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WRONG-WAY MOVEMENTS ON DIVIDED HIGHWAYS

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PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

Final Report

WRONG-WAY MOVEMENTS ON DIVIDED HIGHWAYS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

February 19, 1974

Project: C-36-59Q

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 8-5-17

The attached Final Report by Peter N. Scifres titled "Wrong-Way Movements on Divided Highways" is submitted on the JHRP study of similar title approved February 8, 1973.

The study reported herein has developed and refined the knowledge of the wrong-way movement problem on rural highways, especially as it pertains to Indiana. Ninety-six (96) accidents involving wrong-way vehicles were identified as occurring in Indiana during 1970, 1971 and 1972. Thirty-nine fatalities resulted. Possible measures which would minimize such accidents were found to be night lighting of intersections, raising elevation of the crossroad, use of simple configurations at intersections, making medians more distinct, and use of channelizing islands to block wrong-way movements. Many of these measures are applicable to the design of new facilities as well as in improvements to existing highways.

The Report is presented for review, comment and acceptance as fulfillment of the objectives of the approved research study.

Respectfully submitted,

Harold L. Michael

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by

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Project No.: C-36-59Q

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ABSTRACT

Scifres, Peter N. M.S.E. Purdue University, December, 1973. Wrong-Way Movements on Divided Highways. Major Professor: Roy C. Loutzenheiser.

The purpose of this research was to study the problem of wrong-way movements on divided, rural highways in Indiana. The research was in two parts: a general review of the characteristics of wrong-way accidents that have occurred in Indiana, and an investigation of various alternatives that could be used to reduce wrong-way movements.

The basic data were obtained by searching the Indiana State Police accident records for wrong-way accidents that occurred in 1970, 1971, or 1972. Field investigations were made at each accident site to supplement data shown on the accident records and to determine the physical characteristics of access point where wrong-way movements originated.

Wrong-way accidents were exceptionally severe with 39 deaths resulting from 96 accidents over a three year period. Studies of wrong-way drivers indicated that only 31% of them were not drunk, were not old (over 65) and/or were not fatigued (driving between 12:00 a.m. and 6:00 a.m.). Conditions at typical wrong-way movement origin sites included darkness, low land-use and low traffic volumes.

Any measure that improves the driver's visibility and perception of access points to divided highways would decrease wrong-way movements. Possible measures included night lighting, raising the elevation of crossroads, making medians more distinct and the use of simple, understandable configurations. At certain locations, the use of additional channelization and barrier curbs will direct traffic in the right direction and could block wrong-way movements.

CHAPTER I

INTRODUCTION

From traffic data collected on multi-lane highways across the country it has become apparent that on virtually all such facilities vehicles occasionally travel in the wrong direction. This phenomenon, known as a wrong-way movement, is a function of many factors, notably driver error, inadequacies in driver information devices and geometric design. Wrong-way movements have a high potential to result in head-on collision type accidents and, as such, represent a significant threat to the safety of motorists.

The chief distinguishing characteristic of wrong-way accidents, that is accidents caused by wrong-way movements, is their severity. Data collected in Indiana and other states have indicated that between one-third and one-half of all wrong-way accidents result in one or more fatalities. Over the past three years 39 persons have died from wrong-way accidents in Indiana. A traffic safety problem of this nature and magnitude demands attention from both transportation engineers and policy makers, as well as special preventive measures.

This report has developed and refined knowledge of the wrong-way movement problem on rural highways, especially as it pertains to Indiana. This was done through an interaction of the current literature on the subject, the expertise of those involved in the project and the data collected and analyzed in the execution of the project. Considerable amounts of data on the nature of wrong-way accidents, characteristics of wrong-way drivers and environmental factors affecting wrong-way drivers have been collected, analyzed and presented. Preventive measures, involving both geometric design and driver information devices, that may reduce the frequency of wrong-way movements have been outlined.

Before examining the data collected specifically for this report, a survey of the existing literature on wrong-way movements is made. This provides a perspective of the problem and a look at the current knowledge and prevention methods of wrong-way movements.

CHAPTER II

LITERATURE REVIEW

Nature and Characteristics

History and Recognition of the Problem

Recognition of the general problem of wrong-way movement has grown over the past ten years as a result of both vigorous research efforts and numerous traffic acci dents, many of them fatal. In 1964, the Bureau of Public Roads (now the Federal Highway Administration) conducted a survey of the fifty states concerning wrong-way movements onto the exit ramps of freeway type facilities (1). The results of this survey revealed that 15 percent of the states felt that wrong-way movements onto exist ramps were a definite problem and warranted further attention.

The remaining 85 percent did not respond to the survey, felt that existing protection mechanisms were adequate or that low traffic volumes did not warrant up-graded protection mechanisms. Considerable correlation existed between those states that had the greatest miles of freeway and highest traffic volumes and those states that believed the wrong-way movement problem was significant.

However, over the last eight years, the balance of informed opinion has generally reversed. In 1967 the Special AASHO Traffic Safety Committee stated:

> In view of the serious nature of the wrong-way traffic problem, it is recommended that existing highways be reviewed and work initiated without unreasonable delay to avert or redirect wrong-way traffic. (2, pp. 122)

A Federal Highway Administration Instructional Memorandum circulated in 1971 states:

> Accident statistics and some particularly tragic wrong-way accidents have prompted the Federal Highway Administration to firmly restate its policy of attempting to prevent wrong-way driving through practical and effective means. (3, pp. 1)

The state highway departments of both California and Texas have also expressed concern over the problem

The growing recognition of the wrong-way movement problem has prompted vigorous research and operational programs; the California Division of Highways, with the FHWA, has assumed leadership in this area. Extensive field surveys, ramp monitoring and operational improvements have been undertaken on the California freeway system. This effort has apparently paid off as the state's yearly number of wrong-way accidents remained relatively constant even though the opportunity for such accidents has increased (4). It is notable, as stated earlier, that nearly all published research on wrong-way movements has dealt with the problem as it pertains to highways with fully controlled access.

Magnitude of the Problem

From data compiled in three states (4, 5, 6, 7) the magnitude of the wrong-way movement problem was assessed. The importance of this lies in both providing some cognizance of wrong-way movement characteristics and to establish a framework to evaluate the priority attached to the problem.

California. In a three phase study (7) conducted in the mid-sixties in cooperation with law enforcement agencies, the California Division of Highways attempted to determine both the frequency of wrong-way accidents and wrong-way movements (both these were lumped together under the category of wrong-way incidents). Each phase lasted nine months. The data, summarized in Table 1, was collected through accident reports and observations by law enforcement officials.

Data was also available for fatal wrong-way accidents on California freeways. Table 2 gives approximate fatal accident rates per mile of freeway for 1961, 1964, and 1970. Figure 1 summarizes fatality rate trends from 1961 to 1971.

In general, the magnitude of the problem is large enough for considerable concern although it is declining in terms of fatal accidents per freeway mile.

Texas. Absolute totals of wrong-way accidents were not available for Texas; however data published by the Statistical Services Division of the Texas Department of

TABLE 1: Wrong-Way Driving Incidents in California

Source: 7, pp. 26

Phase	Freeways	Expressways	Conventional Roads	Total
I	312	187	243	742
II	451	167	97	715
III	379	79	66	524
TOTAL	1142	433	406	1981

TABLE 2: Fatal Wrong-Way Accidents on California Freeways

Source: 4, pp. 2

Year	Number of Fatal Accidents	Approximate Freeway Mileage	Approximate Annual Fatal Accident Rate (per thousand freeway miles)
1961	13	925	14.1
1964	32	1625	19.7
1970	36	3100	11.6

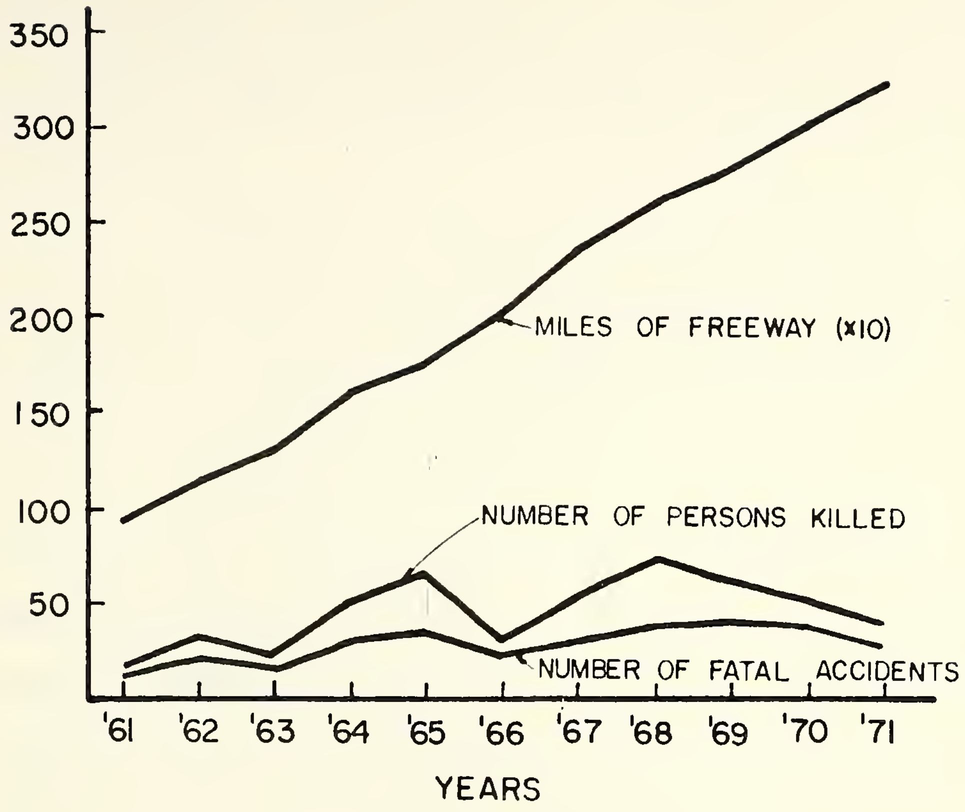


FIGURE 1. WRONG-WAY FATALITY TRENDS IN CALIFORNIA

Public Safety for 1967, 1968, 1969, and the first half of 1970 indicated that approximately 0.2% of all accidents in Texas resulted from wrong-way movements (5). Approximately 1.4% of all fatal accidents in Texas resulted from wrong-way movements.

Virginia. A survey from June 1, 1971 to May 31, 1972 by the Virginia State Police evaluated the magnitude of the wrong-way movement problem in Virginia (6). The findings are summarized in Table 3.

In Virginia the mileage of divided primary routes is considerably larger than of the interstate system (no exact figures were available). Although State Highway Department personnel were interested in the problem and had up-graded some problem locations, they did not express as great a concern as did other organizations.

Summary. From the data presented in California, Texas, and Virginia reports, several findings are noted:

1) Wrong-way accidents generally account for less than 1.5% of a states total accidents.

2) Wrong-way accidents generally account for more than 1.0% by less than 2.0% of a states fatal accidents.

3) Wrong-way movements are far more numerous than wrong-way accidents.

4) On California freeways the numbers of wrong-way accidents has remained relatively constant over a ten-year period, in spite of increased freeway mileage. This

TABLE 3: Wrong-Way Incidents and Accidents on Virginia Highways

Source: 6, pp. 2-4

	Incidents	Accidents	Deaths	Injuries
Interstate System	68	25	9	35
Divided Primary Routes	174	41	1	26
TOTAL	242	66	10	61

may be indicative of a national trend caused by improved wrong-way movement prevention system.

Characteristics of Wrong-Way Movement Origins

Wrong-way movement origins, types and characteristics, were examined to gain insight into why they occur and how they can be prevented; overall characteristics of wrong-way movements are considered in the next section.

Because types and characteristics are considerably different, wrong-way accidents on highways with fully controlled access were explored separately from highways without fully controlled access. Four basic wrong-way movements can occur on highways with fully controlled access (hereafter referred to as class A highways) and they are as follows:

1) U-turn--This wrong-way movement sometimes happens when a driver misses an exit ramp. He makes a U-turn remaining on the same side of the median, and thus travels the wrong-way.

2) Crossing the median--Ocassionally drivers fall asleep and drive across the median without realizing it. They sometimes drive the wrong-way for some distance unaware of what has happened.

3) Entering the exit ramps of non-directional interchanges (parclos and diamonds)--These types of interchanges are generally designed with no physical barriers to wrong-way entry. Drivers become confused and select the wrong ramp to enter the highway.

4) Entering the exit ramps of directional interchanges (cloverleafs and others)--Unusual and difficult manuevers are required to make a wrong-way movement onto these ramps. Sometimes the driver enters the divided crossroad from the wrong-way.

Of these four types of wrong-way movements on Class A highways the third is the most common. For any of the other three types of movements the wrong-way movement must be willful or very unusual circumstances must be present; understandably, there is little the highway engineer can do about these. Wrong-way movements at the exit ramps of diamonds and parclos are, at least partially, preventable and this is where most research efforts have been concentrated.

Wrong-way movements on divided highways without fully controlled access (hereafter referred to as Class B highways) have five types. The five types are:

1) U-turns--Same as described for Class A highways although they are very uncommon on Class B highways.

2) Crossing the median--Same as described for Class A highways.

3) Left-turn at an access point with no median opening--Many minor access points on a Class B highway do not have a median opening. This forces left-turning drivers to make a right turn, travel until a median opening is located, and make a U-turn to proceed in the desired direction. Either by intent or accident, a driver ocassionally does not do this and makes a left turn at the minor access point and travels the wrong-way.

4) Wrong-way movements originating from an access point with a median opening--Two situations can arise here. A left turn into the near lanes as above, or a right turn into the lanes on the far side of the median. Based on statements from numerous literature sources, this type of access point, ranging from driveways to major intersections, is where most wrong-way movements on Class B highways originate.

5) Transitions--Drivers entering a transition from the undivided highway sometimes drive down the wrong lanes of the divided highway.

Data, using slightly different categories, are available from the three phase study in California mentioned earlier (7). Tables 4 and 5 give information on wrong-way movement origins for Class A and B highways. This data was collected over a nine month period during the second phase of the study.

Similar type data collected in Virginia yielded the information on Tables 6 and 7.

Wrong-way movements involving U-turns or other erratic and dangerous manuevers are usually intentional or made by a driver whose ability is impaired. Although the highway engineer has been able to do little about these cases, nearly half of the Class A and over half of the Class B wrong-way movements are by some other cause and are at least theoretically preventable. Here is where reductions in wrong-way movements can hopefully be achieved.

TABLE 4: Wrong-Way Movement Origins on Class A Highways in California

Source: 7, pp. 36

Point of Origin	Number	Percentage
Freeway off Ramp	165	48.7
Made U-turn from off ramp (right-way on freeway)	13	3.8
Made U-turn in traffic lanes	71	20.9
Drove across median	17	5.0
Made U-turn on off or on ramp	10	3.0
Made U-turn from on ramp (wrong-way on freeway)	38	11.2
Made U-turn into on ramp (right-way on freeway)	25	7.4
	339	100.0
Origins unknown	111	
TOTAL	450	

TABLE 5: Wrong-Way Movement Origins on Class B Highways in California

Source: 7, pp. 37

Point of Origin	Number	Percentage
Access point with median opening	67	47.2
Transition to divided highway	7	4.9
Drove through median opening (no intersection)	35	24.7
Drove across median	4	2.8
Made U-turn	26	18.3
Other (driveways)	3	2.1
	142	100.0
Origins Unknown	25	
TOTAL	167	

TABLE 6: Wrong-Way Origins on Class A Highways in Virginia

Source: 6, pp. 3

Point of Origin	Number	Percentage
Interchanges	36	77
Crossovers and U-turns	11	23
	47	100
Origins Unknown	23	
TOTAL	68	

TABLE 7: Wrong-Way Origins on Class B Highways in Virginia

Source: 6, pp. 5

Point of Origin	Number	Percentage
Intersections	70	45
Interchanges	10	6
Commercial Driveways	38	24
Private Driveways	14	9
Crossovers	16	10
U-turns	7	6
	155	100
Origins Unknown	19	
TOTAL	174	

Characteristics of Wrong-Way Movements

Consideration of wrong-way movements was approached by isolating parameters and characteristics which give insight into the nature of the accidents. The parameters used include:

1) Type of vehicle involved.
2) Day of the week the accident occurred.
3) Visibility conditions at the time the accident occurred.
4) Weather conditions at the time the accident occurred.
5) Distance the wrong-way vehicle travelled.
6) Traffic conditions.
7) Accident severity.

Data gathered in Virginia (6) indicated that approximately 80% of wrong-way vehicles were passenger cars with the remainder being trucks or miscellaneous vehicles.

Data gathered in California, Texas and Virginia (5, 6, 7) has indicated that a disproportionate percentage of wrong-way movements occur on Fridays, Saturdays and Sundays. This is generally attributed to the greater number of drunken drivers on the road during these days.

More than half of all wrong-way movements occur during conditions of restricted visibility (7). California data indicated a peak in wrong-way movement occurrence between 2:00 a.m. and 3:00 a.m.

Weather apparently does not have a significant effect on wrong-way driving--approximately 80% of all wrong-way movements occur during clear weather (6).

A wide variation in the distance travelled by wrong-way vehicles has been recorded as shown in Table 8.

Table 9 gives traffic conditions on California freeways where and when wrong-way movements occurred.

Wrong-way movements are an exceptionally severe type of accident. In 66 wrong-way crashes in Virginia, 10 persons were killed and 61 were injured. Data collected in California have indicated that 18% of all wrong-way accidents result in one or more fatalities and another 46% produce injuries.

Although not all of the seven isolated parameters have significance, parameters 3 (visibility) and 7 (severity) are of interest to the highway engineer. Conditions of restricted visibility seem to encourage wrong-way driving; this is a logical point of attack for wrong-way movement reduction measures. The severity of wrong-way accidents makes them of special interest, and their restriction of special urgency.

Characteristics of Wrong-Way Drivers

As was done for wrong-way movements, important variables of wrong-way drivers were isolated and examined. A perusal of the literature indicated the following variables were of interest:

1) Driver's age.
2) Presence of alcohol or drugs in the driver's system.

TABLE 8: Distances Wrong-Way Vehicles Travelled the Wrong-Way on Virginia Highways

Source: 6, pp. 3-5

	Maximum Distance Travelled	Minimum Distance Travelled	Average Distance Travelled
Class A Highways	25 miles	200 feet	2-3 miles
Class B Highways	16 miles	20 feet	3/4 mile

TABLE 9: Traffic Conditions on California Freeways at the Time of a Wrong-Way Movement

Source: 7, pp. 29

Traffic Volumes	Number	Percentage
Light	225	57.1
Moderate	131	33.2
Heavy	38	9.7
	394	100.0
Origins Unknown	130	
TOTAL	524	

3) Driver's traffic violation record.
4) Driver's experience.

Age was a significant variable. Data collected in California revealed that older drivers had a much higher wrong-way movement rate, on an annual mileage basis. Tamburri (7) calculated an annual exposure rate for a nine-month period by age group by multiplying the number of registered drivers times average annual miles driven times 0.75. This age group rate was divided into the number of wrong-way movements for each age group to obtain a wrong-way movement rate per age group. The results are shown in Table 10. As can be seen, older drivers have a very high wrong-way movement rate.

Studies in several states have consistently indicated that more than half of all wrong-way drivers have been drinking. Taking Virginia as an example, 57% of the drivers involved in the 68 wrong-way movements on the state's Class A highways for one year had been drinking (6). In terms of wrong-way accidents, Estep (4) noted that "Our studies have consistently shown that about 3 out of 4 wrong-way drivers who caused accidents have been drinking" (4, p. 11). The importance of these observations cannot be overstated. Clearly many wrong-way drivers' reasoning abilities have been degraded by alcohol and do not respond normally to the driving environment.

Wrong-way drivers have a tendency to have other

TABLE 10: Driver's Wrong-Way Movement Rate by Age Group

Source: 7, pp. 30

Age	Incidents		Registered Drivers		Average Annual Miles Driven	Exposure (BVM)[a]	Wrong-Way Rate
	No.	Percent	No. $(x\ 10^6)$	Percent			
16 to 20	19	4.2	0.922	9.3	7,300	5.05	3.76
21 to 24	31	6.8	0.842	9.0	13,700	9.17	3.38
25 to 29	41	9.0	1.121	11.3	15,200	12.77	3.21
30 to 39	75	16.4	2.241	22.6	15,900	26.72	2.81
40 to 49	89	19.5	2.122	21.4	15,000	23.87	3.73
50 to 59	79	17.3	1.438	14.5	13,300	14.34	5.51
60 to 69	65	14.3	0.802	8.1	10,400	6.26	10.38
70 and over	57	12.5	0.377	3.8	6,900	1.95	29.23
Unknown	2						
TOTAL	458	100.0	9.865	100.0	13,400[b]	100.13	4.55[b]

[a]Billion vehicle miles

[b]Average, not total

driving problems. In an in-depth interview of 168 wrong-way drivers, Tamburri (7) found that their accident rate and traffic violation rate was approximately twice those of the average driver.

The wrong-way driver tends to be slightly less experienced than average as shown in Table 11.

The finding from these four driver characteristic variables are quite significant. The wrong-way driver tends to be older, tends to be drunk, tends to be less experienced than average and tends to be a more reckless driver than average. This all adds up to a driver of reduced ability not likely to respond normally to the driving environment. This finding should be definitely considered in the design of wrong-way movement prevention measures.

Prevention of Wrong-Way Movement

Having examined some aspects of previous research on the nature and characteristics of the wrong-way movement problem, current design and operational practices, as well as theories, to prevent wrong-way movements were reviewed and discussed. Reducing or preventing wrong-way movements has proven to be a difficult task. To start with, they are relatively infrequent and persons whose driving ability is up to par seldom make them. The problem if further compounded by the very large number of locations where wrong-way movements can be made. One overall impact of these

TABLE 11: Average and Wrong-Way Driver Annual Mileages

Source: 7, pp. 32

Age Group	Annual Mileage Driven by the Average Driver	Annual Mileage Driven by the Wrong-Way Driver
16 to 29	14,400	13,000
30 to 39	18,500	15,900
40 to 49	16,200	15,000
50 to 59	16,000	13,300
60 to 69	14,900	10,400
70 to 79	8,300	Not Available
80 and over	13,000	Not Available

factors is that it is very difficult to identify problem locations, and, correspondingly, equally as difficult to isolate variables that contribute, or inhibit, wrong-way movements.

