

STATE-OF-THE-ART OF WRONG-WAY DRIVING
ON FREEWAYS AND EXPRESSWAYS

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ABSTRACT

A review of the state of knowledge was conducted for the purpose of evaluating the problem of wrong-way driving on freeways and expressways. The extent and causes of wrong-way driving as well as preventive measures that are used or could be used have been reviewed. This is to provide additional insight in the development of a detection and communication system to warn drivers of wrong-way maneuvers.

DISCLAIMER

The opinions, findings, and conclusions expressed or implied in this report are those of the authors and not necessarily those of the Texas Highway Department or of the Federal Highway Administration.

SUMMARY

This report contains a review of the state of knowledge on wrong-way driving on freeways and expressways. Information has been drawn from studies conducted the past few years across the nation in an effort to provide additional insight and direction toward the development of a detection and communication system to warn drivers of wrong-way driving. The extent, causes, and locations of wrong-way driving as well as preventive measures that have been or could be used have been reviewed to provide this additional insight. From this review, the following findings may be drawn:

1. Roadway geometry and ramp geometry in particular appear to influence the rate of wrong-way incidents. The most frequent wrong-way maneuver on freeways seems to be entrance to the freeway via an exit ramp. Ramps on full cloverleaf interchanges have been observed to have the lowest rate of wrong-way entry. This may partially be due to the low ramp merging angles at the cross streets that discourage wrong-way maneuvers. Wrong-way incident rates at partial interchanges were observed to be almost twice the rate observed at full interchanges.
2. Two-way frontage roads are generally unsatisfactory as they tend to mislead the motorist and induce wrong-way entry to the freeway via an exit ramp.
3. Inadequate sight distance on the main lanes of the freeway may not always allow sufficient time for a right-way driver to

- react to avoid a collision with a wrong-way driver.
4. Motorists entering an opposing lane of traffic through a median opening at an intersection appears to be the major cause of wrong-way maneuvers on expressways.
 5. The drinking driver appears to be one of the major factors in the frequency of wrong-way maneuvers, accidents and fatalities. Researchers in California, for example, observed that in approximately four-fifths of the fatal wrong-way accidents studied in which the sobriety of the driver was known, the wrong-way driver had been drinking.
 6. A portion of the wrong-way driving problem appears to be due to drivers who intentionally make a wrong-way maneuver in seeking a shorter route to their destination.
 7. A high percentage of wrong-way maneuvers occur during the hours of darkness or reduced visibility.
 8. Pavement markings, including painted markings and raised retro-reflective markers to supplement signing, appear to be effective in warning drivers of attempted wrong-way driving. These appear to be especially valuable at night when signing may not be visible.
 9. The use of divergent roadways on exit ramps to redirect the wrong-way driver into the normal flow of traffic or to lead him into a sand trap device have been proposed in the literature. Although these special roadways may be a solution to wrong-way driving on exit ramps, no results of testing or usage were documented in the literature.

10. Wrong-way vehicle actuated warning devices that include audio and visual mechanisms have been tested for use on freeway exit ramps. These devices appear to have quite a sensory impact on the wrong-way driver and may be effective in alerting him to his mistake in sufficient time for him to avoid entering the freeway lanes. This concept may also be effective in controlling the drunk wrong-way driver.
11. Spike barriers on the roadway designed to disable a vehicle going the wrong-way do not appear to accomplish the desired objective in an effective manner.

Recommendations for Implementation

Based on the review of the literature the following recommendations are offered:

1. Ways must be sought to reduce or eliminate drunk drivers if significant reductions in wrong-way maneuvers, accidents, and fatalities are to be achieved.
2. Additional research should be undertaken to determine the geometric features of the roadway that influence the occurrence of wrong-way maneuvers.
3. Consideration should be given to studies to test the feasibility and effectiveness of providing a divergent ramp roadway that either redirects a wrong-way vehicle into the normal flow of traffic or guides the vehicle into an area where it would not constitute a hazard to traffic flow.

