reversal and Driving Task Demand," Human Factors 22(6) (December 1980):733-9.

64. Marsh, B. W., and Carson, W. L. "Engineers' Approach to Speed Limits," Traffic Engineering and Control 7(7) (June 1960):84-7.

65. Matanzo, F. Jr., and Rockwell, Thomas. "Driving Performance Under Nighttime Conditions of Visual Degradation," Human Factors 9(5) (1976):427-32.

66. Matson, M. T.; Smith, W. S.; and Hurd, F. W. Traffic Engineering. McGraw-Hill Book Company, Inc., New York, 1955.

67. Matteson, J. H.; Hall, J. W.; and Sawhil, R. B. Accident Rates and Costs on Urban Anterials and Freeways.

68. May, Adolf D. "Traffic Characteristics and Phenomena on High Density Controlled Access Facilities," Traffic Engineering 31(6) (March 1961).

69. May, Adolph D., and Wagner, F. A. Fundamental Characteristics of Traffic Flow. Joint Research by Michigan State University and Michigan State H. D. East Lansing, Mich., July 1960.

70. May, John F. "A Determination of an Accident Prone Location," Traffic Engineering 34(5) (February 1964):25-8.

71. McFarland, Ross. "Measurement of Human Factors in Accident Research," Traffic Digest and Review 14(6) (June 1966):4-20.

72. McLean, J. R. "Driver Behavior on Curves: A Review," ARRB Proceedings 7 (Part 5) (1974):129-47.

73. McLean, John B., and Hoffman, R. "Steering Reversals as a Measure of Driver Performance and Steering Task Difficulty," Human Factors 17(3):248-56.

74. McMillan, Claude R. "South Carolina's New Speed Law," Traffic Quarterly (October 1957):492-500.

75. Messer, C. J. Highway Geometric Design Consistency Related to Driver Expectancy. Vol. 11, Research Report. Report No. FHWA-RD-81-037. Prepared for the Federal Highway Administration under contract DOT-FH-11-9230 by Texas A & M Research Foundation, April 1981.

76. Messer, C. J.; Mounce, J. M.; and Brackett, R. Q. Highway Geometric Design Consistency Related to Driver Expectancy. Vol. III, Procedures for Determining Geometric Design Consistency. Report No. FHWA-RD-81-037. Prepared for the Federal Highway Administration under contract DOT-FH-11-9230 by Texas A & M Research Foundation, April 1981.

77. Meyer, Robert L. "Hourly and Daily Variation in Vehicle Speeds on a Rural Highway," Traffic Engineering 21(10) (July 1951):343-6.

78. Ministry of Communication, Kingdom of Saudi Arabia. The Great Achievement of 19,000 Kilometers: A Report on the Construction of Saudi Arabia's Highway Network. October 1978.

79. Minnesota Mining and Manufacturing Company. The Price of Not Walking: A System for Cheating Death on Minnesota Highways. September 1969.

80. Mohn, H. W. "Results of Speed Zoning on Rural Highways," Highway Research Board Proceedings 33 (1954):429-46.

81. Moyer, R. A., and Berry, D. S. "Marking Highway Curves with Speed Indicators." Highway Research Board, Proceedings of the Twentieth Annual Meeting, 1940, pp. 399-428.

82. National Transport Survey: Roads and Road Transport. Central Planning Organization, Kingdom of Saudi Arabia. Prepared with the assistance of the International Bank for Reconstruction and Development, 1975.

83. Ogawa, T.; Fisher, E. S.; and Oppenlander, J. C. "Driver Behavior Study: Influence of Speed Limits on Spot Speed Behavior Characteristics in a Series of Continuous Rural and Urban Areas," HRB Bulletin 341 (1962):18-29.

84. Ohio Department of Highways. "The Effect of Speed Zoning on Traffic Operations." February 1965.

85. Oppenlander, J. C. "Multivariate Analysis of Vehicular Speeds," HRB Record 35(1963):44-76.

86. Oppenlander, J. C. "Sample Size Determination for Spot Speed Studies at Rural, Intermediate, and Urban Locations," HRB Record 35 (1963):78-80.

87. ________. "Sample Size Requirements for Vehicular Speed Studies," HRB Bulletin 281 (1961):68-86.