Signing for Wrong-Way Movement Prevention

Efforts to date have concentrated chiefly on signing and to a lesser extent on geometric design. As a wrong-way movement prevention system, signing has several desirable characteristics, notably that most drivers respond favorably to it and it is relatively inexpensive. Studies conducted by the California Division of Highways have given some measure of the effectiveness of signing in reducing the wrong-way movements. Tamburri (7) reported that after the installation of various wrong-way prevention signing packages, as well as directional pavement arrows, wrong-way driving at night was reduced 60% on freeways and 70% on expressways. On the basis of accidents per vehicle mile wrong-way accidents on California freeways were reduced 22%.

Over the years fairly sophisticated wrong-way signing systems have been developed. Figures 2, 3, and 4 detail three types of signs usually located at the entrances of one-way roads depending on the direction of traffic flow. The signs in Figure 4 are also located approximately 200 feet up a one-way road. The sign in Figure 5 is used to

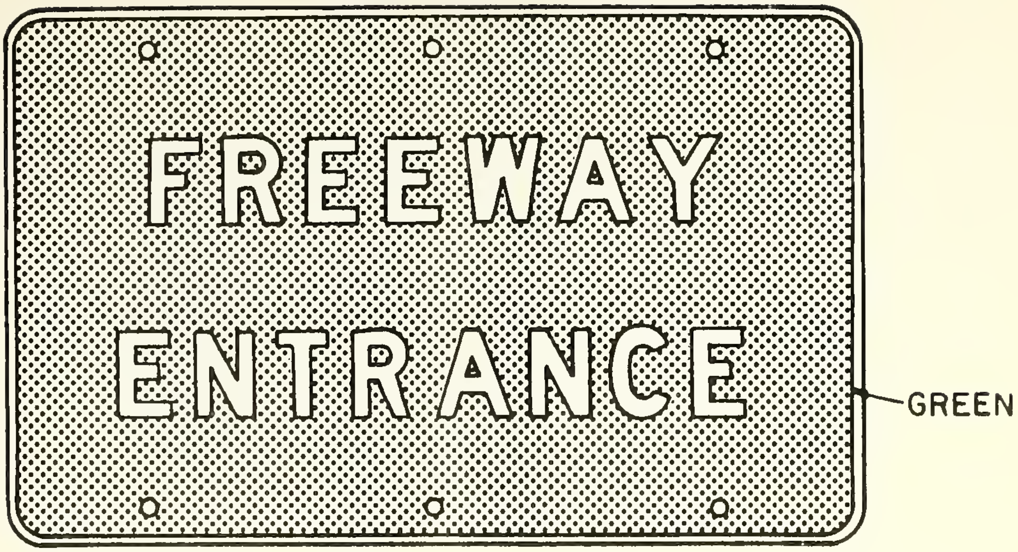


FIGURE 2. FREEWAY ENTRANCE SIGN

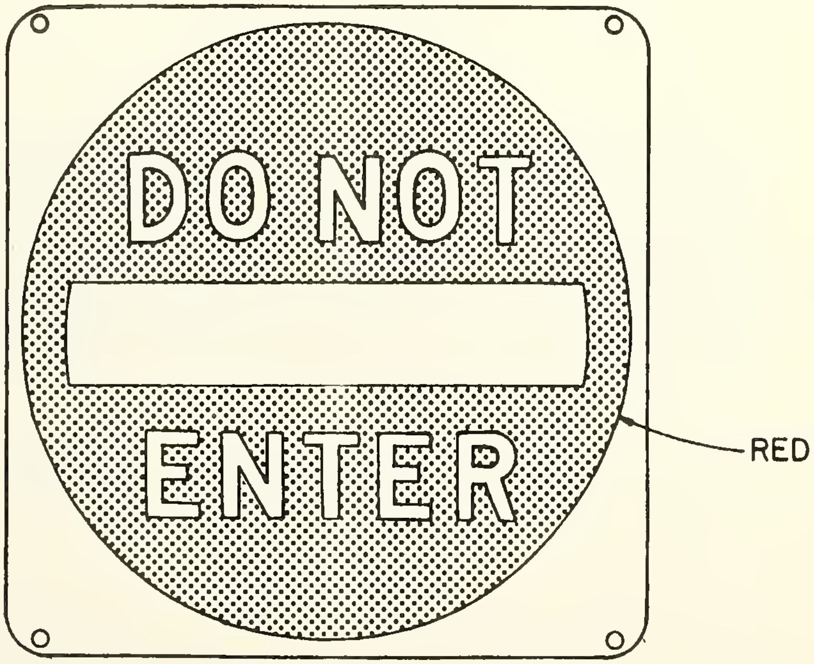
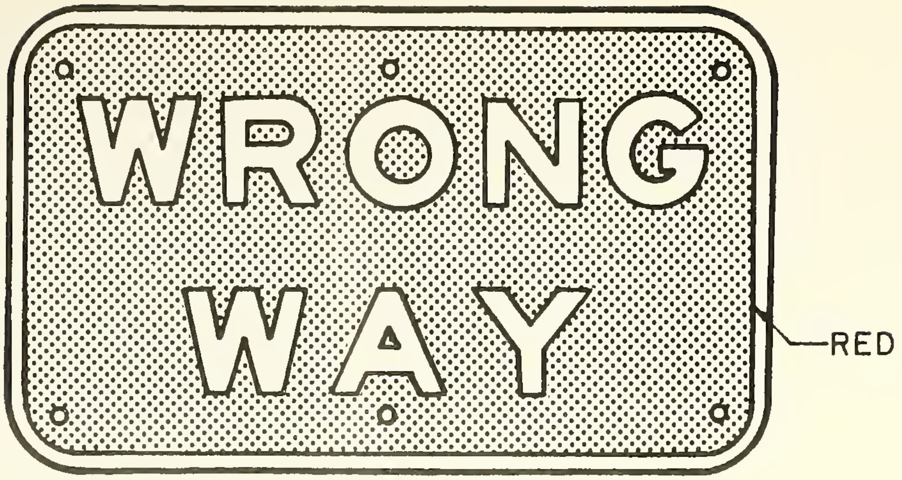


FIGURE 3. DO NOT ENTER SIGN



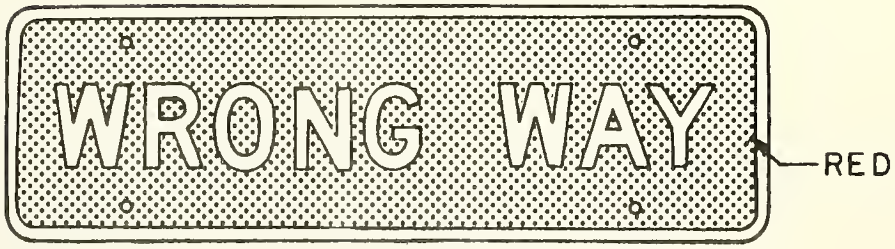


FIGURE 4. WRONG WAY SIGNS

show drivers the proper direction of travel on a one-way road. The sign in Figure 6 is used to direct traffic to the proper road if the two one-way roads (opposite directions) are adjacent. Turn prohibition signs (Figure 7) are used to supplement the other signs, previously described, at the entrance to a one-way road.

Pavement Markings for Wrong-Way Movement Prevention

As noted earlier, pavement arrows have had some effect in reducing the frequency of wrong-way movements. FHWA Instructional Memorandum 21-9-71 issued in August 1971 states:

> One or more arrow pavement markings also shall be placed in each lane of an exit ramp near the crossroad terminal, at a location where it would clearly be in sight of a wrong-way driver (3, pp. 3).

Also, Tamburri said:

> ...it is believed that the small, white pavement arrows painted on all off ramps between the first and second incident studies had a pronounced effect in reducing wrong-way entries (7, pp. 32).

Geometric Design for Wrong-Way Movement Prevention

Attempts to reduce wrong-way movements through modified and improved geometric design have been made in four areas.

First, researchers have classified wrong-way movements originating from interchanges by the types of

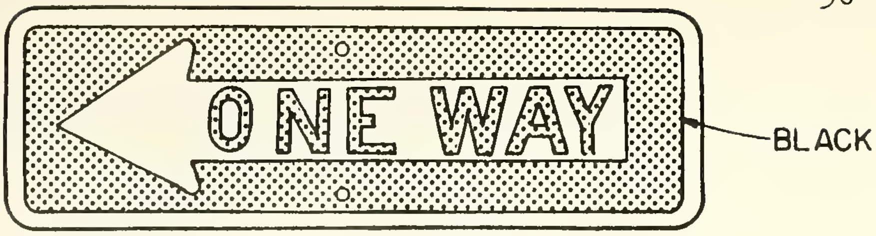


FIGURE 5. ONE-WAY SIGN

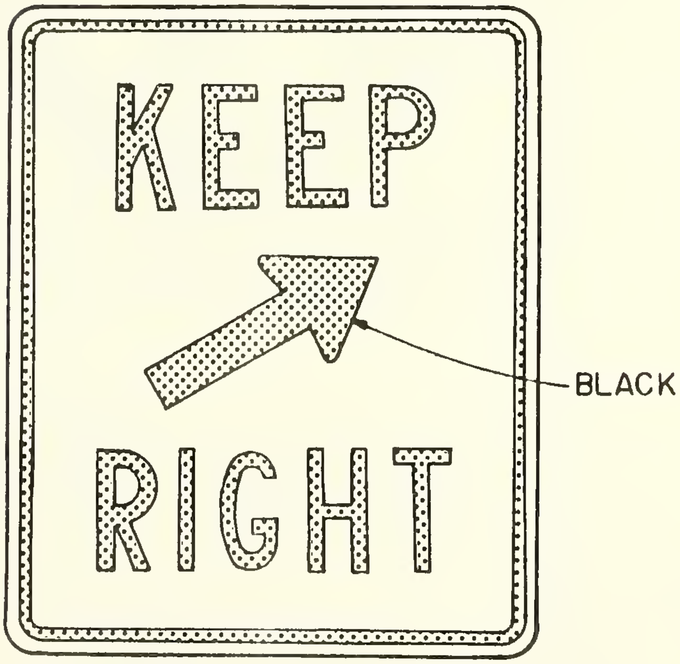


FIGURE 6. KEEP RIGHT SIGN

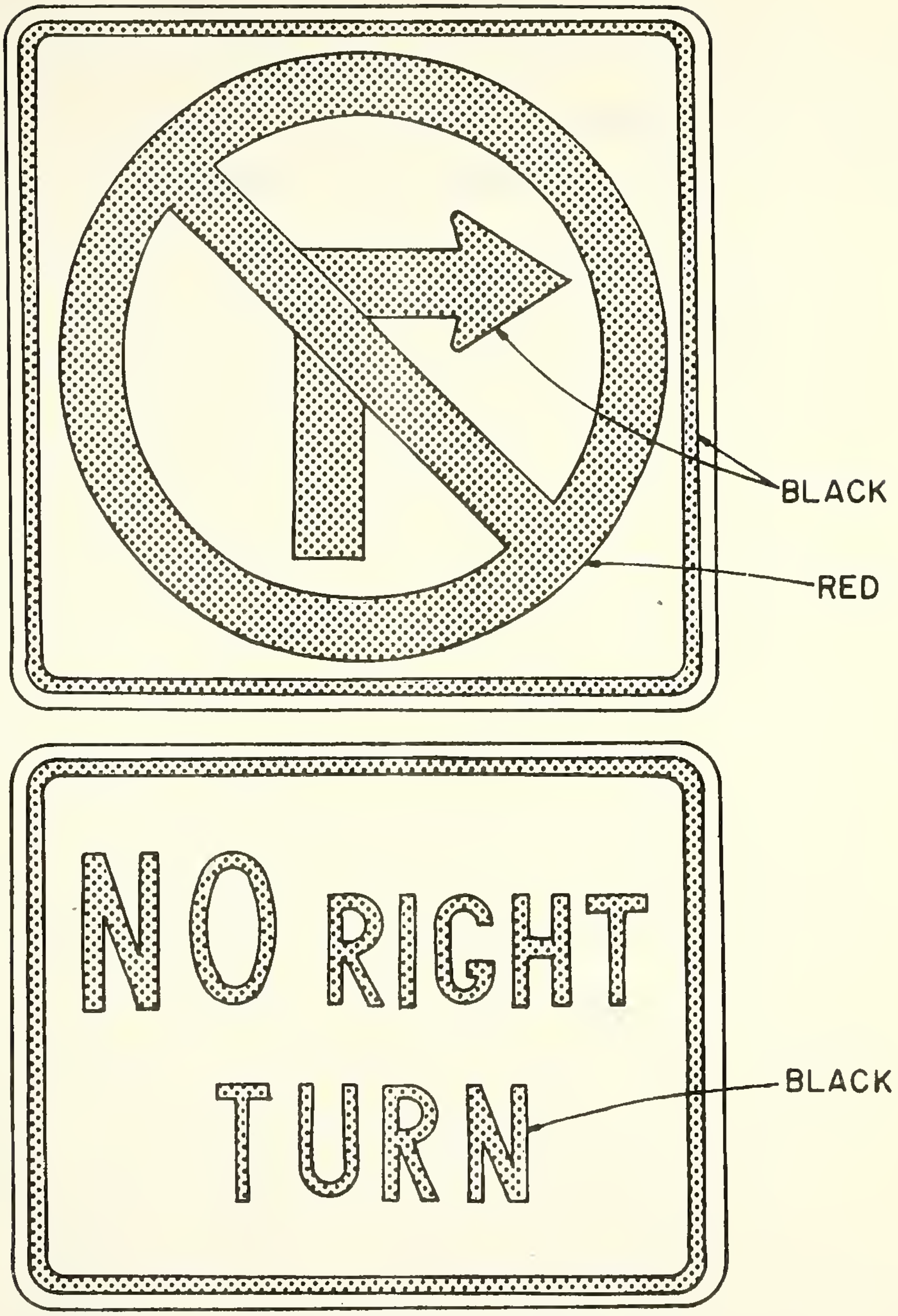


FIGURE 7. NO RIGHT TURN SIGNS

interchange. Unusual designs (trumpet, scissors, etc.) and those that do not provide for all movements, have a much higher incidence of wrong-way movements (see Table 12). As a result, many highway departments discourage or prohibit the use of these designs.

Second, efforts have been made to improve the design of the ramp/crossroad interface to make wrong-way entry via interchange exit ramps more difficult. Although there is little published research on this concept, FHWA Instructional Memorandum 21-9-71 briefly outlines approaches to redesigning this interface. Basically, the edge or curb on the left side of the exit should be of a small radius to make right turns into the exit ramp difficult. Also, median openings, whether physical or painted, should be located to make left turns into the exit ramp difficult (see Figure 8). These modifications have considerable promise to keep drivers who are confused, tired, drunk, etc. from making wrong-way movements. They would probably not be too effective against a deliberate wrong-way driver but not much can be done about that problem except law enforcement.

Third, in order to reduce the likelihood of a wrong-way accident once a wrong-way movement has been made, Tamburri (7) recommended that the sight distance on all divided highways be at least 1200 feet. Making certain assumptions about vehicle speeds and the time needed for evasive manuevers, it was calculated that a sight distance

TABLE 12: Wrong-Way Entry Rates by Interchange Type

Source: 10, pp. 7

Interchange Type	Wrong-Way Entry Rate (Incidents per 100 Ramp-Years)
Four-quad Cloverleaf	2.00
Buttonhook	4.12
Parclo	6.08
Diamond	7.46
Trumpet	14.19

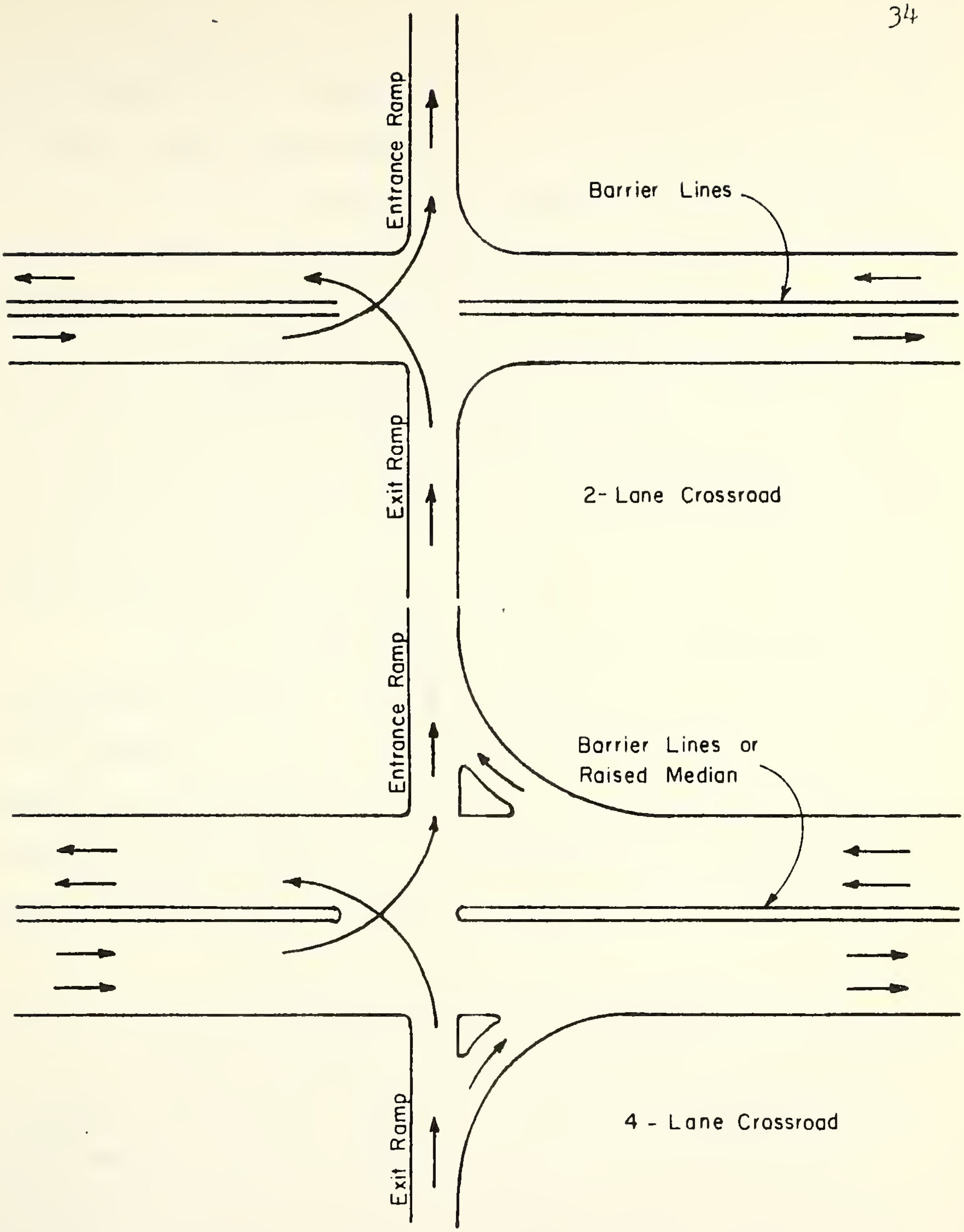


Figure 8 Median Opening Positioning to Discourage Wrong-way Movements

of 1200 feet was necessary to allow a right-way driver time to avoid a wrong-way driver.

The fourth aspect of improved geometric design has been the development of interchange configurations that automatically redirect wrong-way vehicles. In a 1969 article appearing in Traffic Engineering, Goodman (8) proposed the use of so-called "ear ramps" that would direct wrong-way drivers back to the crossroad. Typical "ear ramp" layouts are shown in Figures 9 and 10. There is no known operational experience with these designs.

It is significant to note that of all the modifications in geometric design discussed, most of them deal with freeways (Class A) or freeway interchange. This suggests that there may be much to learn about how to prevent wrong-way movements at intersections of divided highways through improved geometric design.

Warning and Disabling Mechanisms

The California Division of Highways has developed a system that detects and warns vehicles entering freeway exit ramps in the wrong direction (9). A directional detector of the induction loop type was used to actuate lights and horns when a wrong-way vehicle went over the loop. To increase the effectiveness of the lights, they were trained on white-on-red reflective background sign with the message "GO BACK -- YOU ARE GOING -- WRONG WAY".