4. Future developments in the technology of detection and communication systems for warning drivers of wrong-way movements on ramps and one-way roadways should be monitored to determine if their performance justifies future consideration toward testing and implementation of these warning systems.

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BACKGROUND

Many thousands of miles of freeways have been built during the past two decades to provide motorists with convenient access to every section of the country. Freeways have been designed for safety and comfort by providing a high speed facility with grade separated intersections and divided one-way roadways. The one-way roadways, however, subject freeway motorists to the possibility of a very hazardous traffic situation - the wrong-way driver. The wrong-way driver, travelling head-on into an unsuspecting traffic stream, is simply a time bomb ticking off the seconds toward a possible disaster. Since freeways span the entire country, highway engineers, traffic safety officials, and interested citizens have expressed their concern about the traffic safety hazards associated with wrong-way driving. The Special AASHO Traffic Safety Committee expressed this concern (1):

"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."

In an effort to more clearly determine the nature of wrong-way driving, the causes and possible solutions, several research studies have been conducted across the nation during the past several years. Each of these studies has provided additional insight and direction toward the ultimate objective of eliminating wrong-way driving. This report draws heavily from the information and findings of these previous studies.

Objectives

This review of the state of the knowledge on wrong-way driving was conducted as a first step in evaluating the feasibility of developing a detection and communication system to warn drivers of wrong-way maneuvers occurring on the main-lanes and exit ramps of freeways. To meet this objective, a review of the literature was directed toward examining the following:

1. The extent and magnitude of wrong-way driving in areas with controlled access facilities.
2. Apparent causes of wrong-way driving on freeways, frontage roads, ramps, and expressways.
3. Design and control measures used to prevent or reduce wrong-way driving on the freeways, frontage roads, ramps, and expressways.
4. Wrong-way detection and warning devices that have been proposed or used, to reduce or prevent wrong-way driving.

Magnitude of the Problem

"Wrong-Way Crash Kills Five" reads a bold type headline to a story concerning a wrong-way accident on an urban freeway. The television and press coverage show all the tragic, gory, but spectacular details of the wreckage. Wrong-way accidents have all the necessary characteristics for the making of a headline news story. As subsequent data show, they are rate accidents that tend to be very severe, and thus spectacular. It is under this aura of overexposure and emotionalism that

factual data and evidence concerning wrong-way driving must be carefully analyzed to insure that satisfactory findings and solutions are obtained.

A 1964 Federal Highway Administration national survey (2) of state and local highway engineers revealed that only 15 percent of the respondents felt that a definite problem existed as a result of wrong-way movements. The remaining 85 percent of the respondents either didn't express an opinion, or felt existing signing practices were adequate, or low volumes had not, as yet, caused the situation to develop.

In 1970, the Texas Transportation Institute conducted a questionnaire survey of engineers and law enforcement personnel in Texas (3) in an effort to qualitatively determine the nature of the wrong-way problem in the state. A majority of the 32 engineers and 19 law enforcement personnel surveyed from the state indicated that wrong-way driving accidents constituted less than two percent of the total accident problem and that wrong-way driving has not been increasing during the past few years.

Data published yearly by the Statistical Services Division of the Texas Department of Public Safety for the years 1967, 1968, 1969, and the first half of 1970, revealed that approximately 0.2 percent of all accidents in Texas were wrong-way types. Only about 1.4 percent of all fatal accidents were the result of wrong-way maneuvers. However, the data indicated that, although wrong-way accidents constituted a small part of the total accident picture, the results of such accidents usually are severe. For instance, one out of every 100 accidents (of all types) on rural Texas highways is fatal, whereas 15 out of every 100 wrong-way accidents are fatal.

EVALUATION OF WRONG-WAY DRIVING MANEUVERS

This section describes the various types of wrong-way maneuvers, apparent reasons for them and where they most commonly occur. In evaluating these maneuvers, discussion will relate to the following factors:

1. The Roadway
2. The Driver
3. The Driving Environment

Discussion of the relationship of these factors to the wrong-way driving problem will focus on previous studies that have investigated the problem in various parts of the country.