88. ________. "A Theory on Vehicular Speed Regulation," HRB Bulletin 341 (1962):77-91.

89. ________. "A Theory on Vehicular Speed Regualtion," HRB Bulletin 341 (1961):77-78.

90. ________. "Variables Influencing Spot Speed Characteristics: Review of Literature," HRB Sr. 89, 1966.

91. Oppenlander, J. C.; Bunte, W. F.; and Kadakia, P. L. "Sample Size Requirements for Vehicular Speed Studies," HR Bulletin 281 (1961):68-86.

92. Pahl, Juergen. "A Comparison of Direct and Indirect Methods for Determining Accident Potential." Accident Analysis and Review 2(3) (December 1970):201-207.

93. Pak-Poy, P. G. "Traffic Theory and Practice." Traffic Engineering 34(3) (December 1963)25-35.

94. Perchonok, Kenneth; Ranney, Thomas A.; Stephen, S. B.; Morris, Dominic F.; and Eppich, Douglass J. Hazardous Effects of Highway Features and Roadside Objects. Report No. FHWA-RD-78-202. Prepared for the Federal Highway Administration under contract DOT-FH-11-8501 by Calspan Field Services, Inc., September 1978.

95. Perkins, S. R., and Harris, J. I. "Traffic Conflict Characteristics: Accident Potential at Intersections," Highway Research Record 225 (1968):35-43.

96. Persaud, Bhagwant, and Hauyer, Ezra. "A Comparison of Two Methods for De-Biasing Before-and-After Accident Studies." Department of Civil Engineering, University of Toronto. Paper presented at the Annual TRB Meeting, 1983.

97. Prisk, C. W. "The Speed Factor in Highway Accidents." Traffic Engineering 29(11) (August 1959).

98. Raff, M. S. "Interstate Highway Accident Study," HRB Bulletin 74 (1953):18-45.

99. ________. "Interstate Highway Accident Study," HRB Bulletin 158 (1957):4-26.

100. Ritchie ,M. L.; McCoy, W. K.; and Welde, W. L. "A Study of the Relation Between Forward Velocity and Lateral Acceleration in Curves During Normal Driving," Human Factors 10(3) (1968):255-8.

101. Roberts, Robert R. "The Influence of Speed Limits on Urban Speed Distribution," Traffic Engineering 38(3) (December 1967).

102. Robinson, R. "The Selection of Geometric Design Standards for Rural Roads in Developing Countries."

103. Rowan, N, J., and Keese, C. J. "A Study of Factors Influencing Traffic Speeds," HRB Bulletin 341 (1962):30-76.

104. Saudi Arabian Highway Program. "An IRF Case History." International Road Federation, June 1981.

105. Schoppert, David W. "Predicting Traffic Accidents From Roadway Elements on Rural Two-Lane Highways with Gravel Shoulders," Highway Research Board Bulletin 158 (1957):4-18.

106. Senders, J. W. "The Attentional Demand of Automobile Driving," HRB Record 195 (1967):15.

107. Shelby, M. D., and Tutt, P.R. "Vehicle Speed and Placement Survey," HRB Bulletin 170 (1958):24-38.

108. Shihar, D.; McDonald, S. T.; and Treat, J. R. "The Interaction Between Driver Mental And Physical Conditions and Errors Causing Traffic Accidents: An Analytical Approach," Journal of Safety Research 10(1) (Spring 1978).

109. Shor, Ronald E. "A Program of Research in 'Highway Hypnosis': A Preliminary Report," Accident Analysis and Prevention 2(2) (December 1970):103-109.

110. Shumate, R. P., and Crowther, R. F. "Ariability of Fixed-Point Speed Measurements," HRB Bulletin 281 (1961):87-94.

111. Shumate, R. P., and Dinksen, J. R. "A Simulation System for Study of Traffic Flow Behavior," HRB Record 72 (1963):19-33.

112. Smeed, R. J. "The Influence of Speed and Speed Regulations on Traffic Flow and Accidents," International Road Safety and Traffic Review 9(1) (Winter 1961):51-65.

113. ________. "Road User Behavior in Relation to Road Conditions," Traffic Engineering (June 1955).