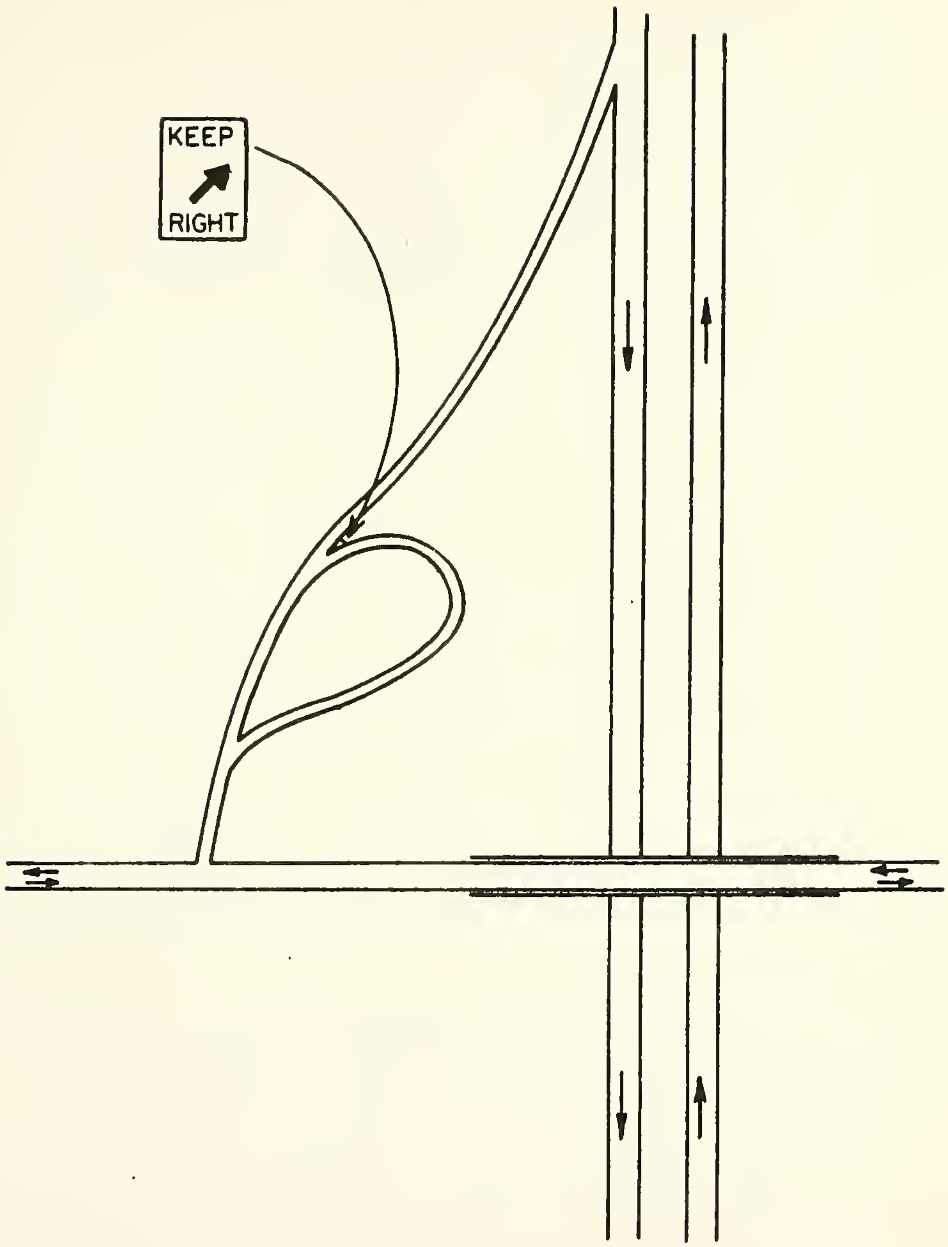


Figure 9 Ear Ramp — Redirection of Wrong-way Vehicle to the Crossroad

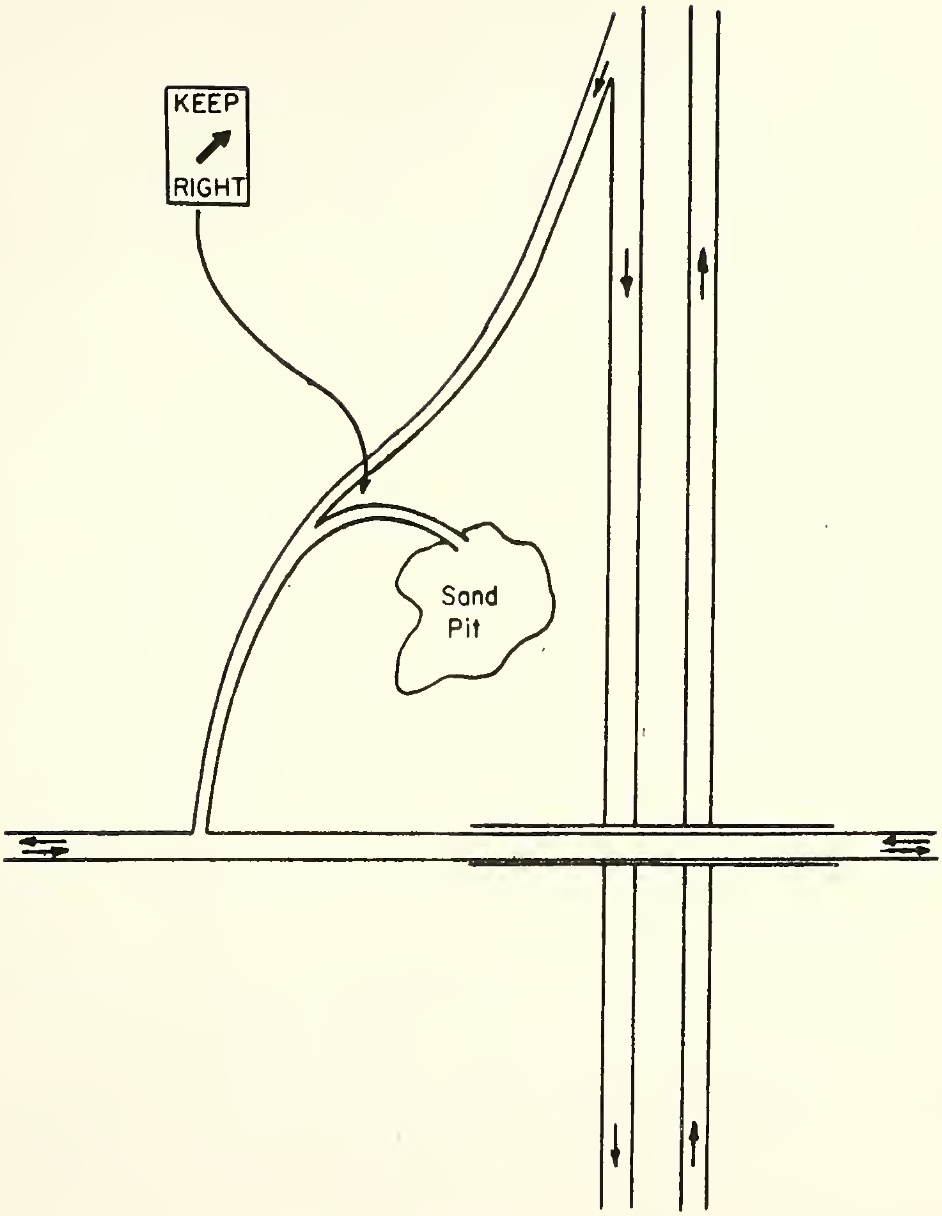


Figure 10 Ear Ramp — Disabling of Wrong-way Vehicle in a Sand Trap

This mechanism was quite effective as 89% of the drivers who actuated the device stopped, backed up or turned around. Wrong-way entry to the freeway was reduced by 54%.

Two types of vehicle disabling mechanisms have been considered in the past--one-way spike barriers and reverse delineations to guide wrong-way vehicles off the road into a sand trap. A serious drawback to either of these methods is the possibility of legal action against state highway departments installing them.

During tests, several operational problems of the wrong-way spike barrier were noted. Although the tires of wrong-way vehicles were easily punctured by the system it took sometime for the tires to deflate allowing the vehicle to reach the freeway. The spikes themselves were sometimes damaged and the presence of the spikes often led to panicky reactions by right-way drivers who could not distinguish the direction that the spikes were pointing.

Little operational data was available on the effectiveness of the reverse delineators in guiding wrong-way vehicles off the freeway.

Summary

The major conclusions of this literature review were as follows:

1) Wrong-way accidents are very severe and represent a significant highway safety problem.

2) Drivers making wrong-way movements are usually less skillful than the average driver and their driving abilities are often degraded by alcohol, age, and other factors.

3) Relatively advanced and effective signing and pavement marking systems have been developed for divided highways with and without fully controlled access.

4) Some research on improved geometric design to reduce the frequency of wrong-way movement on divided highways with fully controlled access has been conducted. Many of these ideals have not been implemented or fully developed.

5) A warning system installed on freeway exit ramps, triggered by the passage of a wrong-way vehicle has demonstrated some effectiveness in alerting wrong-way drivers to their mistakes.

CHAPTER III

OBJECTIVES AND WORK PLAN

Objectives

As noted in the introduction, this research study has attempted to develop and refine knowledge of the wrong-way movement problem on Indiana highways. The specific objectives, originally outlined in the research proposal (13), were as follows:

1) A quantitative assessment of the frequency of wrong-way movements on selected sections of highways with and without fully controlled access.

2) An evaluation of the effects existing geometric design practices, including channelization and median design, have on the frequency of wrong-way movements on divided highways without fully controlled access.

3) An evaluation of the effects existing driver information practices have on the frequency of wrong-way movements on divided highways without fully controlled access.

4) Proposals for alternative geometric design practices to reduce the frequency of wrong-way movements on divided highways without fully controlled access.

5) Proposals for alternative driver information practices to reduce the frequency of wrong-way movements on divided highways without fully controlled access.

During the execution of the project these objectives were somewhat modified and generally expanded with fully controlled access highways receiving more consideration than originally proposed.

Work Plan

The initial work plan was also altered slightly. During Phase I twenty-one man-days were expended examining some 30,000 accident reports for wrong-way accidents. Over 99% of all divided highway mileage in Indiana for the years 1970, 1971, and 1972 was surveyed with approximately 100 wrong-way accidents found. Information from the accident reports was recorded on a data form as shown in Figure 11.

Phase II of the work plan involved gathering data on the sites where these wrong-way movements originated. All 100 sites were subjected to field investigations requiring about 75 man-days of effort; the data forms in Figures 12 and 13 were used to compile pertinent characteristics of the sites. Many times the origin of the wrong-way movement was not specified in the accident report forcing special efforts in the field. In these cases attempts were made to reconstruct the course of the wrong-way driver and to isolate his probable entry point. When a probable entry point could not be determined notes were taken on characteristic access points in the area.

Road: ____________

County: ____________

Date: ________

Day: ________

Time: ________

Location:

____

____

Comments:

____

____

____

Weather: ____________

Alcohol: ____________

Volume: ____________

Accidents: ____________

________ ____________

________ ____________

Diagram:

Note Appx. Scale: ________

Injuries: ____________

Property Dmg: ________

N

Figure 11. Accident Report Data Sheet

Wrong-Way Movement Site Report (Non-Interstate)	Date ________ Time ________	Sector ______ Acc # ______

Area Land-Use ____________________________

Area Land-Use Density ________________________

Terminal Types ____________________________

Access Points/1000' __________

Median Gaps/ 1000' __________

X-Road Volume ____________________________

Volume __________ Acc. Freq. ____________ Speeds ________

Comments ______________________________

Wrong-Way Movement Origin Analysis	Confirmed Possible	Probable No Analysis

Comments ______________________________

Wrong-Way Movement
Origin/Site Report

Signing ______________________________

Geometrics ______________________________

Visibility ______________________________

Pvmnt. Mrkngs. ______________________________

Other ______________________________

Figure 12. Field Data Sheet, Page 1

Wrong-Way Movement Site Diagram	1. Apprx. Scale 2. Note Directions 3. Note Topography 4. Note Visibility Restrict.

Figure 13. Field Data Sheet, Page 2

After the data collection phases were completed analysis work was initiated. The relationships of the nature and characteristics of the wrong-way accidents and drivers to objectives 2 through 5 was clear. Consequently, Phase III was devoted to a computer analysis of about ten parameters of these factors. Various findings and statistical summaries were constructed.

The fourth and final phase involved the use of the findings reached in Phase III in conjunction with the field data previously collected. Significant variables of the access points to divided highways were isolated and explored. The key to this analysis process was an interaction of the field data, previous published research and the transportation engineering expertise of those involved in the project. After the characteristics of divided highway access points influencing wrong-way movements were determined, they were evaluated to determine how they could be modified to reduce the frequency of wrong-way movements.

It must be understood that, both statistically and practically, wrong-way movements are a very rare event. The resulting lack of a well defined inference space made the reaching of rigorous conclusions, in a statistical sense, impossible; however, the findings presented in fulfillment of this research project's objectives have been studied carefully and correlated as closely as possible with existing data and knowledge. They should be of use to Indiana State Highway Commission in dealing with the wrong-way movement problem.

CHAPTER IV

WRONG-WAY ACCIDENT CHARACTERISTICS

As was noted earlier, approximately 100 wrong-way accidents occurred on Indiana's divided highways during 1970, 1971, and 1972. The data on the wrong-way accident situation was collected by a manual search of the Indiana State Police accident records for divided highways located outside of the city limits. Naturally, a manual search of accident records leaves open the possibility of error; although it is unlikely that an overcount of wrong-way accidents occurred, a small undercount may have taken place. In any event, care was taken to minimize the possibility of this happening.

The information collected on wrong-way accidents was divided into four general categories and is presented by those categories within this chapter. The categories are:

1) Numbers and location
2) Type and severity
3) Time and date
4) Environmental factors

Data on each of these groups are presented and discussed; at the end of this chapter, overall significant findings are listed.

Numbers and Location

Ninety-six wrong-way accidents occurred in Indiana during the study period on virtually all divided highways within the state.

The breakdown of wrong-way accidents by road types are as follows:

1) State or US Routes had 58 accidents.
2) Interstate Routes had 38 accidents.
3) Total accidents were 96.

Using access classification as the criteria, the breakdown is

1) Fully-controlled roads had 40 accidents.
2) Not fully-controlled roads had 56 accidents.
3) Total accidents were 96.

Generally speaking no road, road type, or area was immune from the problem; conversely, there did not appear to be any significant concentrations of wrong-way accidents by any of these categories.

Examining the access classification variable more closely, it was found that wrong-way accidents are more frequent on highways without fully controlled access, both in terms of accidents/mile and accidents/vehicle-mile.

This can be demonstrated by noting that divided roads with fully controlled access (i.e., the Interstate system and part of US 50 in Knox County) carry higher volumes and have greater mileage than those without fully controlled access. Also, divided roads with fully controlled access had fewer accidents during the study period. Therefore, the conclusion that roads without fully controlled access have a higher wrong-way accident rate in terms of accidents/mile and accidents/vehicle-mile is inevitable.

Type and Severity

Because of their nature, wrong-way accidents are generally of the head-on type, although the data showed that this was not always the case. Often wrong-way vehicles caused right-way vehicles to run off the road or to sideswipe when trying to avoid a collision.

As discussed in the literature review, data collected in other states have generally indicated that wrong-way accidents are abnormally severe, typically involving more casualties than the average accident. The data collected for this research project have tended to confirm this finding. Of the ninety-six wrong-way accidents studied:

27 had one or more fatalities

29 had one or more injuries but no fatalities

40 had property damage only

Therefore, 28.1% of all wrong-way accidents were fatal compared with 0.67% of all accidents in Indiana resulting in fatalities. Wrong-way casualties for the three year study period were 39 dead and 74 injured.

In Table 14, these statistics are broken down by highway access type.

Clearly, wrong-way accidents occurring on highways with fully controlled access are more severe than on highways without control, probably because of the higher speeds on such facilities. Fully controlled highways had 46% fatalities, while highways without full-access control had only 17%.

Using accident cost data developed by Winfrey (14) and projected to 1972 using a 5 percent per year compounded interest, yearly costs of wrong-way accidents to the state were calculated. The costs in Table 15 were assigned to each accident type and multiplied by the number of accidents. The yearly cost of wrong-way accidents for Indiana was over 121,000 dollars.

Time and Date

Figures 14, 15, and 16 present time and date of occurrency data on Indiana's wrong-way accidents. Where the data does not sum to 96 accidents, information was not available.

Interpreting these graphs it can be noted that there is little significance in the monthly distribution

TABLE 13: Wrong-Way Accidents by Type

Type	Number
Head-on	69
Sideswipe	2
Rear-end	4
Run-off-the-road	6
Right-angle	8
Head-on with secondary collisions	6
TOTAL	95

TABLE 14: Access Control vs. Wrong-Way Accident Severity

Access Type	Fatal Accidents	Injury Accidents	Property Damage Accidents
Fully Controlled	17	12	8
Not Fully Controlled	10	17	32

TABLE 15: Accident Costs

Type of Accident	Total Cost (dollars) per Accident
Property Damage	242
Injury	2,110
Fatal	10,988

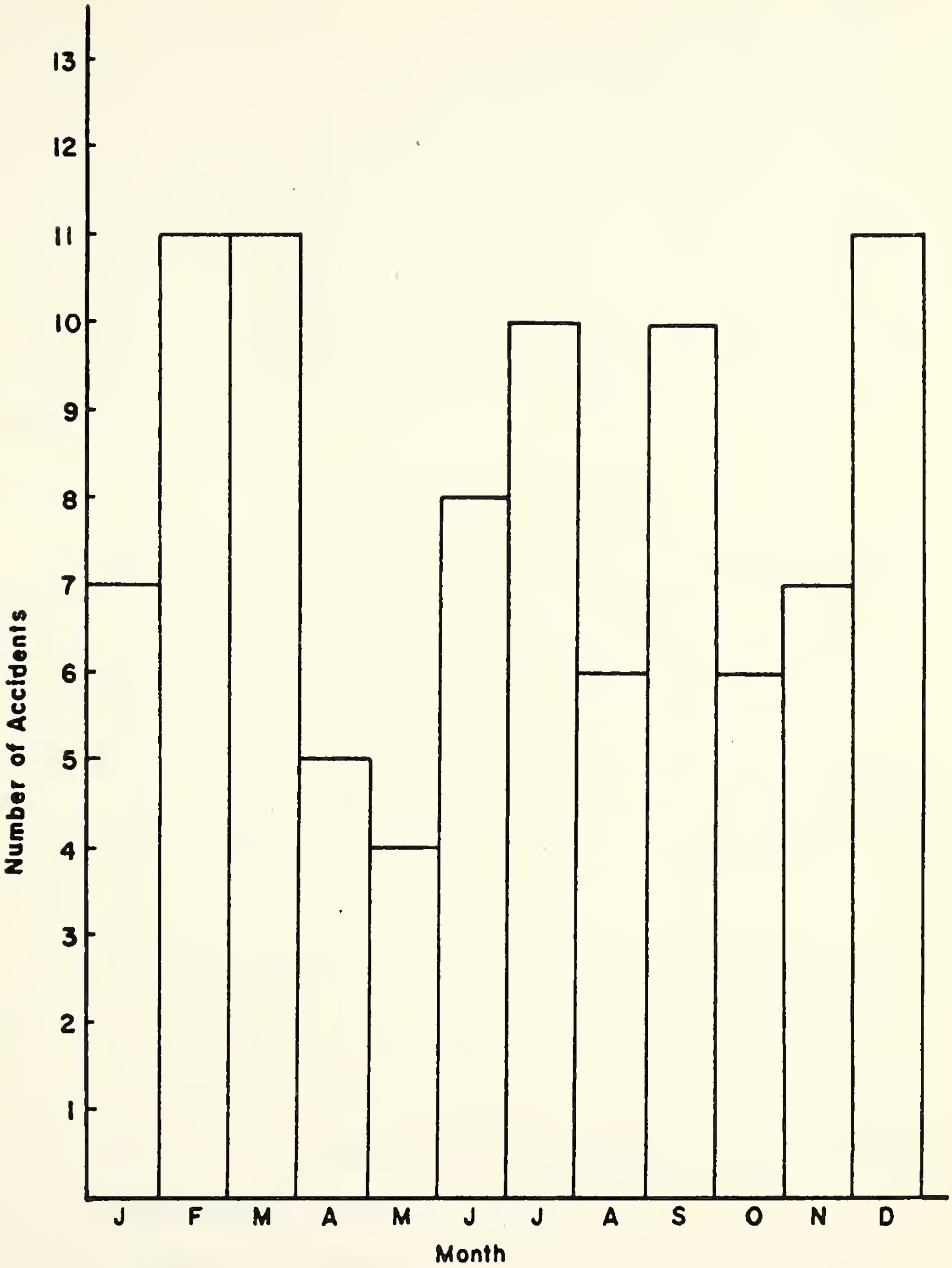


Figure 14 Wrong-way Accidents By Month of Occurrence

of wrong-way accidents. However, in Figure 15, wrong-way accidents are concentrated on Friday, Saturday and Sunday. In the literature this has been attributed to the greater number of drunken drivers on the road on these days. In Figure 16, wrong-way accidents occur more frequently than average between the hours of 6:00 p.m. and 4:00 a.m. This phenomenon has been variously explained by reduced visibility during these hours and the greater tendency for drivers to be fatigued and/or drunk during these hours.

Environmental Factors

Data on environmental factors pertaining to where and when the wrong-way accidents occurred was available from the accident reports. Three factors, weather, visibility and land-use, were considered in this phase of the analysis; due to the non-numerical nature of these parameters approximate qualitative terms were employed as parameter levels.