The Roadway

Studies of the relationships of wrong-way driving maneuvers to roadway design have been conducted primarily in California. These studies have been directed toward a statistical analysis of the types and locations of wrong-way maneuvers. Insufficient data have been presented, however, to clearly indicate why these maneuvers occur on any particular type of facility.

Ramps, Interchanges and Frontage Roads - Various studies (2,4) have indicated that the problem of wrong-way entries on exit-ramps is serious. Tamburri and Theobald (5) found that over 50 percent of all wrong-way driving incidents on California freeways resulted from drivers entering via an exit ramp (Table 1). Drivers making U-turns in traffic lanes resulted in about 19 percent of all the wrong-way maneuvers made, and another 9 percent were attributed to drivers making U-turns off of an entrance ramp into opposing traffic flow.

Table 1

ORIGINS OF WRONG-WAY MANEUVERS
ON CALIFORNIA FREEWAYS*

Wrong-Way Maneuvers		
Type of Wrong-Way Maneuver	Number	Percent
Entered freeway via an exit ramp	311	52.7
Made U-turn from exit ramp (right-way on freeway)	18	3.0
Made U-turn from entrance ramp (wrong-way on freeway)	54	9.1
Made U-turn into entrance ramp (right-way on freeway)	34	5.8
Made U-turn in traffic lanes	114	19.3
Drove across median divider	22	3.7
Other U-turns on entrance or exit ramps	38	6.4
Subtotal	591	100%
Maneuver Unknown	172	
Total Incidents	763	

*Data for two 9-month studies conducted from 1962 to 1964.

Source: Reference (5).

The relationships between wrong-way incidents and freeway interchange type were analyzed in California studies (5,6). Wrong-way maneuvers at the following types of interchanges and ramp configurations were considered:

"Diamond - A ramp of fairly good alignment usually terminating at a two-way crossroad with provision for turning right or left at the crossroad. The right turn (or direct connecting) ramps at cloverleaf interchanges were also included.

Loop (Full Cloverleaf) - A one-way, small radius ramp of approximately 270° for left turning movements located at interchanges with four such facilities.

Loop (Two Quadrant Cloverleaf) - The same as above except at interchanges with only two such facilities. Usually, both left and right turns are provided at the crossroad termination of these ramps.

Buttonhook - Button hook ramps have small radius curves of approximately 90° and terminate at a local road parallel to the freeway. Some of the ramp pairs (on-off) in this category are an integral portion of a full interchange with a freeway crossing and others are isolated pairs without a near by facility for the reverse movements.

Trumpet - The ramps, both left and right turning, at three-leg interchanges.

Cul-de-Sac or Scissors - An off ramp with a geometric design which allows direct and preferential alignment across opposing traffic of a two-way parallel road. Traffic on the two-way road which is opposite to the flow on the off-ramp is usually channelized to cross the off-ramp traffic at approximately 90°.

Unclassified - Unclassified ramp types are all those that would not fit any of the standard named interchange types."

A total of 440 wrong-way incidents were observed during the study where entry was made to the freeway via an off-ramp. Since some ramp types were more prevalent than others, a parameter of wrong-way incidents per 100 ramp years was used to place all ramp types on an equivalent rate basis for comparative purpose. Table 2

Table 2

WRONG-WAY ENTRY RATES
TO FREEWAY VIA AN OFF-RAMP *

Interchange Type	Wrong-way Entry Rate (Incidents per 100 Ramp-Years)
Four-quad cloverleaf	2.00
Buttonhook	4.12
Two-quad cloverleaf (parclo A and B)	6.08
Diamond	7.46
Trumpet	14.19

* 28 months of data for all phases of a three phase California study.

Source: Reference (6).

shows the results of the rate computations for interchanges that provided all possible turning movements. The trumpet-type interchange had the highest rate of wrong-way entry with 14.19 incidents per 100 ramp-years. Full Cloverleaf interchanges had the lowest wrong-way entry rate with 2.00 incidents per 100 ramps-years.