114. Snider, J. W. "Capability of Automobile Drivers to Sense Vehicle Velocity," Highway Research Board 159:25.

115. Solomon, David. "Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle." Washington, D.C.: U.S. Department of Commerce, Bureau of Public Roads, July 1964.

116. Statistics, Department of. Statistical Year Book. Ministry of Finance and National Economy, Kingdom of Saudi Arabia, Sixteenth Issue, 1980.

117. Stewart, R. C. "Driving Exposure: What Does It Mean? How Is It Measured?" Traffic Safety Research Review 4(2) (June 1969):9-11.

118. Stewart, Roger G. "Are We Over-Emphasizing Speed as an Accident Cause?" Traffic Quarterly (October 1957):573-9.

119. Stimpson, W. A.; McGee, H. W.; Kittleson, W. K.; and Ruddy, R. H. Field Evaluation of Selected Delineation Treatments on Two-Lane Rural Highways. Report FHWA-RD-77-118. Prepared for the Federal Highway Administration under Contract DOT-FH-8834 by Alan M. Voolhees & Associates, Inc., October 1977.

120. Taragin, A. "Driver Behavior as Related to Shoulder Type and Width on Two-Lane Highways," HRB Bulletin 179 (1954):54-76.

121. ________. "Driver Performance on Horizontal Curves," Proc. HRB 33 (1954):466-65.

122. Taylor, I.I., and Thompson, H. T. Identification of Hazardous Locations. Report No. FHWA-RD-7783. Prepared for the Federal Highway Administration under contract DOT-FH-8279 by the Pennsylvania Transportation Institute, December 1977.

123. ________. Identification of Hazardous Locations: A User Manual. Report FHWA-RD-8279 prepared for the Federal Highway Administration under contract DOT-FH-11-8279 by the Pennsylvania Transportation Institute, December, 1977.

124. Taylor, William C. "The Effect of Speed Zoning on Traffic Operations." Report No. 3-14819. Columbus, Ohio: Ohio Department of Highways, February 1965.

125. ________. "A New Concept of Speed Zoning," Traffic Engineering 34(12) (September 1964):38-9.

126. ________. "Speed Zoning: A Theory and Its Proof," Traffic Engineering 35(4) (January 1965).

127. Tharp, Kenneth J. "The Highway Contribution to Accident Generation." Raleigh, N. C.: North Carolina Symposium on Highway Safety, Vol. 2, Spring 1970, pp. 74-103.

128. Turner, S. Daniel. "The Police Chief's Role in Deficient Accident Reporting." Paper presented to the 63rd Annual Meeting of the Transportation Research Board, Jan. 18, 1984, Washington, D. C.

129. Uhr, Leonard. "Sex as a Determinant of Driving Skills: Women Drivers," Journal of Applied Psychology 43(1) (1959):35.

130. Versace, J. "Factor Analysis of Roadway and Accident Data," HRB Bulletin 240 (1960):24-32.

131. Wagner, F. A., and May, A. D. "Volume and Speed Characteristics at Seven Study Locations," HRB Bulletin 281 (1961):48-67.

132. Wallen, Patricia. "In Traffic Crashes--Is Human Error the Only Culprit?" Traffic Safety 80(6) (June 1980):14-16.

133. Walpole, Ronald F., and Megen, Raymond H. Probability and Statistics for Engineers and Scientists. MacMillan Co., New York, 1968.

134. Warren, D. L., et al. Synthesis of Safety Research Related to Traffic Control and Roadway Elements. Volume 2.

135. Webster, Lee A. Summary of the Vehicular Speed Regulation Research Project. Urbana, Ill.: Department of Civil Engineering, University of Illinois, June 1966.

136. Webster, Lee A., and Gruen, Wayne T. "Summary of the Vehicular Speed Regulation Research Project." Traffic Engineering Series No. 21, Illinois Cooperative Highway Research Program, Series No. 61.

137. Wesht and Jurgensen Research, Inc. "Evaluation of Criteria for Safety Improvement on the Highway." Report to the Bureau of Public Roads, Washington, D. C., 1966.

138. Wilson, Bryan. "Are Rural Speed Zones Effective?" Traffic Engineering 22(1) (October 1951):28.

140. Wohl, M., and Martin B. V. _Traffic System Analysis for Engineers and Planners_. McGraw-Hill Book Company, New York, 1967.