The weather at the time and location of the accidents was as follows:

74 accidents occurred during clear weather.
5 accidents occurred during rain
4 accidents occurred during snow
1 accident occurred during fog

The weather conditions were not known for 12 accidents. In the majority of the accidents, the weather was dry and clear leading to the finding that weather was not

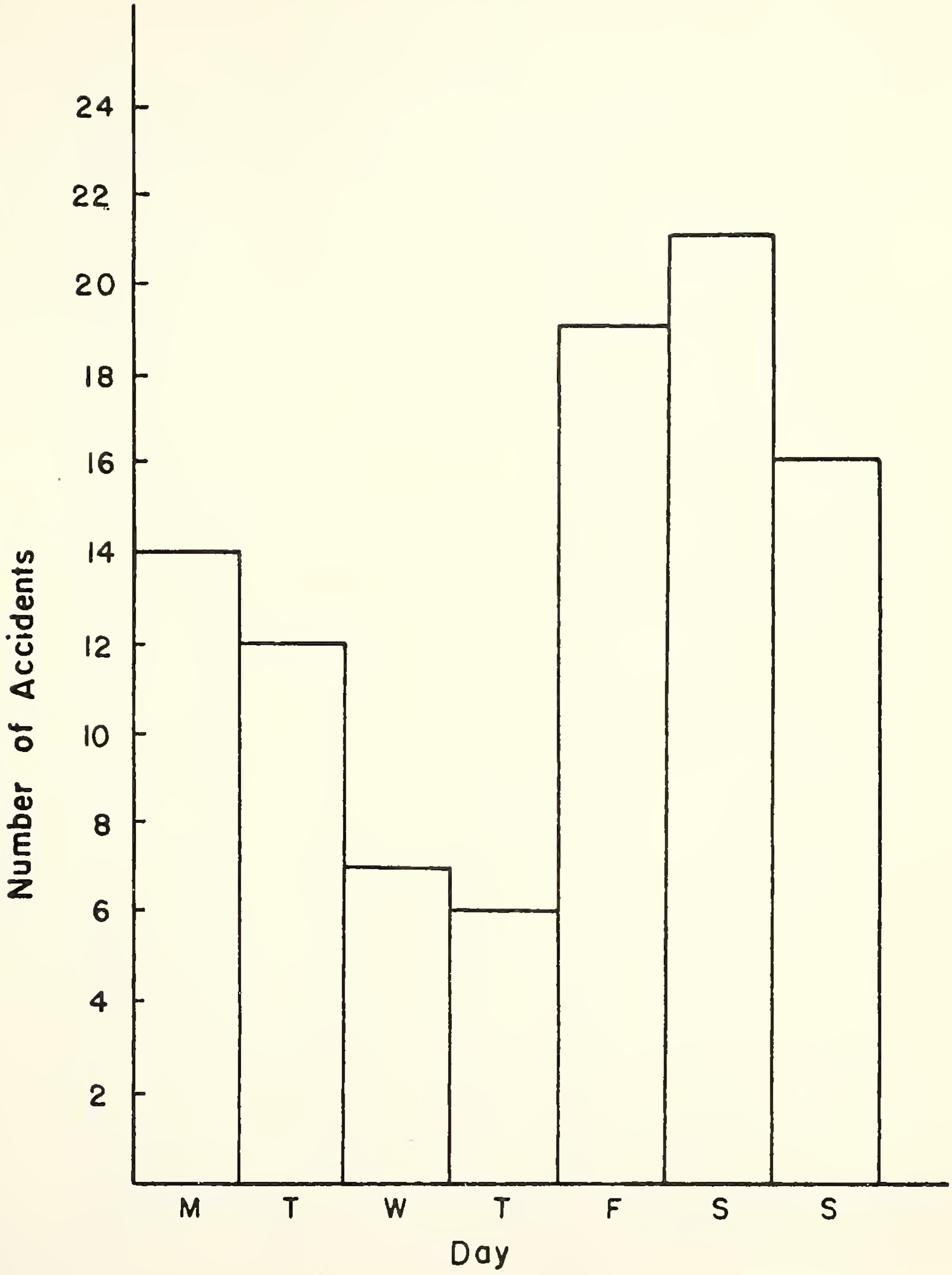


Figure 15 Wrong-way Accidents By Day of Occurrence

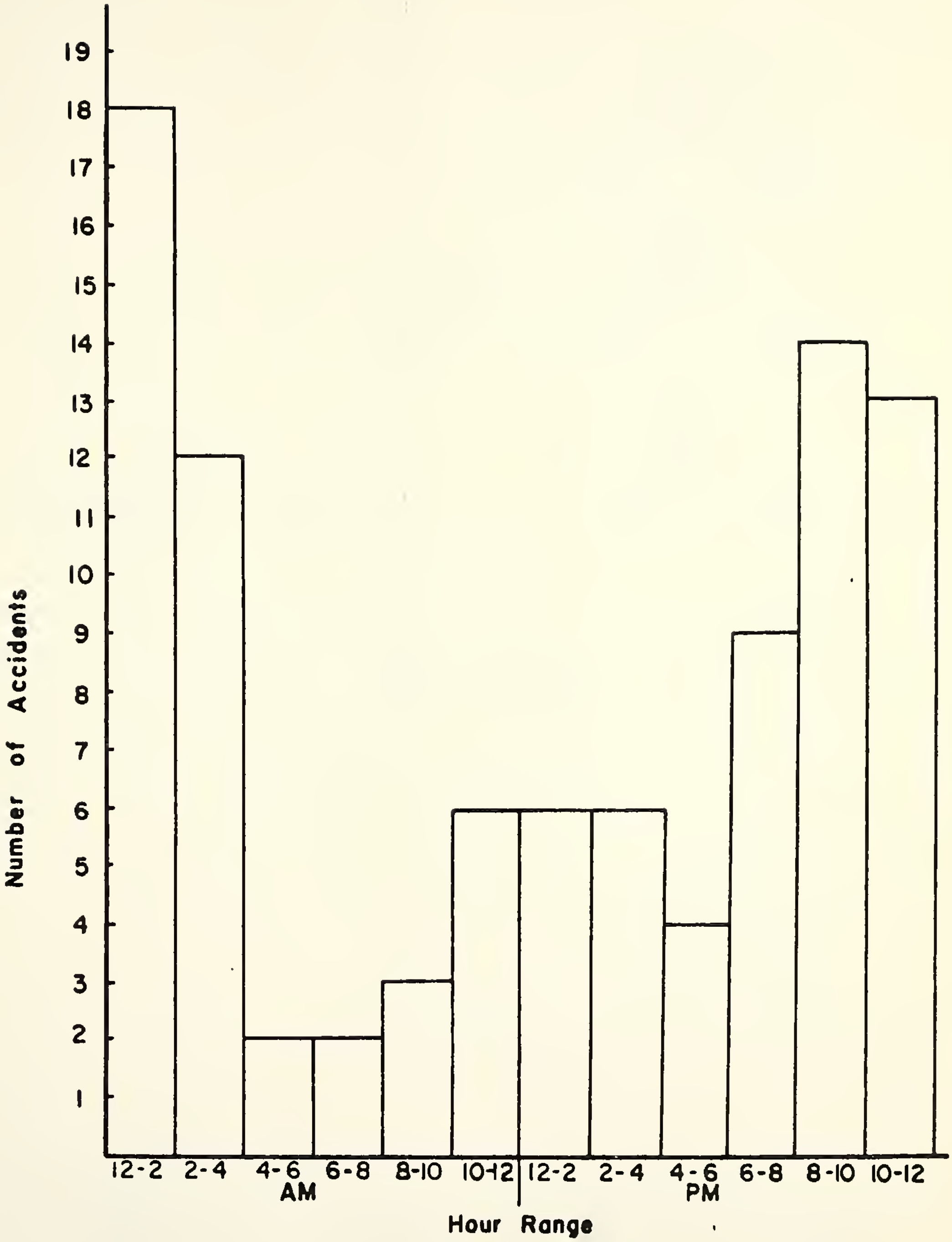


Figure 16 Wrong-way Accidents By Hour of Occurrence

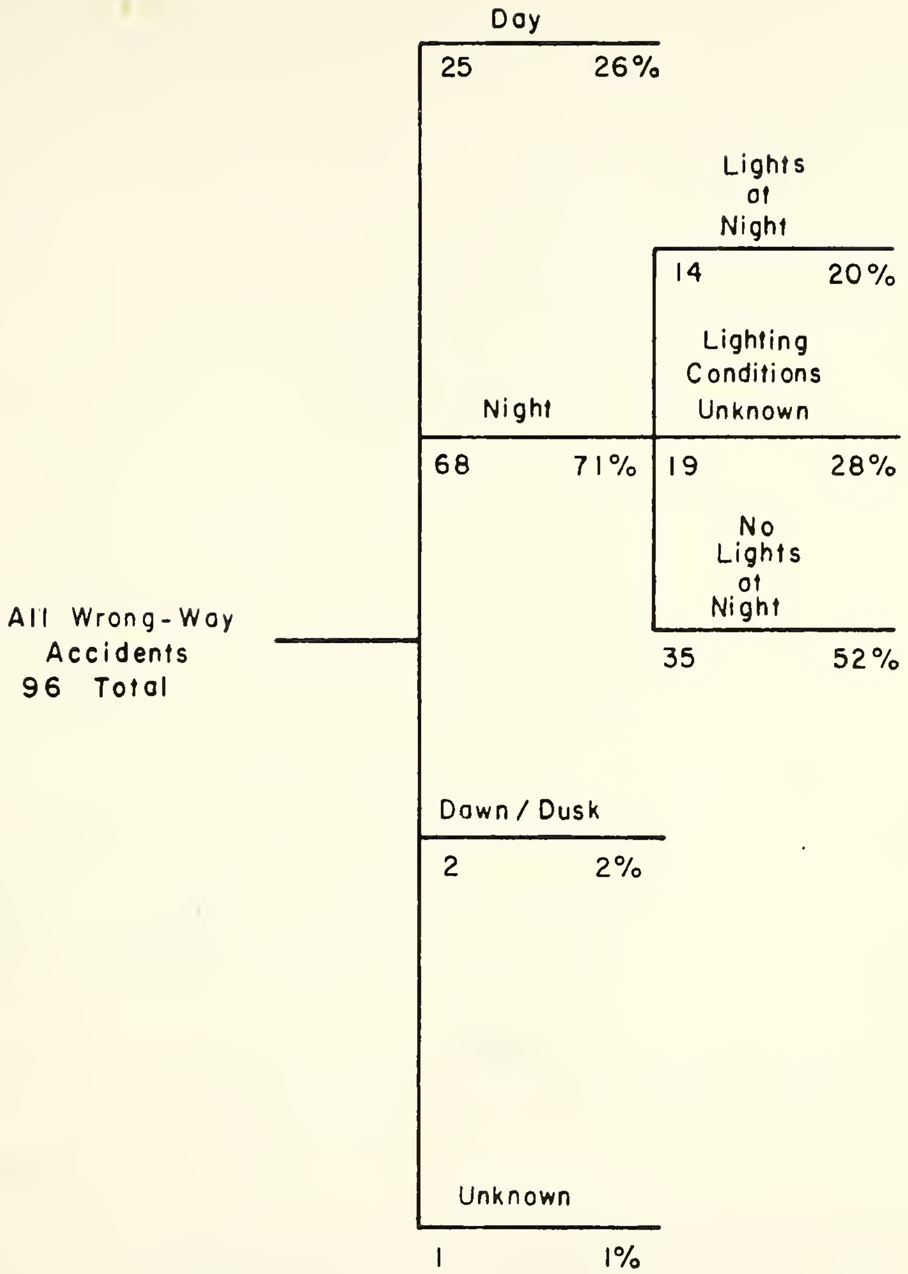


Figure 17 Visibility Conditions At Wrong-Way Movement Origin Areas

a significant variable in wrong-way accident causation.

Visibility conditions at wrong-way accident sites were generally poor as most of the accidents occurred at night on unlit portions of a highway. Figure 17 shows the visibility situation at the area where the wrong-way movement, leading to the wrong-way accident, began. Interpreting Figure 17, 35 accidents occurred under conditions of darkness, 16 during conditions of marginal visibility (dawn, dusk or lighted area at night), 25 during daylight and 20 under unknown lighting conditions. Most of the 20 accidents in the last category apparently occurred either under marginal conditions or in darkness.

Data on the area land-use of the wrong-way movement origins are presented in Table 16. Although definitive trends were hard to establish, these wrong-way movements tended to occur in areas of low land-use density.

Summary

To conclude the chapter the major findings are presented.

1) In terms of accidents/mile and accidents/vehicle-mile, wrong-way accidents are a larger problem on highways without fully controlled access.

2) Wrong-way accidents are exceptionally severe in nature. They are more severe on highways with fully controlled access than on those without.

TABLE 16: Wrong-Way Movement Origin Area's Land-Use Type and Density

LAND-USE DENSITY	LAND-USE TYPE: Commercial	Farm	Industrial	Residential
Very Light	4	25	0	3
Light	5	10	3	14
Medium	7	0	0	1
Heavy	4	0	0	0

3) The yearly cost of the wrong-way accident problem to Indiana is approximately 121,000 dollars.

4) Wrong-way accidents are more common than average on Fridays, Saturdays, and Sundays and also between the hours of 6:00 p.m. and 4:00 a.m.

5) The wrong-way movements, leading to wrong-way accidents, tend to originate from times and areas of restricted visibility and low land-use density.

CHAPTER V

WRONG-WAY DRIVER CHARACTERISTICS

An examination of driver characteristics is important, because wrong-way movements are primarily caused by breakdowns in the highway/driver communication system. Within this chapter factors that possibly contribute to this breakdown are raised and discussed. These factors are:

1) Age
2) Sobriety
3) Fatigue

Age

Eighty-one observations on wrong-way drivers' age were available from accident record data. Table 17 was generated by breaking down wrong-way accidents by age group. Both older and younger drivers are disproportionately represented in terms of the data developed in Table 10 suggesting that age is related to wrong-way movement proneness. The available information on this problem was not sufficient to definitely ascertain the nature of the relationship; however, other research (7) has shown that driving abilities, in terms of wrong-way accidents, increase and then decline

TABLE 17: Wrong-Way Accident Distribution by Age Group

Age Range	Number of Wrong-Way Accidents
0-20	6
21-30	21
31-40	13
41-50	13
51-60	10
61-70	10
Over 70	8

with increasing driver's age. This data may be indicative of the trend.

Sobriety

Driver sobriety was one factor that clearly stood out as a cause of wrong-way accidents. In 19 of 96 wrong-way accidents the sobriety of the driver was not known; however of the 77 in which it was known the driver was drunk 54.6% of the time (42 observations of drunkness). This is obviously a far higher percentage than would be true for a sample of 77 random drivers.

The reduction in mental capabilities caused by alcohol seems to increase the tendency of drivers to make wrong-way movements.

Fatigue

The information available did not provide a direct measure of driver fatigue therefore, forcing the use of a somewhat circumspect methodology. If fatigue is assumed to be highly correlated with time of accident, Figure 16 is of considerable use. Thirty-three of all wrong-way accidents occurred between the hours of 12:00 a.m. and 6:00 a.m., times when drivers are likely to be fatigued.

To complete this analysis the three wrong-way driver variables were overlayed on each other to determine the number of drivers adversely influenced by at least one of the variables. The meaning of "adversely influenced" is both subjective and ambiguous. However, for the purposes of the analysis the following definitions were used:

Age: Over 65 years old

Sobriety: Driving under the influence of alcohol

Fatigue: Driving between 12:00 a.m. and 6:00 a.m.

Using these definitions, Figure 18 was developed. The problem of the wrong-way driver is illustrated graphically--only 31% were not adversely influenced by one or more of the three variables. In general, it appears that drivers who are older, drunk or driving late at night are far more likely to be involved in wrong-way accidents than a driver whose abilities are not reduced.

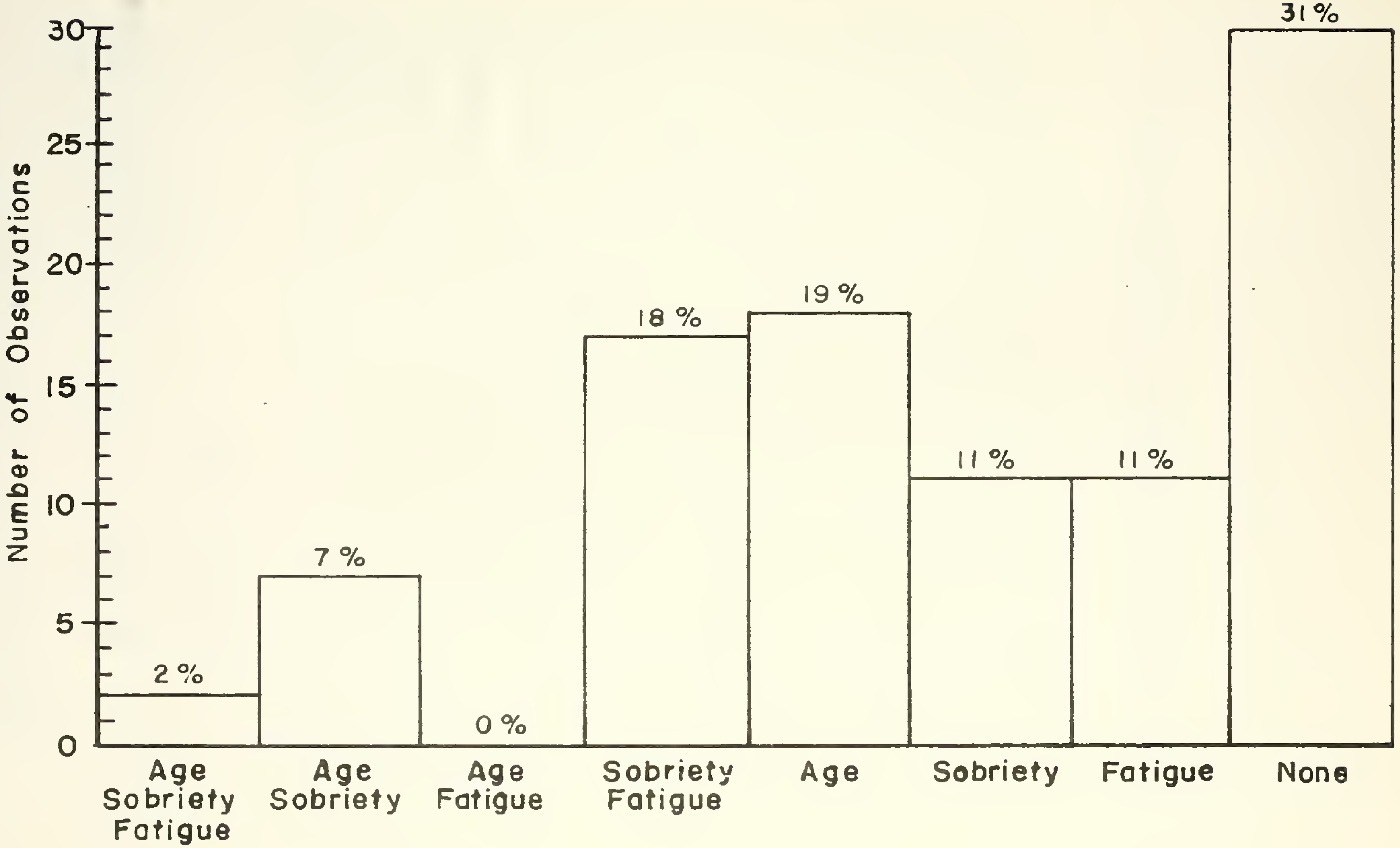


Figure 18 Adverse Influence Factors on Wrong-Way Accidents

CHAPTER VI

CHARACTERISTICS OF WRONG-WAY MOVEMENT ORIGIN SITES

In Phase II of this study, characteristics of wrong-way movement origin sites were determined by means of the field investigations described in Chapter III. The data dealt primarily with the physical characteristics of these sites; however, other factors such as area land-use and traffic volumes were also considered. Two problems were encountered during the field investigations. First, the origin or the beginning of a wrong-way movement was often not specified in the wrong-way accident report and could only be approximately located in the field. Second, there was no quantitative method to measure most of the parameters that were considered important. The net effect of these problems was to force the use of a qualitative analysis of the origin locations of the 57 (of 96 total) wrong-way accidents which had sufficient origin data.

Data Presentation

Initially, the wrong-way movement origin sites were divided into six general categories. The categories were:

1) Diamond and Parclo Interchanges

2) Cloverleaf and Directional Interchanges

3) Major Intersections

4) Minor Intersections

5) Driveways

6) Transitions

The second category was not analyzed due to the lack of conclusive data. However, examples and discussion of the other five categories are presented in the following sections.

Diamonds and Parclos

Figure 19 illustrates a typical access point of this category. It is a diamond interchange providing access to I-74 from S. R. 39. The crossroad is two lane, undivided and has adequate wrong-way signing. Area land-use is light. The driver who made the wrong-way movement was very old and apparently confused as he asked a gas station attendant for directions three times. While it was not possible to assign a definite cause to this wrong-way movement, the drivers reduced ability was a major factor.

The information on the characteristics of the diamond and parclo interchanges where wrong-way movements originated (a total of 24 accidents) is presented in Table 18. Wrong-way movements tended to occur at interchanges where lighting was not always adequate, traffic volumes were low and land-use was light. Signing was

TABLE 18: DATA ON DIAMOND AND PARCLO WRONG-WAY MOVEMENT ORIGIN SITES [a]

		Confirmed	Probable[b]
Interchange configuration simple and non-confusing	yes	5	15
	no	0	4
Channelization and curbs to restrict vehicle paths	installed	3	5
	not installed	2	14
Signing Quality	satisfactory	5	14
	minimal	0	5
Lighting at the time of the wrong-way movement	daylight	3	1
	night but with artifical lighting	1	3
	night	1	15
Area Land-use intensity	none or one building	3	16
	two or three buildings	2	3
	more than three buildings	0	0
Approximate traffic volumes on the divided highway at the time of the wrong-way movement	less than 100 v.p.h.	2	16
	100 to 300 v.p.h.	2	2
	more than 300 v.p.h.	1	1

[a] The number of wrong-way movements originating from an access point of this type.

[b] The origin points for some wrong-way movements were not known with complete certainty.