141. Wolf, A. C. "The Concept of Exposure to the Risk of a Road Traffic Accident: An Overview of Exposure Data Collection Methods," _Accident Analysis and Prevention_ 14(5) (October 1982).

142. Word, Kenneth J. "Techniques for Radar Speed Detection, Part I," _Traffic Digest and Review_ 13(9) (September 1966):3-9.

143. ________. "Techniques for Radar Speed Detecton, Part II," _Traffic Digest and Review_ 14(10) (October 1966):10-18.

144. Wortman, R. H. "A Multivariate Analysis of Vehicular Speeds on Four-Lane Rural Highways," _HRB Record_ 72 (1963-64):1-18.

145. Zegeer, V. Charles. "Identification of Hazardous Locations on Rural Highways in Kentucky." Department of Transportation, Division of Research, Kentucky Bureau of Highways, 1974.

APPENDICES

APPENDIX A

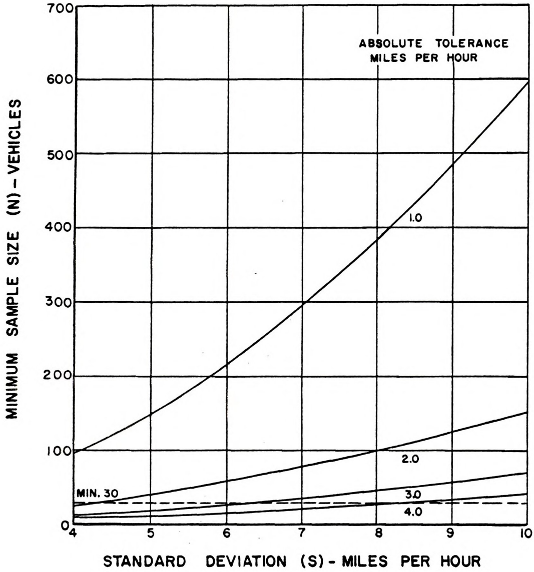


Fig. A-1. Minimum sample size vs. standard deviation (percentile = 15% and 85%, desired confidence level = 95%).

APPENDIX B

TABLE F

0.05 and 0.01 Points of the Distribution of γ_1, Normal Universe* (approximate values)

n	Probability That γ_1 Will Exceed Listed Value in Positive Direction Is 0.05	0.01
25	0.714	1.073
30	0.664	0.985
35	0.624	0.932
40	0.587	0.869
45	0.558	0.825
50	0.533	0.787
60	0.492	0.723
70	0.459	0.673
80	0.432	0.631
90	0.409	0.596
100	0.389	0.567
125	0.350	0.508
150	0.321	0.464
175	0.298	0.430
200	0.280	0.403
250	0.251	0.360
300	0.230	0.329
400	0.200	0.285
500	0.179	0.255
750	0.146	0.208
1,000	0.127	0.180

* Table F is abridged with permission from R. C. Geary and E. S. Pearson, *Tests of Normality* (London: Biometrika Office, University College, 1938) and from Ralph B. Agostino and Gary L. Tietjen, "Approaches to the Null Distribution of $\sqrt{b_1}$," *Biometrika*, Vol. 60 (1973), pp. 169–73. The points listed are on the positive tail of the distribution. With a minus sign attached, they are equally valid for the negative tail. Also see Ralph D'Agostino and E. S. Pearson, "Tests for Departure from Normality. Empirical Results for the Distribution of b_2 and $\sqrt{b_1}$," *Biometrika*, Vol. 60 (1973), pp. 613–22. Since the publication of this paper, Prof. F. J. Anscombe has pointed out that b_2 and $\sqrt{b_1}$ are *not* independent in samples from a normal universe. Hence the joint tests suggested in Section 6 of the paper are not correct, though they might be nearly so. [Letters from E. S. Pearson, April 4, 1974.] For a discussion of the operating characteristics of a γ_1 test for normality, see K. O. Bowman and L. R. Shenton, "Notes on the Distribution of $\sqrt{b_1}$ in Sampling from Pearson Distributions," *Biometrika*, Vol. 60 (1973), pp. 155–67.

TABLE G

Percentage Points of the Distribution of γ_2, Normal Universe*
(approximate values)

	Probability That γ_2 Falls below Listed Value Is:		*Probability That γ_2 Falls above Listed Value Is:*	
n	0.01	0.05	0.05	0.01
25	−1.28	−1.09	1.16	2.30
30	−1.21	−1.02	1.11	2.21
40	−1.11	−0.93	1.06	2.04
50	−1.05	−0.85	0.99	1.88
75	−0.92	−0.73	0.87	1.59
100	−0.82	−0.65	0.77	1.39
125	−0.76	−0.60	0.71	1.24
150	−0.71	−0.55	0.65	1.13
200	−0.63	−0.49	0.57	0.98
250	−0.58	−0.45	0.52	0.87
300	−0.54	−0.41	0.47	0.79
500	−0.43	−0.33	0.37	0.60
1,000	−0.32	−0.24	0.26	0.41
2,000	−0.23	−0.17	0.18	0.28
5,000	−0.15	−0.11	0.12	0.17

* Table G is adapted with permission from R. C. Geary and E. S. Pearson. *Tests of Normality* (London: Biometrika Office. University College. 1938). E. S. Pearson. "Tables of Percentage Points of $\sqrt{b_1}$ and b_2 in Normal Samples; a Rounding Off." *Biometrika*, Vol. 52 (1965), pp. 282–85 and Ralph B. D'Agostino and Gary L. Tietjen, "Simulation Probability Points of b_2 for Small Samples," *Biometrika* Vol. 58 (1971), pp. 669–72. The last reference contains data for values of n from 7 to 50 additional to those listed in Table G. Also see Ralph D'Agostino and E. S. Pearson. "Tests for Departure from Normality. Empirical Results for the Distributions of b_2 and $\sqrt{b_1}$," *Biometrika*, Vol. 60 (1973). pp. 613–22, for charts of the percentage points of the distribution of $b_2 = \gamma_2 + 3$. Since the publication of this paper, Prof. F. J. Anscombe has pointed out that b_2 and $\sqrt{b_1}$ are *not* independent in samples from a normal universe. Hence the joint tests suggested in Section 6 of the paper are not correct, though they might be nearly so. [Letters from E. S. Pearson, April 4, 1974.] For a discussion of the operating characters of *a* γ_2 test for normality, see K. O. Bowman, "Power of the Kurtosis Statistic, b_2 in Tests of Departure from Normality." *Biometrika*, Vol. 60 (1973), pp. 623–28.

APPENDIX C

```
ALISA SPEED DATA

FILE    NONAME    (CREATION DATE =   07/25/83 )
SUBFILE    G5[illegible]

OBS

  CODE
        I
    8.  ** (          1)
        I  36-40 MPH
        I
    9.  ****** (          5)
        I  41-45 MPH
        I
   10.  **************** (          15)
        I  46-50 MPH
        I
   11.  ************************************* (          36)
        I  51-55 MPH
        I
   12.  **************************** (          27)
        I  56-60 MPH
        I
   13.  ******************************************** (          43)
        I  61-65 MPH
        I
   14.  ************************ (          23)
        I  66-70 MPH
        I
   15.  ************************* (          24)
        I  71-75 MPH
        I
   15.  ************* (          12)
        I  76-80 MPH
        I
   17.  ********** (          9)
        I  81-85 MPH
        I
   18.  ******** (          7)
        I  86-90 MPH
        I
   19.  *** (          2)
        I  91-95 MPH
        I
   20.  ** (          1)
        I  96-100 MPH
        I
        I.........I.........I.........I.........I.........I
        0        10        20        30        40        50
        FREQUENCY

VALID CASES     205        MISSING CASES      0
```

```
ALISA SPEED DATA

FILE     NONAME    (CREATION DATE =  01/19/84 )
SUBFILE    G50

COBS

  CODE
        I
   9.   ***** (          5)
        I  41-45 MPH
        I
  10.   *************** (      15)
        I  46-50 MPH
        I
  11.   ************************************ (      36)
        I  51-55 MPH
        I
  12.   *************************** (      27)
        I  56-60 MPH
        I
  13.   ******************************************* (      43)
        I  61-65 MPH
        I
  14.   *********************** (      23)
        I  66-70 MPH
        I
  15.   ************************ (      24)
        I  71-75 MPH
        I
  16.   ************ (      12)
        I  76-80 MPH
        I
  17.   ********* (       9)
        I  81-85 MPH
        I
  18.   ** (       2)
        I  86-90 MPH
        I
        I.........I.........I.........I.........I.........I
        0        10        20        30        40        50
        FREQUENCY

VALID CASES     196      MISSING CASES     0
```