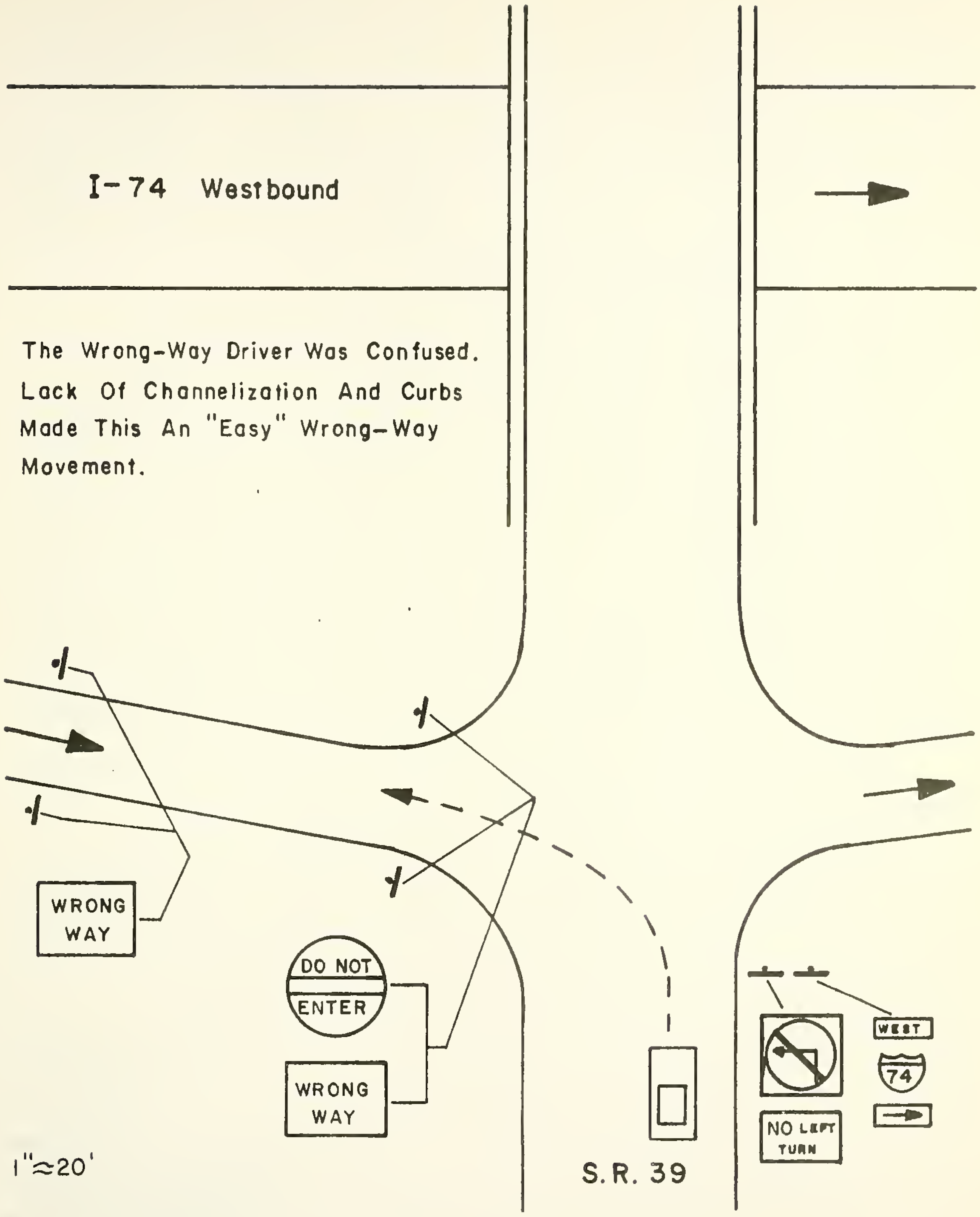


Figure 19 The Interchange Of I-74 And State Road 39 —A Typical Diamond Interchange Where A Wrong-Way Movement Occurred

generally adequate and the overall interchange layout was not usually confusing. Channelization and curbs to restrict vehicle paths were installed at some locations, but noticeably missing at other locations.

Major Intersections

In Figure 20, the intersection of U. S. 40 and S. R. 267, one of the major intersections where wrong-way movement began, is shown. Although the intersection's signing is good, the width of the median causes visibility problems and vehicles on U. S. 40 must traverse a wide unchannelized space to make a left turn correctly. The accident occurred at night and the lighting was poor. Some commercial development exists on U. S. 40 east of the intersection. The driver of the wrong-way vehicle was drunk.

This wrong-way movement was probably caused by a combination of poor lighting, the drivers drunkeness, and the geometric layout of the intersection.

The data collected at major intersections where wrong-way movements (7 accidents) originated are presented in Table 19. A major intersection was defined as one with any type of signalization. The data for all major intersection parameters was sparse and seemed inconclusive.

Minor Intersections

The intersection of U. S. 24 and Cherry Lane, near Fort Wayne, (Figure 21) is a minor intersection

TABLE 19: DATA ON MAJOR INTERSECTION WRONG-WAY MOVEMENT ORIGIN SITES

		Confirmed	Probable
Crossroad elevation higher	yes	3	1
	no	3	0
Median width	less than 10 feet	2	0
	more than 10 feet	4	1
Median well delineated	yes	3	1
	no	3	0
Signing quality	satisfactory	3	1
	minimal	3	0
Lighting at the time of the wrong-way movement	daylight	2	1
	night but artifical lighting	2	0
	night	2	0
Area land-use intensity	none or one building	2	0
	two or three buildings	4	0
	more than three buildings	0	1
Approximate traffic volumes on the divided highway at the time of the wrong-way movement	less than 100 v.p.h.	2	0
	100 to 300 v.p.h.	3	0
	more than 300 v.p.h.	1	1

The Wide Medians At This Intersection Result In A Somewhat Confusing Layout With Marginal Visibility. This, Plus The Fact That The Wrong-Way Driver Was Drunk, Caused The Accident.

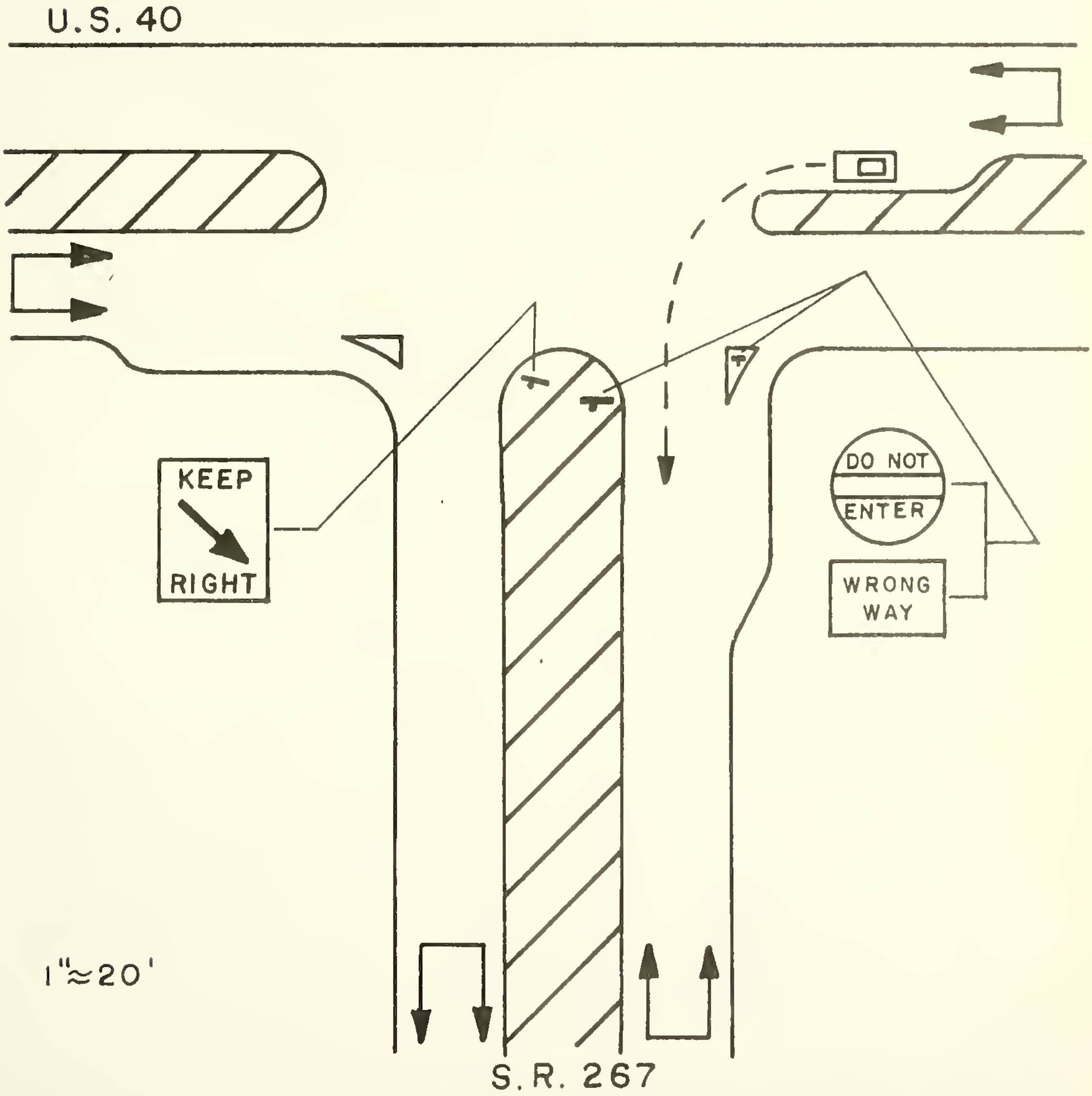


Figure 20. The Intersection of U.S. 40 and S.R. 267, A Major Intersection Where a Wrong-Way Movement Occurred.

This Wrong-Way Movement Took Place At Night. Low Visibility And Lack Of Signing Did Not Provide Sufficient Guidance For The Driver.

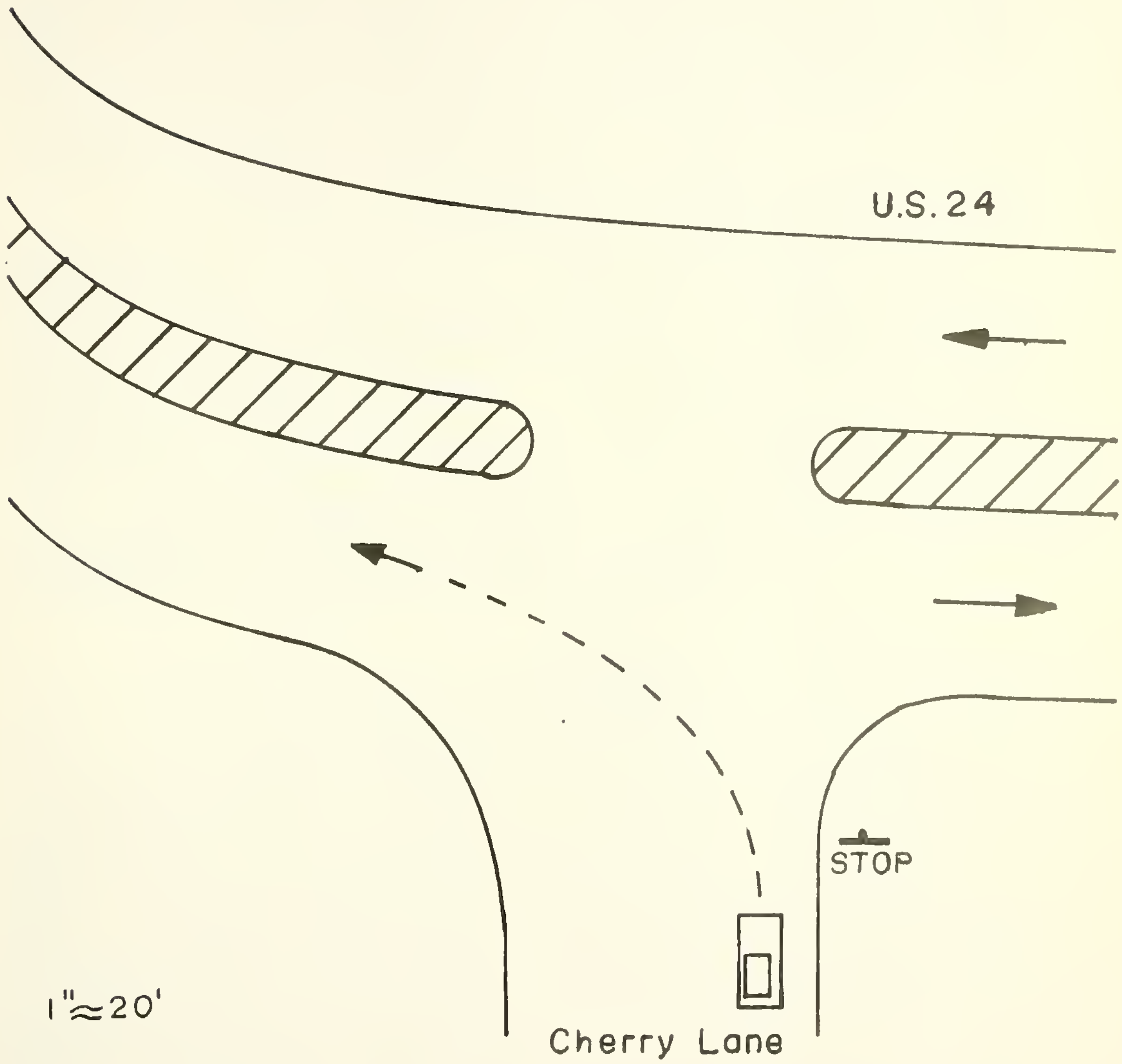


Figure 21 The Intersection of U.S. 24 and Cherry Lane — A Typical Minor Intersection Where Wrong-Way Movement Occured

providing access from a residential area to U. S. 24. Although the overall intersection visibility is very good, it lacks any type of directional signing. The accident occurred on a dark rainy night with very low visibility. With no directional signing, the driver apparently became confused and made a wrong-way left turn into west-bound lanes.

The data (11 accidents) on minor intersections are presented in Table 20. Wrong-way movements tended to occur at minor intersections located in an area of low land-use and poor lighting. All medians at these intersections were greater than ten feet in width and the presence of a divided roadway was evident in most cases. The quality of signing varied as did traffic volumes.

Driveways

A typical wrong-way movement originating from a driveway is shown in Figure 22. Visibility conditions were excellent, land-use was heavy and traffic volumes were heavy. However, there was no directional signing and it is likely that a directional, channelized driveway exit could have prevented this accident.

Wrong-way movements originating from driveways were somewhat infrequent (5 accidents, see Table 21) and trends were not easily identified. Like other wrong-way movement origins, land-use was not intense. Signing was minimal or non-existent and directional exits were not used.

TABLE 20: DATA ON MINOR INTERSECTION WRONG-WAY MOVEMENT ORIGIN SITES

		Confirmed	Probable
Crossroad elevation higher	yes	1	4
	no	0	6
Median Width	less than 10 feet	0	0
	More than 10 feet	1	10
Median well delineated	yes	1	7
	no	0	3
Signing quality	satisfactory	0	6
	minimal	1	4
Lighting at the time of the wrong-way movement	daylight	0	3
	night but artifical lighting	0	1
	night	1	6
Area land-use intensity	none or one building	1	9
	two or three buildings	1	0
	more than three buildings	0	1
Approximate traffic volumes on the divided highway at the time of the wrong-way movement	less than 100 v.p.h.	0	4
	100 to 300 v.p.h.	1	5
	more than 300 v.p.h.	0	1

The Driver Being Drunk Was The Cause Of This Accident.
Some Signs Or Channelization Might Have Helped.

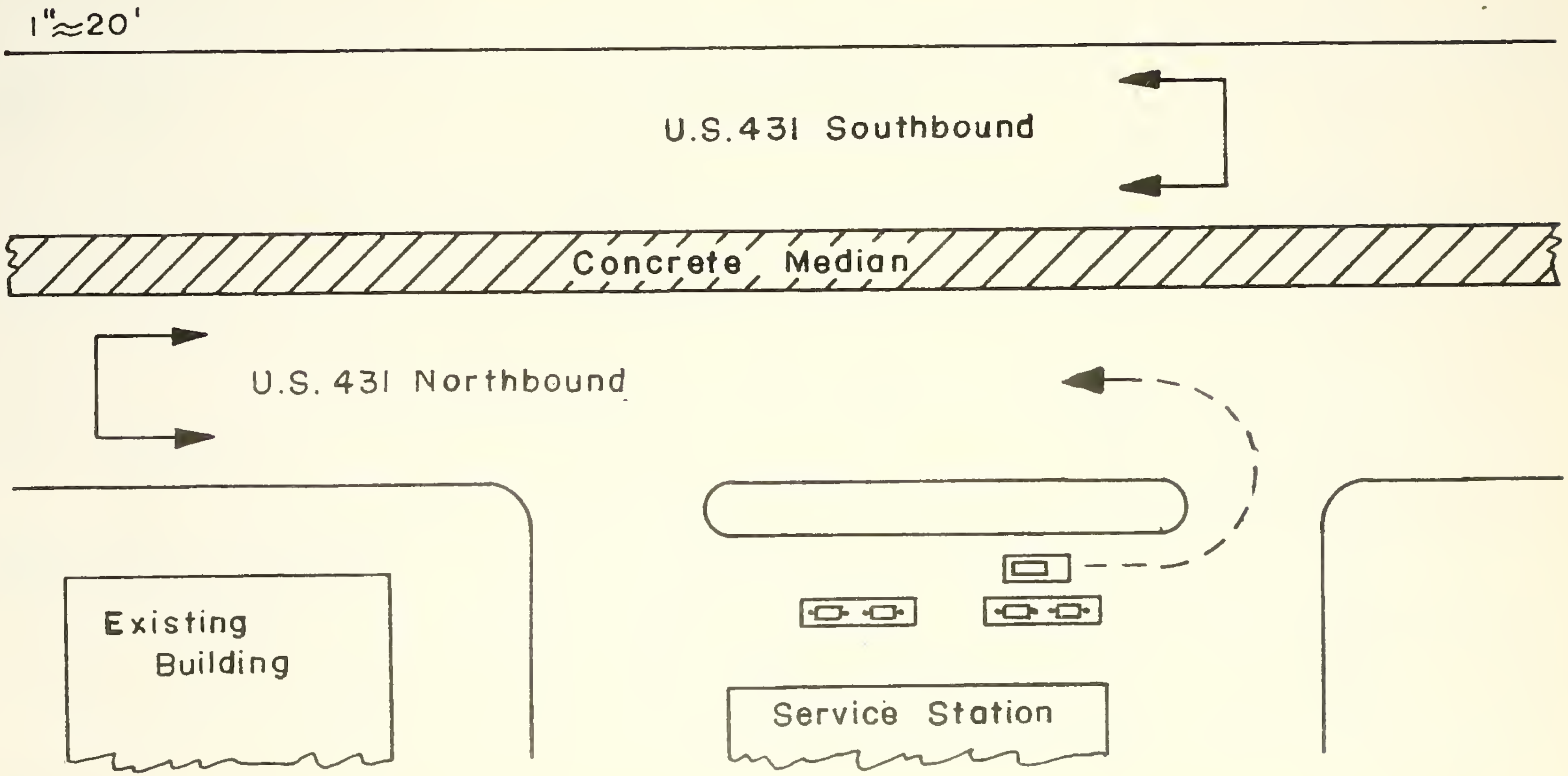


Figure 22 Driveway on U.S. 431 — Typical Driveway Where A Wrong-Way Movement Originated

TABLE 21: DATA ON DRIVEWAY WRONG-WAY MOVEMENT ORIGIN SITES

		Confirmed	Probable
Crossroad elevation higher	yes	1	0
	no	0	4
Median width	less than 10 feet	1	2
	more than 10 feet	0	2
Median well delineated	yes	1	1
	no	0	3
Signing quality	satisfactory	0	0
	minimal	1	4
Median opening opposite driveways	yes	0	4
	no	1	0
Directional exit	yes	0	0
	no	1	4
Lighting at the time of the wrong way movement	daylight	1	2
	night but artificial lighting	0	0
	night	0	2
Area land-use intensity	none or one building	0	4
	two or three buildings	0	0
	more than three buildings	1	0
Approximate traffic volumes on the divided highway at the time of the wrong-way movement	less than 100 v.p.h.	0	2
	100 to 300 v.p.h.	0	2
	more than 300 v.p.h.	1	0

Transitions

Not less than seven accidents occurred at the transition on U. S. 31 north of Kokomo (Figure 23). This transition, used while part of U. S. 31 was being improved to a divided, four-lane highway had a configuration conducive to wrong-way movements. Vehicles approaching it had to bear right to avoid driving into the wrong lanes of the divided part of U. S. 31. Most of the accidents happened at night. Generally, the configuration of this transition,and possibly its temporary nature, was responsible for its wrong-way movement problem.

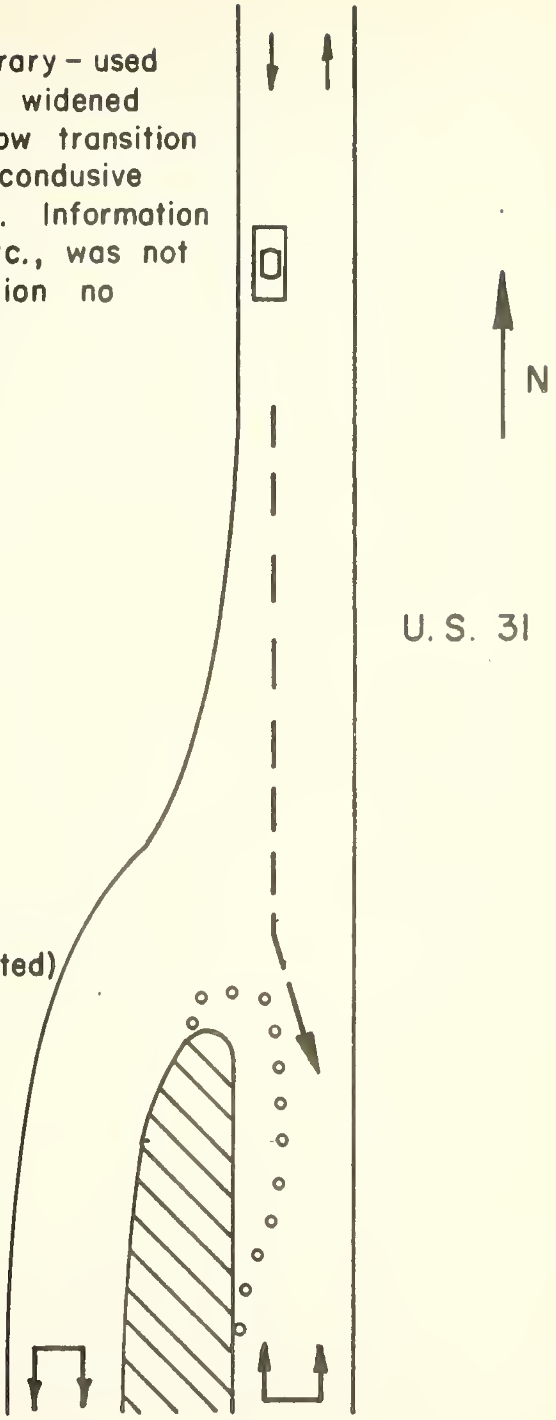
Trends concerning transition were difficult to establish (Table 22). However, poor lighting and configurations of transitions tended to cause wrong-way movements.

Summary

1) Most wrong-way movements tend to originate from areas of low land-use, regardless of the type of access. This would tend to indicate that potential origin points in such areas should receive special consideration.

2) Wrong-way movements tend to take place when traffic volumes are low. This is probably because under low volumes traffic on the divided highway is not present to indicate the correct direction of travel for each roadway. Also, a motorist may gamble more often in making a deliberate wrong-way movement knowing that he will usually not meet an opposing car.

This transition was temporary – used while U.S. 31 was being widened to four lanes. Note how transition configuration was very condusive to wrong-way movements. Information on signing, visibility, etc., was not available as this transition no longer exists.



Scale: 1" ≈ 10'
(verticle scale exaggerated)

Figure 23. Transition on U.S. 31 – Site of Seven Wrong-way Accidents.

TABLE 22: DATA ON TRANSITION WRONG-WAY MOVEMENT ORIGIN SITES

		Confirmed	Probable
Median well delineated	yes	0	0
	no	2	1
Configuration condusive to wrong-way movements	yes	2	1
	no	7	0
Signing quality[a]	satisfactory	2	0
	minimal	0	1
Lighting at the time of the wrong-way movement	daylight	1	0
	night but artificial lighting	0	0
	night	8	1

[a]Data were unavailable in seven cases.

3) Wrong-way movements tend to take place at times of low visibility. Artificial lighting would probably reduce the frequency of wrong-way movements at most access points.

4) Signing for most origin types appeared to be adequate. Driveways were the exception, when little or no signing was the rule.

5) Design elements that tended to reduce the driver's ability to see and understand overall access point configuration tended to increase the frequency of wrong-way movements. Efforts should be made to design access points that offer good visibility of the access point layout. Also the access point should be a relatively simple and understandable design.

CHAPTER VII

THE CAUSES OF WRONG-WAY MOVEMENTS

Using the findings from the previous chapters the causes of wrong-way movements are analyzed in this chapter. Wrong-way movements are a relatively rare traffic event and reliable and useful data are hard to obtain, thus making analysis most difficult. Although certain trends of the circumstances surrounding wrong-way movements can and have been isolated, rigorous statistical tests and conclusions have proven invalid due to minimum sample size.

This problem was circumvented through the use of a methodology that exploits what is well documented about wrong-way movements and minimizes the use of wrong-way movement parameters that have little documentation. Initially, the overall roadway and driver systems, as they relate to the wrong-way movement problem, are examined. Within this general framework, the findings of chapters II, IV, V, and VI are considered in conjunction with various operational aspects of the problem. In the final part of this chapter the causes and reasons for wrong-way movements are enumerated and the general directions that should be taken to reduce them are outlined.

This approach, i.e., starting in a very general position, allows the isolation of general characteristics and causes of the problem with considerable reliability. From there, more specific design and operational procedures that encourage or discourage wrong-way movements are logically identified thus reducing dependence on statistical procedures.

Driver and Roadway Systems

In Figure 24, a conceptual model of driver performance is illustrated using a flowchart format. Previous data have indicated that in the majority of wrong-way accidents there are either adverse environmental factors (darkness, weather) or external driver stimuli (age, alcohol, fatigue) present that reduce the driver's perception and/or decision making capabilities. Put another way, the performance of typical wrong-way drivers is degraded by these external influencing factors. This would tend to indicate that, whatever wrong-way movement prevention systems are used, they should not rely solely on the driver's decision making capabilities.

In Figure 25, the wrong-way movement prevention system as it functions now is illustrated. Again it can be seen that adverse environmental factors or external driver stimuli hamper the driver in making the correct decision.

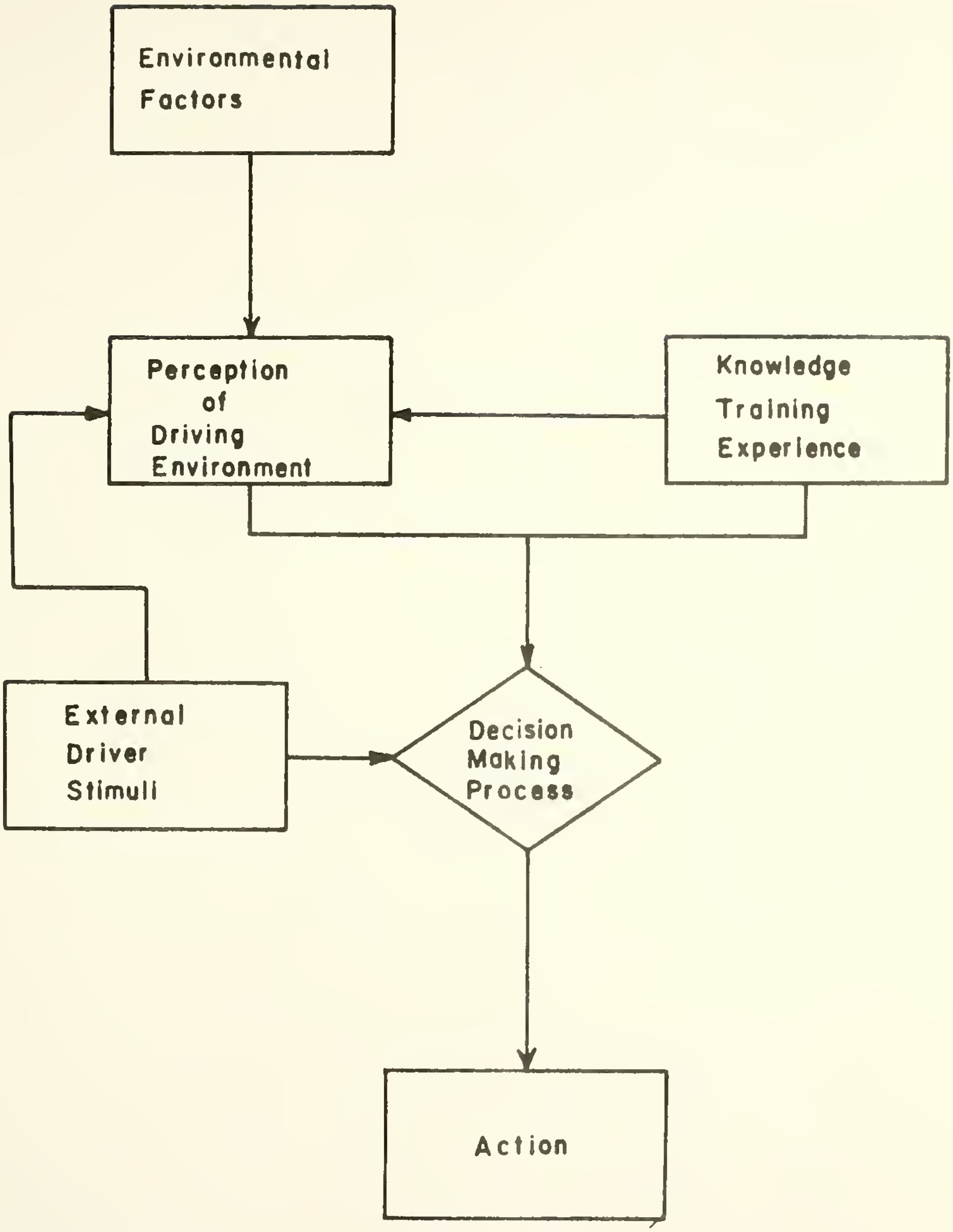


Figure 24 Driver Performance Model

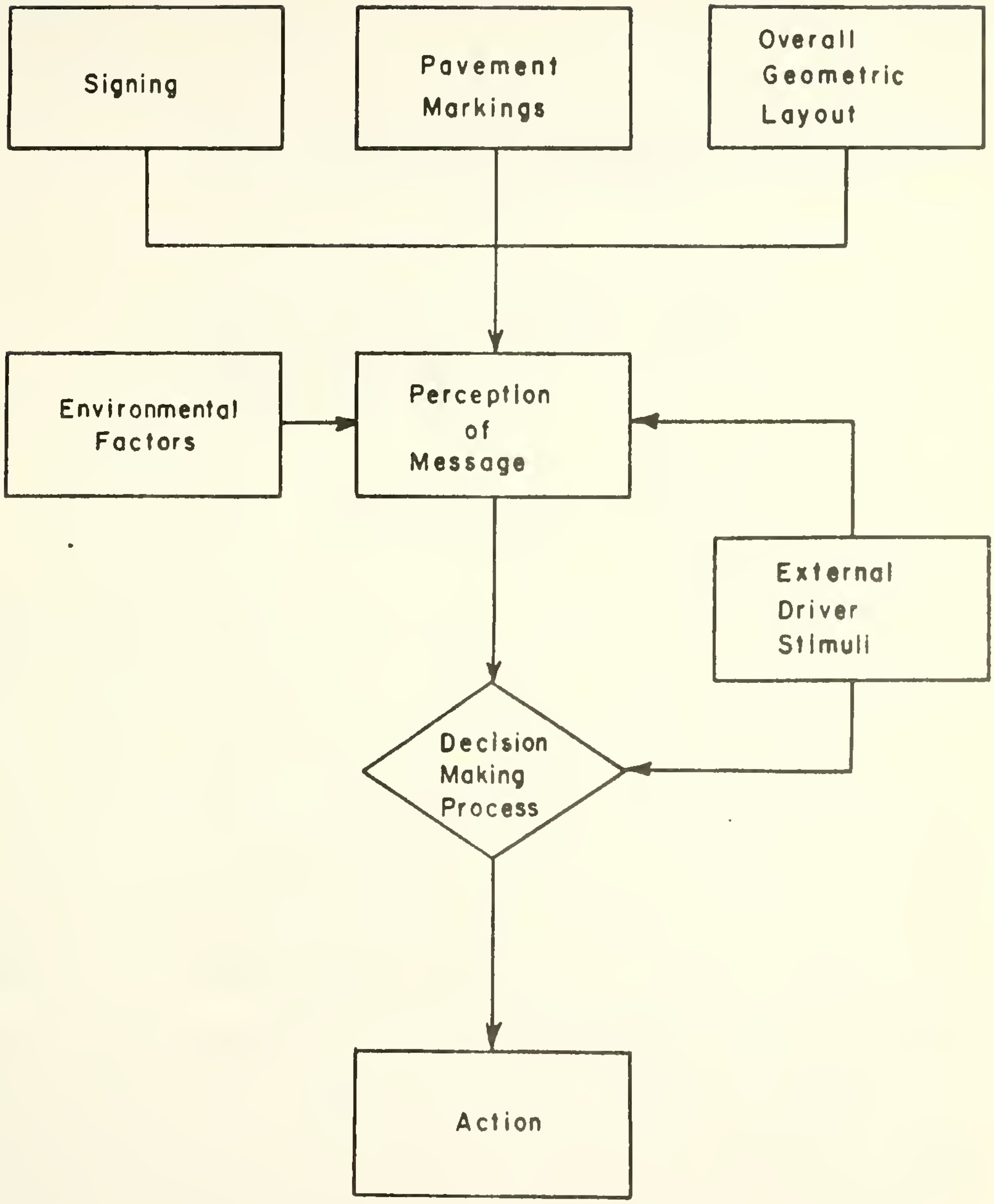


Figure 25 Wrong-way Movement Prevention System

From this discussion, two major points can be developed. In order to significantly reduce the frequency of wrong-way movements:

1) Driver information devices must function effectively even if adverse envirionmental or driver factors are present

and/or

2) New methods of wrong-way movement prevention must be developed that do not depend so heavily on the drivers decision-making capabilities.

Operational Limitations

The nature of the wrong-way movement problem imposes some operational limitations on any wrong-way movement prevention system. Basically, the problem is that no matter what is done drivers can still make wrong-way movements; for example, nothing can stop a driver from making a U-turn on a divided highway and travelling in the wrong direction. Generally, wrong-way movements that involve difficult or unusual manuevers will be least affected by any preventive measures. This is because drivers making such movements are making them deliberately or are not functioning normally. Short of physically blocking such movements (an impractical solution because of geometric design imperatives) little can be done to prevent them. The challenge confronting the highway engineer is to determine which types of wrong-way movements are realistically preventable and to concentrate his efforts on those.

Preventable and Non-Preventable Wrong-Way Movements

The heading of this section is not to imply that certain types of wrong-way movements are completely preventable and that nothing can be done about other types. Rather it is intended to suggest that the sound application of highway engineering techniques can significantly reduce the frequency of wrong-way movements at some locations. However, at other locations no realistic, effective corrective measure (other than possibly improved driver education) has been devised that would be superior to the current wrong-way signing packages now used. A closer examination of preventable locations is now in order.

Class A Locations

Parclo and diamond interchanges are the most adaptable, likely locations for effective wrong-way movement reduction techniques. At other types of interchanges, especially those providing channelized access from the crossroad, significant reductions in wrong-way movements are less likely to be achieved. U-turns and median crossings are other types of class A highway wrong-way movement that are probably not susceptible to prevention techniques.

Class B Locations

In general the frequency of wrong-way movements at most locations on class B highways can be reduced, except for median crossings and U-turns. Intersections of all types, driveways and also transitions (from undivided to divided highways) are at least somewhat preventable locations.

Prevention Techniques: General Philosophy

In the final section of this chapter, the general requirements of effective wrong-way movement prevention systems for the locations discussed are outlined. The general requirements of such systems were developed earlier under two major points. Point 1 is generally applicable to all locations on both class A and B highways as signing is used universally as the primary wrong-way movement prevention system. After a careful study for alternatives, two were explored and considered feasible. The first alternative was simply lighting all areas considered prone to wrong-way movements. Many rural interchanges and intersections are unlit at night which reduces the effectiveness of warning signs and compounding the difficulty of the driver's decision making process. Lighting, in addition to improving wrong-way control, would also improve the total effectiveness of most driver information devices. A system of flashing lights and horns, described in the literature search would also heighten the effectiveness of most driver information devices by calling the drivers attention to the wrong-way signing as he makes a wrong-way movement.

Point 2 is applicable in more restricted situations where various channelization schemes that make wrong-way movements more difficult can be employed. The designs now used for many at-grade intersections, driveways, ramp/cross-road interfaces do not inhibit, and sometimes encourage wrong-way movements. If different designs that impede and block wrong-way movements are used, a wrong-way movement prevention system that functions regardless of the drivers condition will have been developed. Although such measures will not eliminate all wrong-way movements, they should significantly reduce their frequency.

CHAPTER VIII

WRONG-WAY MOVEMENT PREVENTION

Geometric Design Modifications to Reduce Wrong-Way Movements

As pointed out earlier, one way to reduce the frequency of wrong-way movements is through modifications in geometric design. Four general types of locations exist where these modifications could be implemented:

1) The crossroad/exit ramp interface of diamond and parclo interchanges (class A highways).

2) Certain types of intersections (class B highways).

3) Driveways (class B highways).

4) Transitions from undivided to divided highways (class B highways).

Parclos and Diamonds

In Figure 26, the two possible wrong-way turning paths (a P minimum radius turning template was used in all cases) of a diamond interchange are shown. In Figure 27 a right turn, movement A, would be far more difficult or impossible if the curb on the right side of the vehicle was barrier-type and of very small radius (approximately 2 feet). Also, the turn would be more difficult if the off-ramp opening was narrowed to approximately 12 feet and the

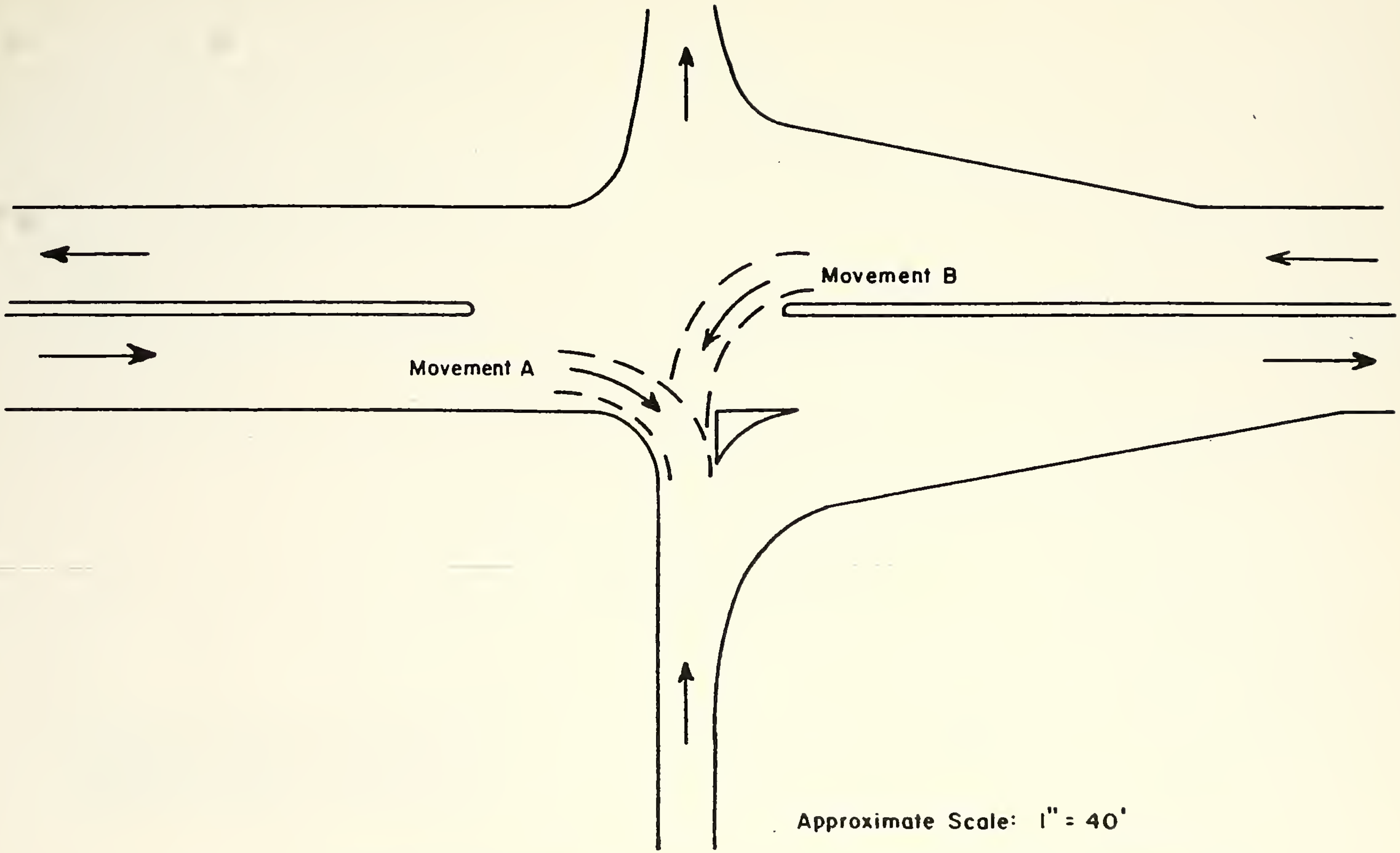


Figure 26 Wrong-way Movements at a Divided Diamond Interchange

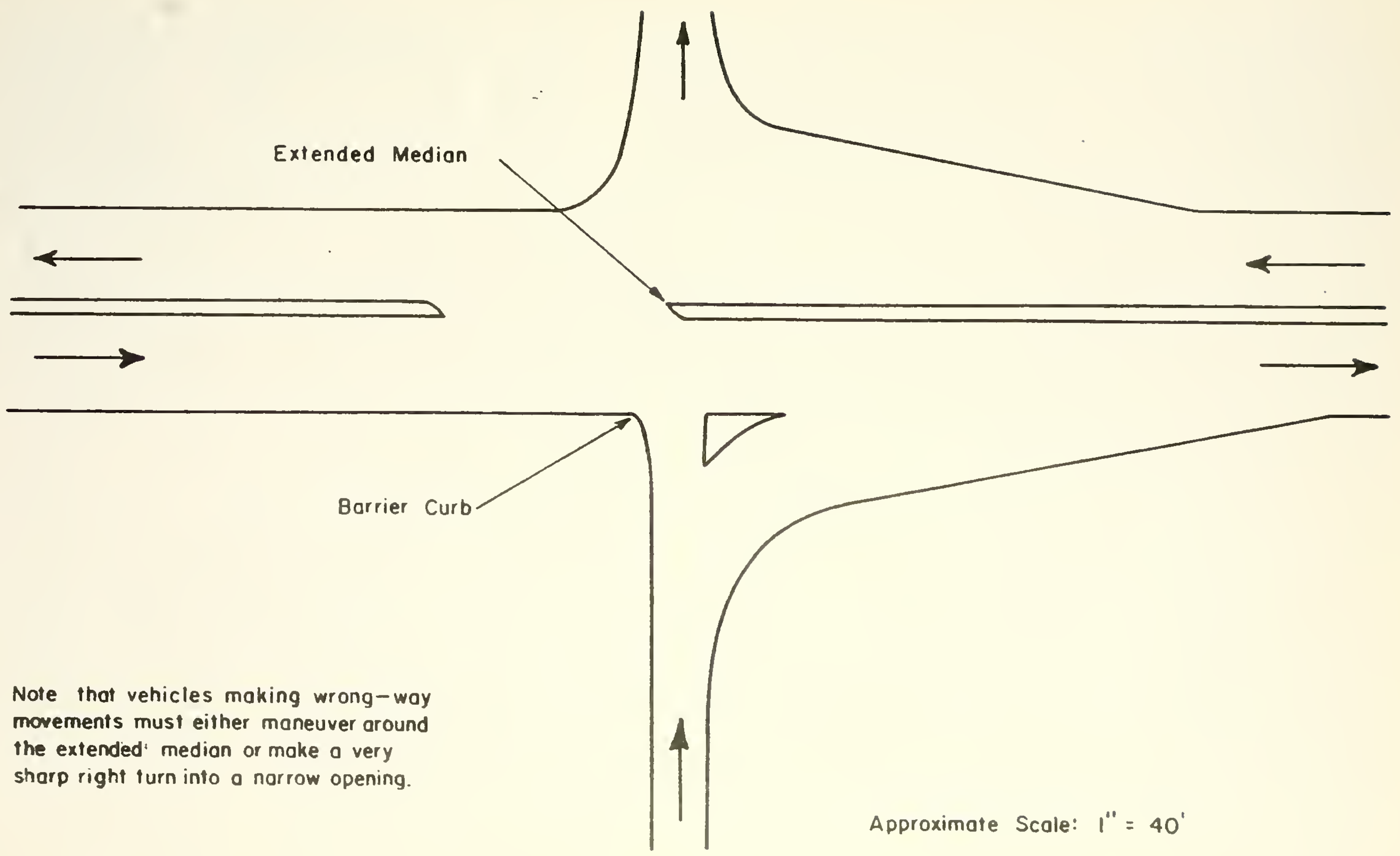


Figure 27 Wrong-way Movement Prevention Modifications

island forming the other side of the opening was also barrier-type. Likewise, difficulty of movement B could be similarly increased by extending the median nose across the off-ramp opening thus blocking the opening from left-turning vehicles (i.e., a wrong-way movement).