APPENDIX D

DEPENDENT VARIABLE.. MEAN

MEAN RESPONSE 41.15295 STD. DEV. 9.43396

VARIABLE(S) ENTERED ON STEP NUMBER 1.. R RADIUS

MULTIPLE R	.75925	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.57650	REGRESSION	1.	3078.49355	3078.49355	80.31488	0
ADJUSTED R SQUARE	.56932	RESIDUAL	59.	2261.48777	38.33030		
STD DEVIATION	6.19115	COEFF OF VARIABILITY	15.0 PCT				

-------------------- VARIABLES IN THE EQUATION --------------------

VARIABLE	B	STD ERROR B	F SIGNIFICANCE	BETA ELASTICITY
R	.23355E-02	.26064714E-03	80.314830 0	.7592753 .10894
(CONSTANT)	36.669[illegible]	.93735653	1530.39120 0	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE	B	STD ERROR B	T	95.0 PCT CONFIDENCE INTERVAL	
R	.23355624E-02	.26064714E-03	8.9618570	.18143287E-02,	.28574361E-02
CONSTANT	36.66959	.93733653	39.120214	34.793942 ,	38.545234

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

R .00000

R

```
DEPENDENT VARIABLE..    MEAN
MEAN RESPONSE        41.15295       STD. DEV.        9.43396


VARIABLE(S) ENTERED ON STEP NUMBER   1..   DA          DEGREE OF CURVATURE

MULTIPLE R              .77724         ANALYSIS OF VARIANCE     DF       SUM OF SQUARES        MEAN SQUARE               F        SIGNIFICANCE
R SQUARE                .60410         REGRESSION                1.          3225.90303         3225.90303         90.02896             0
ADJUSTED R SQUARE       .59739         RESIDUAL                 59.          2114.07829           35.83184
STD DEVIATION          5.98577         COEFF OF VARIABILITY    14.5 PCT

-------------------- VARIABLES IN THE EQUATION ----------------------        ---------- VARIABLES NOT IN THE EQUATION ----------
VARIABLE              B           STD ERROR B          F               BETA                VARIABLE      PARTIAL     TOLERANCE          F
                                                 ------------      ----------                                                     ------------
                                                 SIGNIFICANCE      ELASTICITY                                                     SIGNIFICANCE

DA              -.94747075        .10006670      90.029964 *       -.7772411                    .
                                                         0.         -.20944
(CONSTANT)      49.731030        1.1852164      1760.5956
                                                         0

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE              B           STD ERROR B          T                95.0 PCT CONFIDENCE INTERVAL

DA              -.94747076        .10005630      -9.4833594           -1.1497042    ,  -.74923734
CONSTANT        49.731030        1.1852164      41.955452            47.359417    ,  52.102643

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

DA              .01001    .
                DA
```

DEPENDENT VARIABLE.. STDEV STANDARD DEVIATION

MEAN RESPONSE 7.05482 STD. DEV. 2.33914

VARIABLE(S) ENTERED ON STEP NUMBER 1.. R RADIUS

MULTIPLE R	.75539	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.57061	REGRESSION	1.	187.32609	187.32609	78.40278	0
ADJUSTED R SQUARE	.56333	RESIDUAL	59.	140.96744	2.38928		
STD DEVIATION	1.54573	COEFF OF VARIABILITY	21.9 PCT				

-------------------- VARIABLES IN THE EQUATION --------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
R	.57621025E-03	.65075161E-04	78.402779 / 0	.7553043 / .15668
(CONSTANT)	5.9528738	.23402761	647.02218 / 0	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE	B	STD ERROR B	T	95.0 PCT CONFIDENCE INTERVAL
R	.57621025E-03	.65075161E-04	8.8545344	.44599515E-03, .70642535E-03
CONSTANT	5.9528738	.23402761	25.436631	5.4845857 , 6.4211620