Similar techniques can be used to protect parclo off-ramp openings from wrong-way movements (see Figure 28). Movement C would be made more difficult by shortening the right-hand curb radius to approximately 2 feet and narrowing the off-ramp opening to approximately 12 feet as was suggested for diamond interchanges. To prevent left-turns into the wrong opening (movement D), the median should be extended to a point where it covers one-third to two-thirds of the off-ramp opening.

As can be seen from Figures 28 and 29, these alterations would make wrong-way movements onto off-ramps a procedure that could only be accomplished with difficulty because of constraints imposed by vehicle turning radii. In the case of the undivided crossroad, similar techniques could be used (excluding the median alterations) although their wrong-way movement prevention capabilities would be reduced in the absence of a median barrier.

As was noted earlier, any alterations in medians and curbs must be consistent with good geometric design practice; more specifically, these alterations must not interfer with the exiting traffic's normal use of the

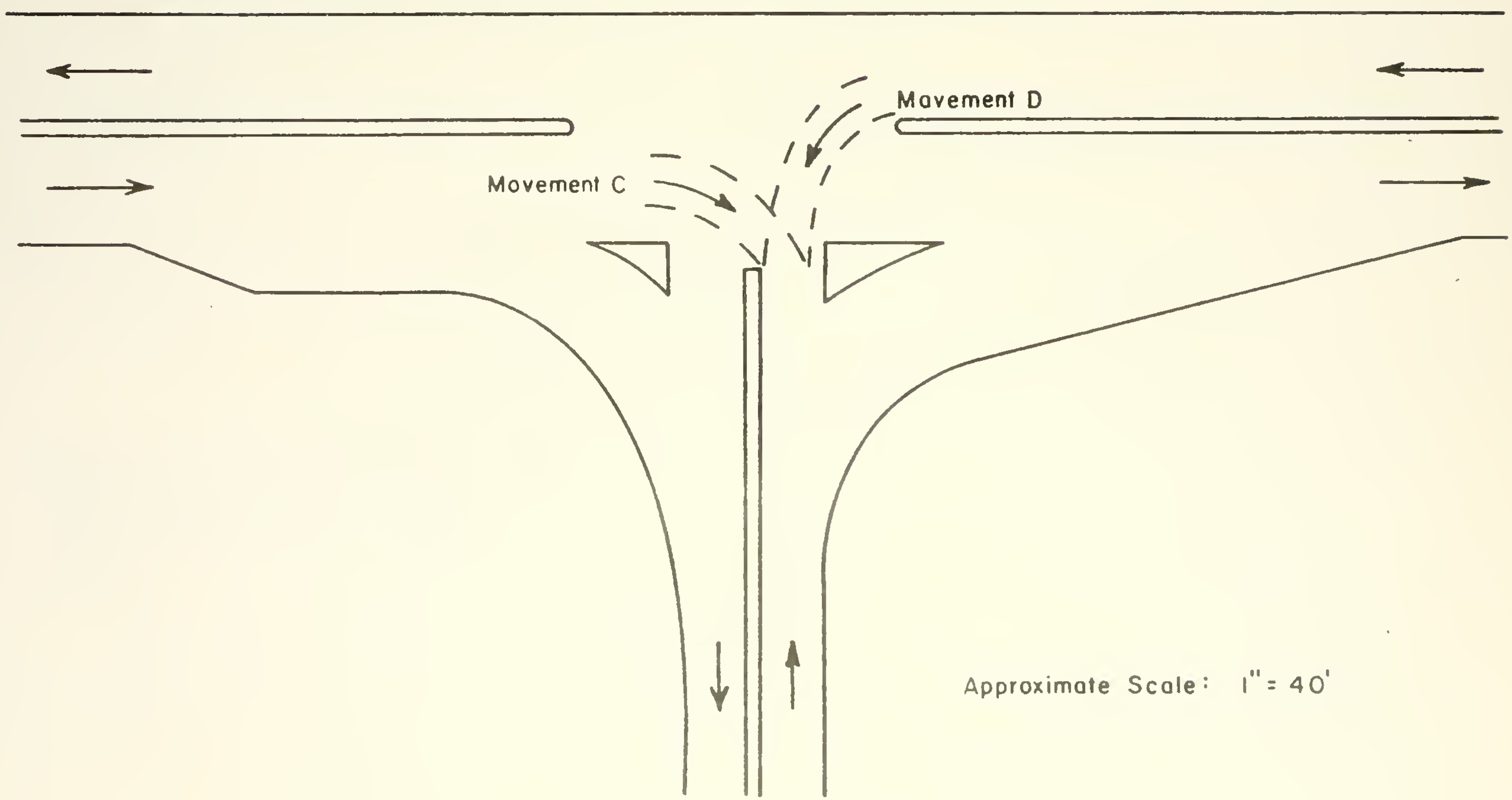


Figure 28 Wrong-way Movements at a Divided Parclo Interchange

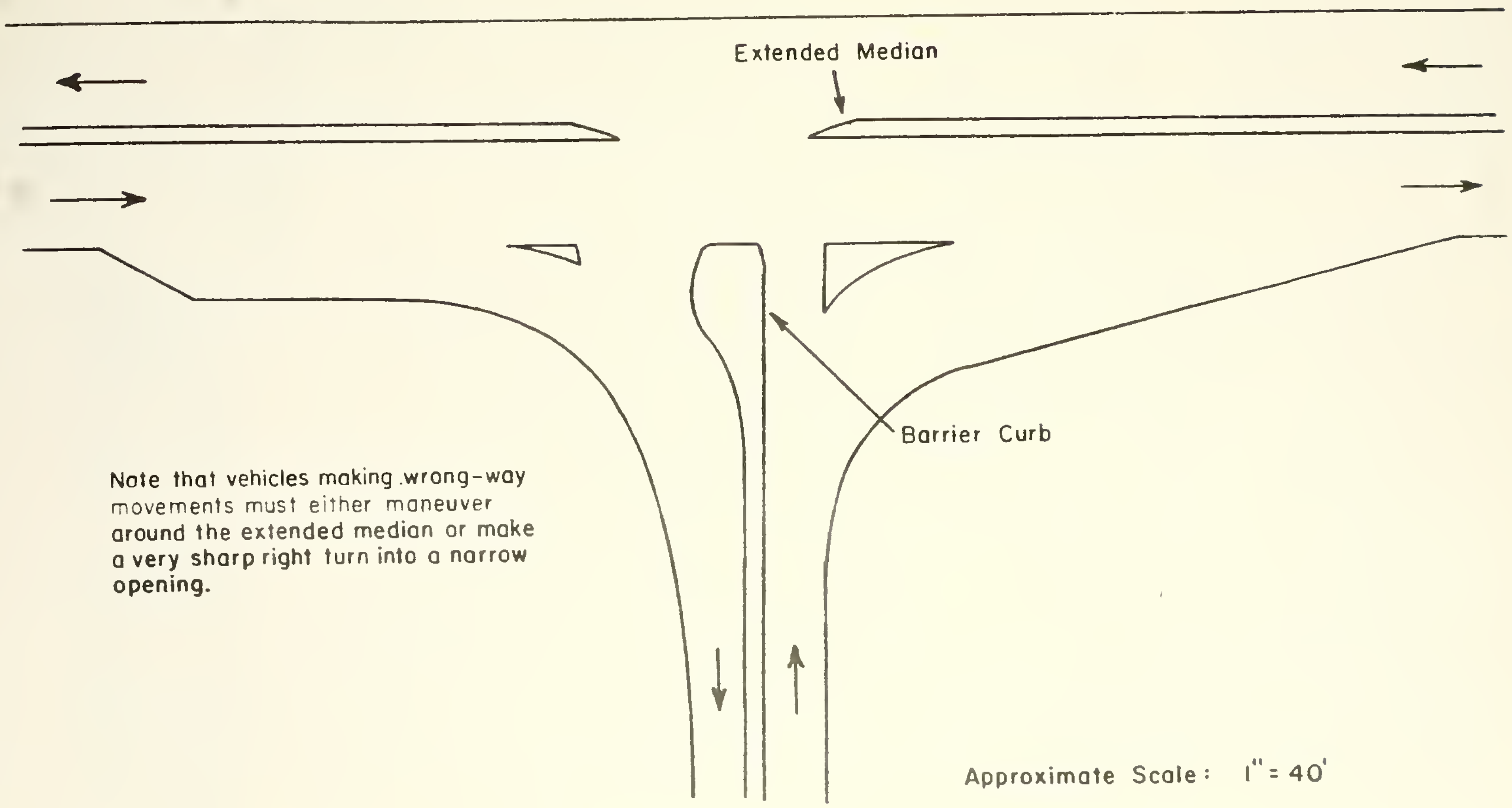


Figure 29 Wrong-way Movement Prevention Modifications for a Parclo Interchange

off-ramp. Figures 30 and 31, using C-50 minimum radius turning templates, demonstrate that medians and curbs can be located in a way that blocks wrong-way movements but leaves exiting vehicles space to make left turns without obstruction. Right turns are not affected by the proposed alterations.

The possibility exists that these wrong-way movement prevention alterations could cause some new operational problems. Such problems would have to be determined and evaluated in comparison with the advantages of reduced wrong-way accidents.

Intersections

Because movements in all directions must be provided for at intersections of divided, class B highways, channelization is not a good means of blocking wrong-way movements. However, several elements can be incorporated into intersection design that would tend to make the overall intersection configuration more visible and understandable to drivers. This would probably reduce the frequency of wrong-way movements and certainly improve the overall operation of the intersection. Three principles that improve intersection visibility are discussed.

1) In a situation where an undivided highway intersects a divided highway, the elevation of the undivided highway should be equal to or greater than that of the divided highway. This would give the approaching motorist (on the undivided

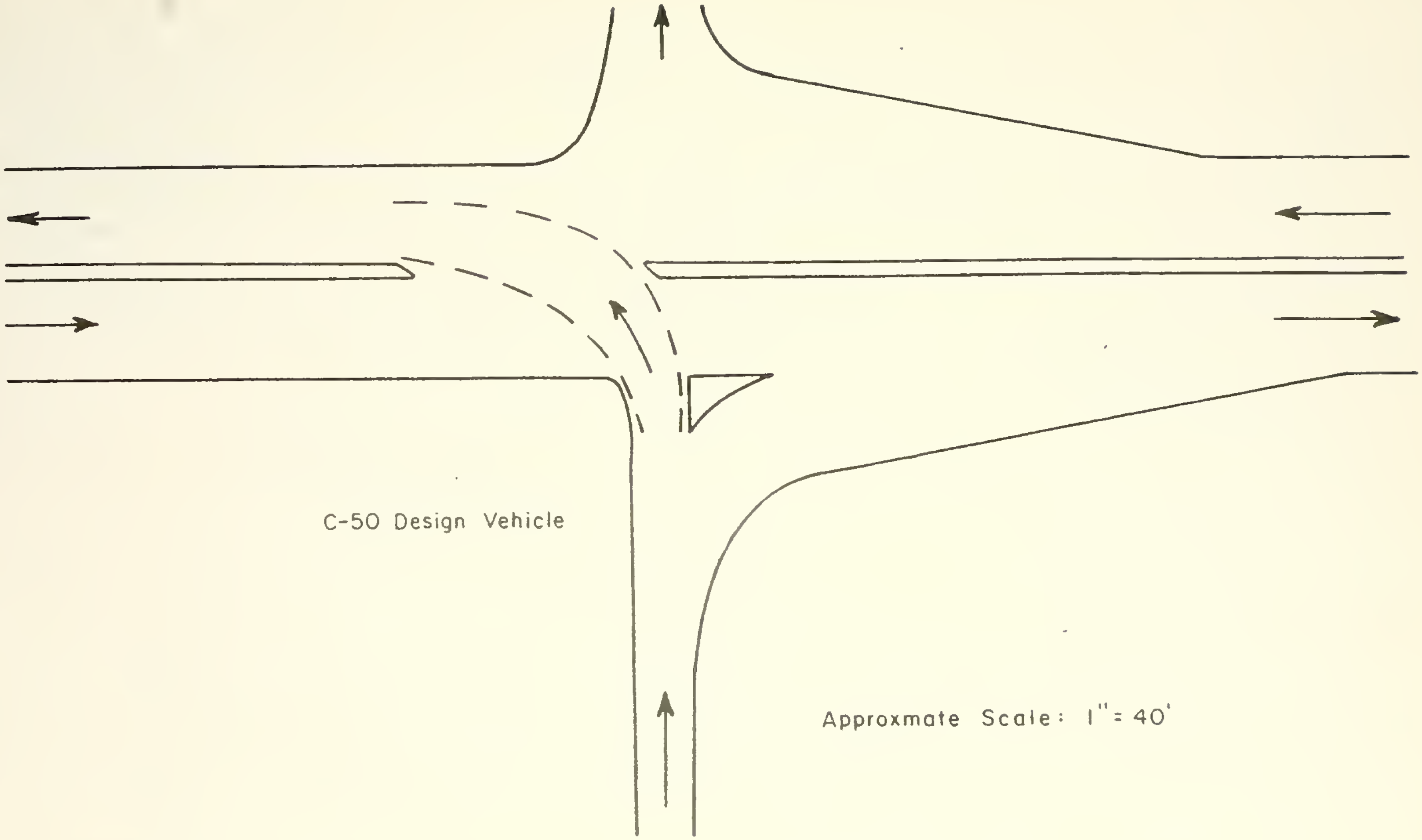


Figure 30 Left Turn Exit Movements From a Modified Diamond Interchange

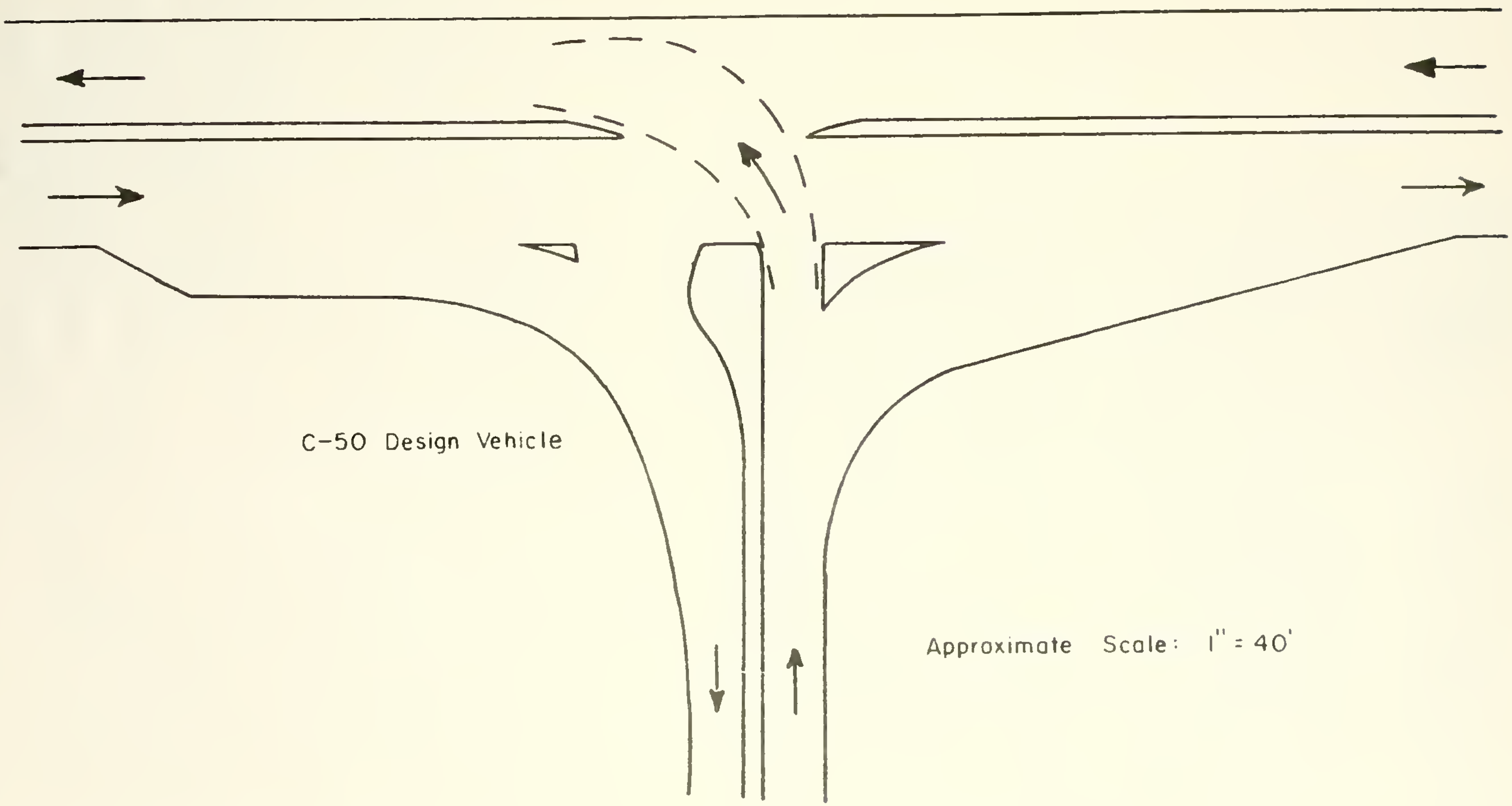


Figure 31 Left Turn Exit Movements From a Modified Parclo Interchange

highway) a clearer view of both lanes of traffic and make their directions more apparent. Although the undivided road probably carries a smaller volume of traffic, the visibility problem is more critical.

2) Wherever possible, angles of intersection of other than 90 degrees, as well as other unusual layouts, should be avoided. Such layouts are frequently confusing and some of the data gathered for this project have indicated that they encourage wrong-way movements.

3) At intersections where median storage space is not required, medians should be narrow but distinct. Narrowing the median will make the far lanes of travel more visible, improving the drivers visibility of the overall intersection. A narrow median would also reduce the amount of unchannelized space that the motorist must negotiate. The median must be distinct to aid the driver in understanding the intersection layout and function. Distinctness can be achieved by both raising and coloring the median.

Driveways

Wrong-way movements from driveway type access points can be reduced through geometric design modifications. Generally speaking, all driveways on divided highways not provided with a median opening should be directional. With the use of barrier curbs, exiting vehicles can be channelized so that wrong-way movements are very difficult and the right direction of travel is very obvious (see Figure 32). Such channelization improvements would be relatively inexpensive, easy to install and would improve overall facility operation.

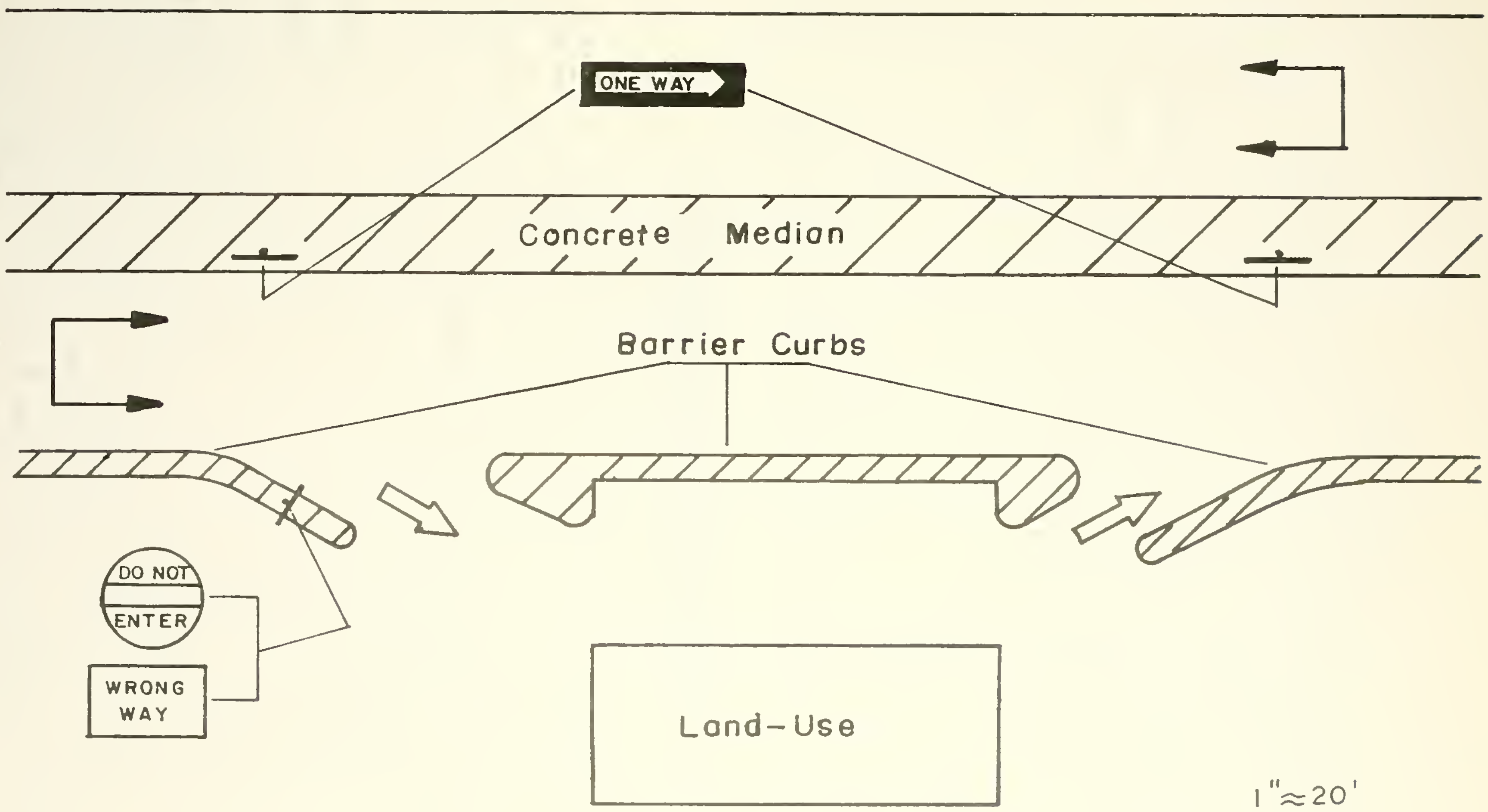


Figure 32 Possible Directional Driveway Design

Transitions

Transitions from an undivided to a divided highway are a relatively frequent source of wrong-way movements, as well as other operational problems. Figure 33 illustrates the two basic transition configurations. Configuration A is very poor design and should never be used as it requires drivers to read and understand signing instructing them to bear right to enter the transition in the right direction. This is not in accordance with the principles developed earlier, namely, that wrong-way movement prevention systems should not depend on signing. Configuration B is much better practice and should always be used.