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

R	.00000
	R

```
DEPENDENT VARIABLE..    STDEV      STANDARD DEVIATION
MEAN RESPONSE         7.05342      STD. DEV.        2.33914
VARIABLE(S) ENTERED ON STEP NUMBER   1..   DA          DEGREE OF CURVATURE

MULTIPLE R            .69715       ANALYSIS OF VARIANCE     DF       SUM OF SQUARES       MEAN SQUARE            F      SIGNIFICANCE
R SQUARE              .48602       REGRESSION               1.          159.55600          159.55600      55.78963             0
ADJUSTED R SQUARE     .47730       RESIDUAL                59.          168.73753            2.85996


STD DEVIATION         1.65114      COEFF OF VARIABILITY     24.0 PCT

--------------------- VARIABLES IN THE EQUATION ----------------------        ---------- VARIABLES NOT IN THE EQUATION ----------
VARIABLE          B             STD ERROR B           F             BETA           VARIABLE      PARTIAL     TOLERANCE        F
                                                 ------------   -----------                                             ------------
                                                 SIGNIFICANCE   ELASTICITY                                              SIGNIFICANCE
DA            -.21116041        .28270649E-01     55.789628      -.6971487
(CONSTANT)    6.9665675         .33434434         717.07621      -.27826
                                                          0
                                                          0

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.
VARIABLE          B             STD ERROR B           T                  95.0 PCT CONFIDENCE INTERVAL
DA            -.21116041        .28270649E-01 -7.4692455         -.26772985     ; -.15459098
CONSTANT      6.9665675         .33434434     26.778316          6.2965455      ; 7.6365894

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

DA            .00080
              DA
```

APPENDIX E

DEPENDENT VARIABLE.. SKEW SKEWNESS

MEAN RESPONSE .45535 STD. DEV. .19844

VARIABLE(S) ENTERED ON STEP NUMBER 1.. R RADIUS

MULTIPLE R	.49314	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.24319	REGRESSION	1.	.45005	.45003	14.78104	.000
ADJUSTED R SQUARE	.22573	RESIDUAL	46.	1.40068	.03045		
STD DEVIATION	.17450	COEFF OF VARIABILITY	37.3 PCT				

------------------------ VARIABLES IN THE EQUATION ------------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
R	-.32749292E-04	.85132320E-05	14.781037 / .000	-.4931379 / -.12298
(CONSTANT)	.52595267	.29305559E-01	322.10191 / 0	

----------- VARIABLES NOT IN THE EQUATION -----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE	B	STD ERROR B	T	95.0 PCT CONFIDENCE INTERVAL
R	-.32749292E-04	.85132320E-05	-3.8446114	-.49895604E-04, -.15602980E-04
CONSTANT	.52595267	.29305559E-01	17.947198	.46696363 , .58494170

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

R	.00000
	R

DEPENDENT VARIABLE.. SKEW SKEWNESS

MEAN RESPONSE .45135 STD. DEV. .19844

VARIABLE(S) ENTERED ON STEP NUMBER 1.. DA DEGREE OF CURVATURE

MULTIPLE R	.37136	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.13791	REGRESSION	1.	.25523	.25523	7.35651	.009
ADJUSTED R SQUARE	.11917	RESIDUAL	46.	1.59553	.03469		
STD DEVIATION	.18624	COEFF OF VARIABILITY	39.8 PCT				

------------------- VARIABLES IN THE EQUATION -------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
DA	.88714617E-02	.32703979E-02	7.3595094 .009	.3713583 .18142
(CONSTANT)	.38338768	.41275929E-01	86.274943 .000	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE	B	STD ERROR B	T	95.0 PCT CONFIDENCE INTERVAL
DA	.88714617E-02	.32703979E-02	2.7126573	.22084990E-02, .15454436E-01
CONSTANT	.38338768	.41275929E-01	9.2894306	.30030374 , .46647161

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

DA	.00001
	DA

VARIABLE(S) ENTERED ON STEP NUMBER 2.. DA DEGREE OF CURVATURE

MULTIPLE R	.52083	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.27126	REGRESSION	2.	.50204	.25102	8.37521	.001
ADJUSTED R SQUARE	.23337	RESIDUAL	45.	1.34872	.02997		
STD DEVIATION	.17312	COEFF OF VARIABILITY	37.0 PCT				

------------------- VARIABLES IN THE EQUATION -------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
R	-.27145272E-04	.94609920E-05	8.2346098 .006	-.4088130 -.10195
DA	.44111117E-02	.34033421E-02	1.7336457 .195	.1875786 .09164
(CONSTANT)	.47318567	.49511652E-01	91.337335 0	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE
LC	-.00792	.75357	.27612953E-02 .951

F-LEVEL OR TOLERANCE-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE	B	STD ERROR B	T	95.0 PCT CONFIDENCE INTERVAL
R	-.27145272E-04	.94609920E-05	-2.8696010	-.46204688E-04, -.80936557E-05
DA	.44111117E-02	.34033421E-02	1.3166798	-.23735711E-02, .11335795E-01
CONSTANT	.47318567	.49511652E-01	9.5570568	.37346408 , .57290725

```
DEPENDENT VARIABLE..    SKEW        SKEWNESS

MEAN RESPONSE        .46835      STD. DEV.        .19444

VARIABLE(S) ENTERED ON STEP NUMBER   1..    RSQR        RADIUS SQUARED

MULTIPLE R           .37858      ANALYSIS OF VARIANCE    DF      SUM OF SQUARES      MEAN SQUARE          F       SIGNIFICANCE
R SQUARE             .14332      REGRESSION               1.          .26526             .26526        7.69584         .008
ADJUSTED R SQUARE    .12470      RESIDUAL                46.         1.58550             .03447
STD DEVIATION        .18568      COEFF OF VARIABILITY   39.6 PCT

-------------------- VARIABLES IN THE EQUATION --------------------        ---------- VARIABLES NOT IN THE EQUATION ----------
VARIABLE          B            STD ERROR B         F              BETA            VARIABLE     PARTIAL    TOLERANCE        F
                                              ------------   -----------                                              ------------
                                              SIGNIFICANCE    ELASTICITY                                              SIGNIFICANCE

RSQR        -.17503899E-08   .63096726E-09    7.6958384      -.3785808
                                                   .008       -.00423
(CONSTANT)   .48907160       .27410051E-01  309.09465
                                                   .0000

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE          B          STD ERROR B        T            95.0 PCT CONFIDENCE INTERVAL

RSQR       -.17503899E-08   .63096726E-09 -2.7741374       -.30204611E-08,  -.44031865E-09
CONSTANT    .48907160       .27410051E-01 17.581088         .43307676    ,   .54506643

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

RSQR          .00000
            RSQR
```

DEPENDENT VARIABLE.. SKEW SKEWNESS

MEAN RESPONSE .46835 STD. DEV. .19844

VARIABLE(S) ENTERED ON STEP NUMBER 1.. DASQR DEGREE OF CURVATURE SQUARED

MULTIPLE R	.18990	ANALYSIS OF VARIANCE	DF	SUM OF SQUARES	MEAN SQUARE	F	SIGNIFICANCE
R SQUARE	.03606	REGRESSION	1.	.06674	.06674	1.72087	.196
ADJUSTED R SQUARE	.01511	RESIDUAL	46.	1.78402	.03878		
STD DEVIATION	.19693	COEFF OF VARIABILITY	42.0 PCT				

---------------------- VARIABLES IN THE EQUATION ----------------------

VARIABLE	B	STD ERROR B	F / SIGNIFICANCE	BETA / ELASTICITY
DASQR	.10599178E-03	.80797570E-04	1.7208688 / .196	.1898977 / .03605
(CONSTANT)	.45147066	.31202949E-01	209.34750 / .000	

---------- VARIABLES NOT IN THE EQUATION ----------

VARIABLE	PARTIAL	TOLERANCE	F / SIGNIFICANCE

ALL VARIABLES ARE IN THE EQUATION.

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE	B	STD ERROR B	T	95.0 PCT CONFIDENCE INTERVAL
DASQR	.10599178E-03	.80797570E-04	1.3118109	-.56645227E-04, .26862805E-03
CONSTANT	.45147066	.31202949E-01	14.468846	.38866230 , .51427894

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

DASQR	.00000
	DASQR