Redirection and Diviersion Systems to Reduce Wrong-Way Movements

Redirection systems to cope with wrong-way movements on class A highways have been described in the literature review. This section analyzes the effectiveness of such systems and makes recommendations concerning their use.

Of the several redirection and diviersion schemes proposed only Goodman's (8) seems to be practical. It is probably not feasible to use the diversion tactic of directing wrong-way vehicles into sand traps. However, Goodman's scheme is different in that it employes an additional inner loop or ear ramp on all exit ramps to return wrong-way vehicles back onto the exit ramp in the right direction (see Figure 9). Such ear ramps would probably eliminate

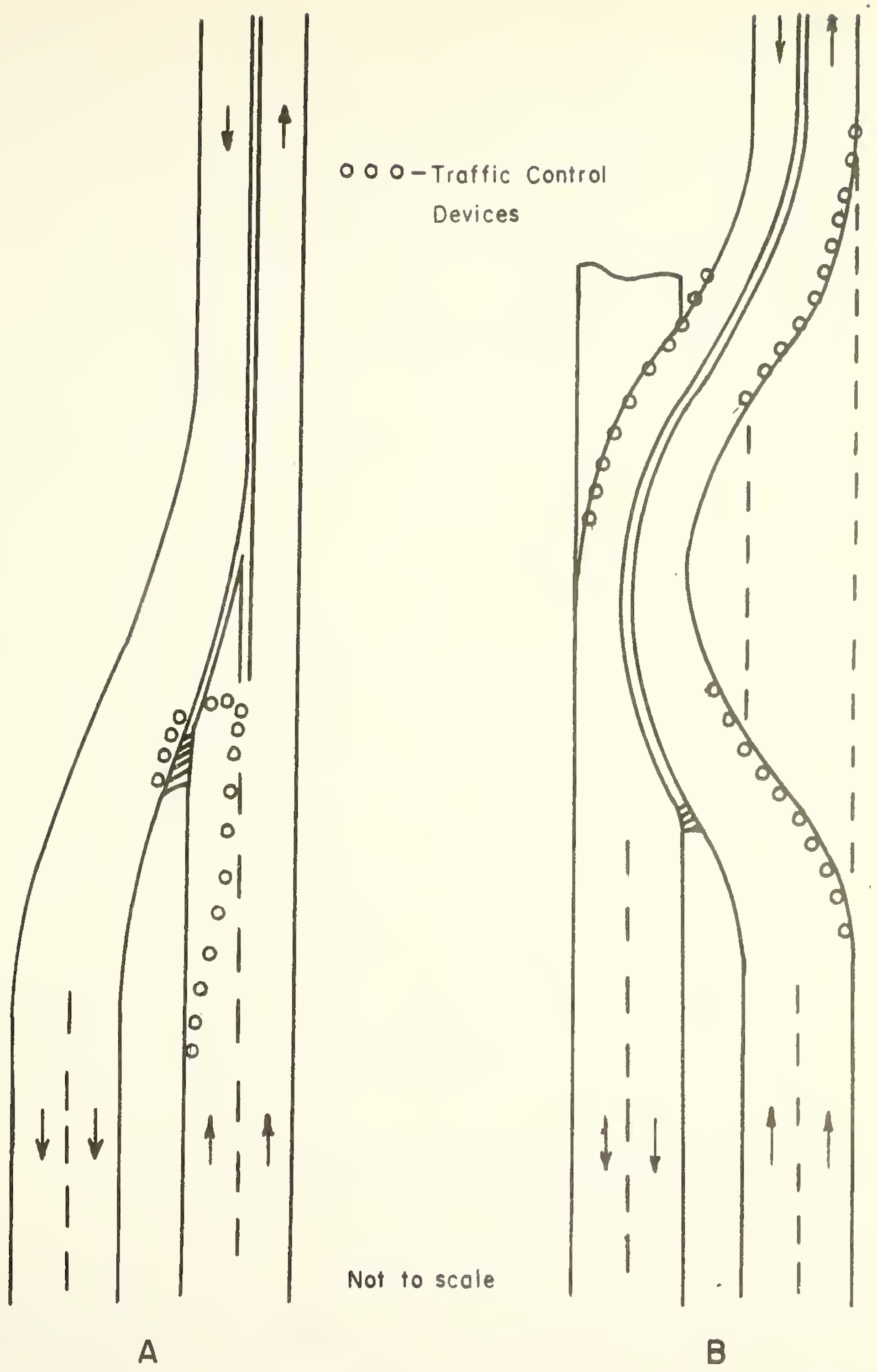


Figure 33. Two Basic Transition Configurations

the majority, if not all, wrong-way movements. Unfortunately, calculations indicate that they would not be very cost-effective. Rough estimates of the annual costs of wrong-way accidents originating from diamond and parclo interchanges were derived, equalling $56,800. Using an interest rate of ten percent and a facility life of twenty years approximately 483,000 dollars could be spent for the construction of ear ramps if benefits are to equal costs. As there are 122 diamond and parclo interchanges in Indiana, each of which would need two ear ramps, approximately 2000 dollars would be available for each ramp. This is clearly far too small an amount. For example, to provide pavement alone for an ear ramp 12 feet wide and 300 feet long would cost roughly 3200 dollars ($8/sq. yd. x 400 sq. yd.) making this approach an uneconomic proposition.

Generally speaking, although ear ramps would be effective in preventing wrong-way accidents, they are too expensive to consider implementation on a state-wide scale.

Alarm Systems to Reduce Wrong-Way Movements

On page 35 the experimental alarm system by the California Division of Highways is described. The device, consisting of an induction loop detector, a horn and flashing lights reduced wrong-way movements by 54%. As noted earlier, approximately 2000 dollars per exit ramp could be spent to achieve a benefit cost ratio of one on a fully effective wrong-way movement prevention system in Indiana. As this system has an effectiveness of around 50 percent, 1000 dollars could be spent per exit ramp.

In Table 23, a rough estimate of the capital cost (price listings from the Eagle Signal Company) of such an alarm system is shown. With a construction cost of 530 dollars, 470 dollars could be spent for twenty year operating costs. This is a reasonable estimate. A prototype should be evaluated to determine the system's feasibility.

Driver Information Practices to Reduce Wrong-Way Movements

For reasons discussed earlier, increased or modified wrong-way driver information practices (mostly signing) are only able to reduce the number of occurrences of, but not eliminate, wrong-way movements. Studies cited earlier have shown that signing is effective for only a certain percentage of wrong-way drivers. Thus, although wrong-way signing is very important, there are certain parts of the problem that it cannot deal effectively with. Increased or up-graded signing is, therefore, unlikely to be very useful.

Rather than exploring new signing techniques, this study was confined to presenting existing signing practices. In Figures 34 and 35, three basic types of wrong-way signing are used. One-way signs are used to indicate the direction of travel on a one-way road. Wrong-

TABLE 23: Wrong-Way Movement Alarm System Capital Costs

Item	Cost (Dollars)
Pedestal Base	40
8-Foot Pole	60
Flasher Motor	60
12-Inch Signal	50
Bell	20
Loop Detector	100
Miscellaneous Parts	100
Labor	100
Total	530

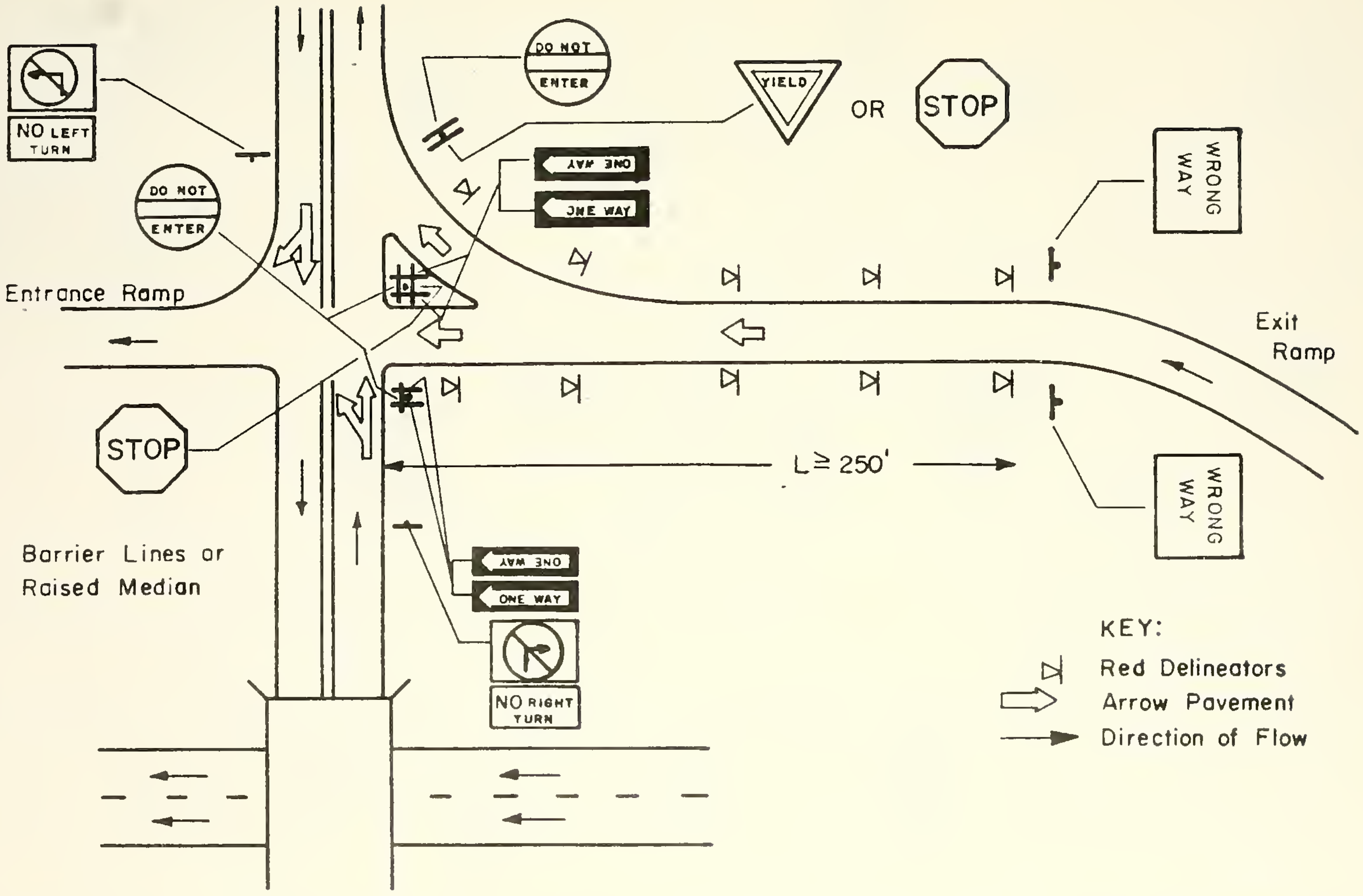


Figure 34 Typical Regulatory Signing, Delineation And Arrow Markings At Exit Ramp Terminals To Deter Wrong-Way Entry (3, pp6)

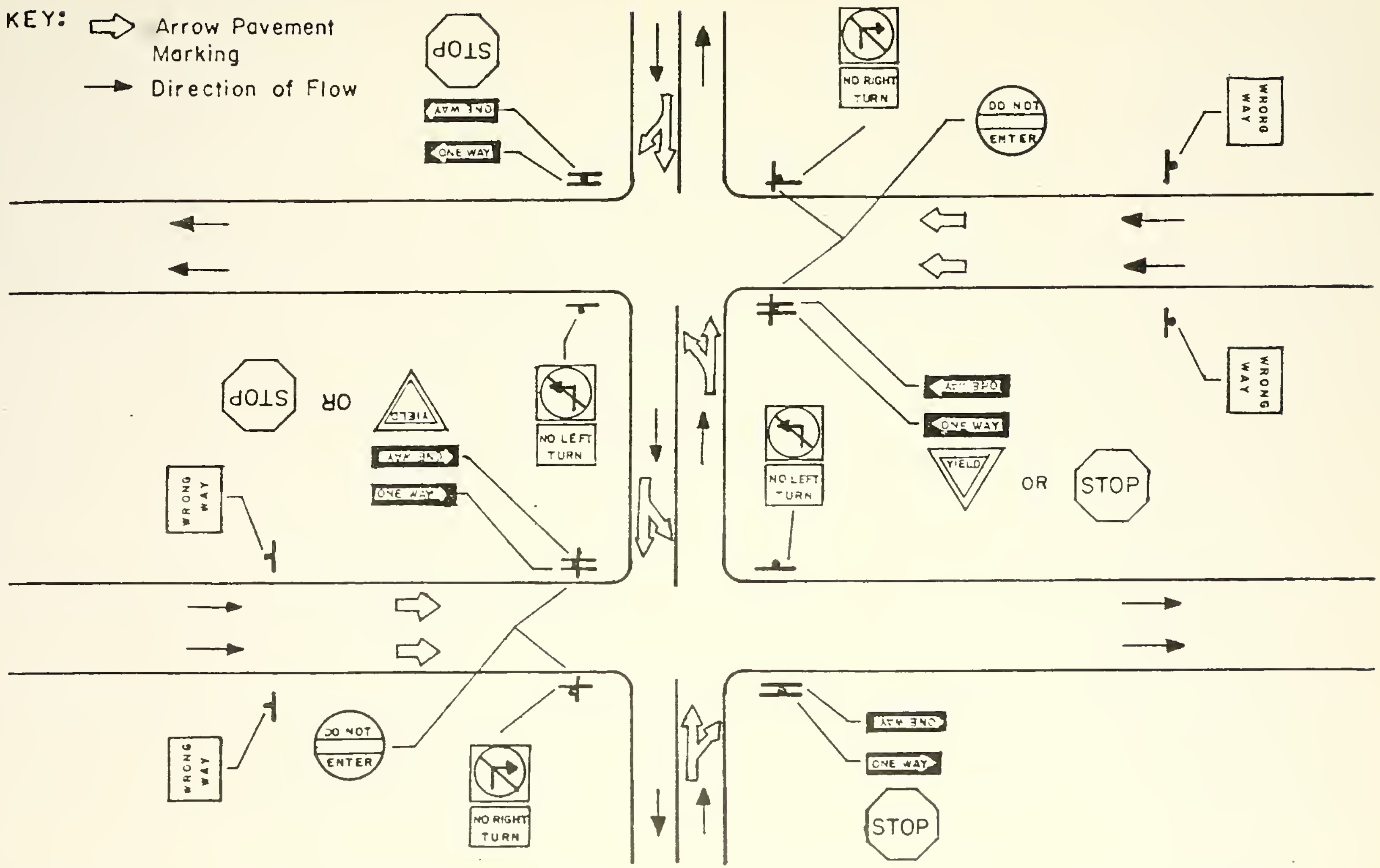


Figure 35. Typical Regulatory Signing And Arrow Markings At Divided Highway Intersections With Median Widths 30 Feet Or More (3, pp. 7)

way and do not enter signs are used to warn drivers that they are, or are about to, travel in the wrong-way on a one-way road. Signs are used to prohibit turns which, if made, would result in a wrong-way movement. The arrangement and number of these signs varies as illustrated.

CHAPTER IX

FINDINGS

The findings of this research are divided into two general groups. The first group is taken directly from the data collected on wrong-way movements from accident reports and field investigations. It primarily includes characteristics of wrong-way accidents and drivers, as well as data on the access points the wrong-way movements originated from.

The second group consists of the major findings reached concerning the causes and prevention of wrong-way movements.

Suggestions for further research are discussed in a final section.

Findings: Characteristics of Wrong-Way Movements

1) Of the 96 accidents that occurred during the three year period, 27 had one or more fatalities, 29 had one or more injuries and 40 resulted in property damage. Only 37 accidents occurred on fully controlled access highways, but these accounted for 17 of the fatal accidents.

2) Wrong-way accidents are more severe and occur less frequently on highways with fully controlled access than on those without.

3) The yearly cost of wrong-way accidents in Indiana is 121,000 dollars.

4) Wrong-way accidents are more common than average on Fridays, Saturdays and Sundays and also between 6:00 p.m. and 4:00 a.m. Only 26% of the 96 wrong-way accidents occurred during daylight.

5) Wrong-day drivers tend to be drunk (42 of 77 observations), tend to be older or tend to be driving late at night when they are likely to be fatigued.

6) Only 31% of the 96 wrong-way drivers were not adversely influenced by advanced age, fatigue and/or alcohol consumption.

7) Wrong-way movements tended to occur from areas with low land-use density.

8) Wrong-way movements tended to take place when traffic volumes were low.

This is probably because under low volumes traffic on the divided highway is not present to indicate the correct direction of travel for each roadway.

9) Wrong-way movements tended to take place at times of low visibility.

10) Signing at most wrong-way movement sites was adequate. Driveway access points were the exception, where little or no signing was the rule.

11) Two types of design elements that had potential to reduce the frequency of wrong-way movements were isolated. Any design that increases the driver's ability to see and understand the overall access point configuration would be likely to reduce wrong-way movements. Also, the use of channelizing islands and curbs to impede potential wrong-way movements appeared to be of use.

<u>Findings: Causes and Prevention of Wrong-Way Movements</u>

1) The abilities, motivation and/or performance of most wrong-way drivers was reduced by adverse influencing factors

Therefore, wrong-way movement prevention systems should function even if adverse influencing factors are present.

2) Geometric design modifications to reduce wrong-way movements at certain locations were developed. Modifications included channelization at diamond and parclo interchanges and raising the crossroad elevation at divided highway intersections and directional driveways.

3) Redirection and diversion systems to reduce wrong-way movement were analyzed to determine their cost effectiveness. The evaluation indicated such systems were not economically feasible.

4) Alarm systems to alert drivers making wrong-way movements were evaluated. If such systems could be constructed for approximately 1,000 dollars, they could be economically installed on the exit ramps of all diamond and parclo interchanges in Indiana.

Suggestions for Future Research

1) More data on the wrong-way movement problem in Indiana should be collected. Divided highway accident records for additional years (other than 1970, 1971, and 1972) should be examined for wrong-way accidents. Also, a program should be instituted in which police officers fill out special data forms whenever they observe a wrong-way movement.

2) Prototypes of some of the wrong-way movement prevention systems described should be built and tested. Channelization modifications and the wrong-way movement alarm system are of special interest. Testing should evaluate both the effectiveness and costs of these systems.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. "Exit Ramps, Wrong-Way Traffic Problem for U.S.," Traffic Engineering, Vol. 35, No. 4, pp. 24-27, 56.

2. Highway Design and Operational Practices Related to Highway Safety, Traffic Safety Committee, American Association of State Highway Officials, Washington, D. C., 1967.

3. Instructional Memorandum 21-9-71, "Signs, Pavement Markings, and Geometry to Avert or Redirect Wrong-Way Traffic Movements", FHWA, Washington, D. C., August 17, 1971.

4. Estep, A. C., "Wrong-Way Driving on California Freeways 1961-1972", paper presented at 1972 Summer Meeting of the AASHO Operating Subcommittee on Traffic Engineering.

5. Messer, C. J., Friebele, J. D., and Dudek, C. L., A Quantitative Analysis of Wrong-Way Driving in Texas, Texas Transportation Institute, Research Report 139-6, May, 1971.

6. Mills, J. P., "Wrong-Way Driving in Virginia", paper presented at the 1972 Summer Meeting of the AASHO Operating Subcommittee on Traffic Engineering.

7. Tamburri, T. N., "Wrong-Way Driving Accidents are Reduced", Highway Research Record Number 292, pp. 24-49.

8. Goodman, Leon, "Interchange Design to Eliminate Wrong-Way Entry", Traffic Engineering, Vol. 40, No. 1, October, 1969, pp. 28-35.

9. Tamburri, T. N., "Report on Wrong-Way Automatic Sign, Light and Horn Device", California Division of Highways, June, 1965.

10. Friebele, John D., Messer, C. J., and Dudek, C. L., State-of-the-Art of Wrong-Way Driving on Freeways and Expressways, Texas Transportation Institute Research Report Number 139-7, June, 1971.

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