It has been suggested (4,7,8) that interchanges that do not provide for all possible movements may result in greater operational problems than those interchanges that do provide all possible movements. Table 3 shows the effect of full and partial interchanges on wrong-way incident rates for the California study. Partial interchanges were found to have a wrong-way incident rate of almost twice that of full interchanges. It was suggested that all turning movements should be provided at interchanges; otherwise, wrong-way entry at the remaining ramps would tend to increase. In addition, the analysis of ramp types indicated the following:

1. Off-ramps that force merging at flat angles at the cross street (cloverleaf right-turn ramps, loop ramps) have the lowest entry rates.
2. A physical median divider on the cross street helps prevent wrong-way entry to the off-ramps.
3. Left-side off-ramps should be avoided. To the wrong-way driver, they appear much like a right-side on-ramp at the freeway, adding confirmation that he is going the "right-way."

Although no reference in the literature review can be cited, it appears that drivers desiring to enter the freeway from accessible property

Table 3

EFFECT OF FULL AND PARTIAL
INTERCHANGES ON WRONG-WAY INCIDENT RATES*

Type	Rate (Incidents per 100 Ramp-Years)**
Full Interchanges (diamonds, full and two-quadrant clo- verleafs, buttonhooks)	5.13
Partial Interchanges (half- diamond, isolated diamond ramp, and buttonhooks without structures)	9.46

* 28 months of data for all phases of a three-phase California study

** χ^2 at 1 df = 19.74 if $P < 0.001$

Source: Reference (6).

abutting or streets intersecting a frontage road at the exit ramp may make a wrong-way maneuver up the ramp.

Two way frontage roads are also of concern in wrong-way driving. The special AASHO Traffic Safety Committee (1) concluded that slip ramps on two-way frontage roads are generally unsatisfactory as they tend to induce wrong-way entry to the through lanes of the freeway. Engineers and law enforcement personnel in Texas responding to an opinionnaire (3) indicated that elimination of two-way frontage roads was a possible solution for reducing the frequency of wrong-way maneuvers.

Sight Distance - Inadequate sight distance on the main lanes of the freeway may not allow sufficient time for the right-way driver to react to avoid a collision. Tamburri (8) evaluated the effects of median barriers, piers, abutments, slopes, and horizontal and vertical alignment in reducing the sight distance to both the wrong-way and right-way driver. It was determined that one-half of the wrong-way accidents observed occurred at locations with less than 1,000 feet of sight distance to the motorist driving in the proper direction.

Tamburri also rationalized the sight distance needed by the right-way driver to avoid an incident by assuming the following conditions:

1. A rate of closure of the right-way and wrong-way drivers of 205 fps.
2. A perception-reaction time of 2.5 seconds.
3. A minimum lane shift time (by the right-way driver) of 3.0 seconds.
4. A total time required for evasion of 5.5 seconds (assuming no correction by the wrong-way driver).

From this, the minimum sight distance needed by the right-way driver

to avoid a head-on collision with the wrong-way driver would be:

$$5.5 \text{ sec.} \times 205 \text{ ft/sec} = 1130 \text{ feet}$$

This would, of course, depend on the ability of the driver to find sufficient maneuvering space on the roadway.

Expressways - The results of the California studies (5) showed that 52 percent of all wrong-way maneuvers on expressways studied were attributed to motorists entering an opposing lane of traffic through a median opening at an intersection; 17 percent of the movements were due to drivers entering an opposing lane of traffic through a median opening not at an intersection (Table 4). The wrong-way movement on expressways, especially through a median opening was thought to be due to driver confusion - confusion due to the many different combinations of intersecting streets and parallel frontage roads encountered at many of the expressway intersections. It may be conjectured that excessive pavement area at intersections which allows the driver greater freedom to inadvertantly choose the wrong-way direction may, in part, contribute to the confusion.

Wrong-Way Maneuvers and the Driver

Wrong-way driving violations are frequently the result of a physical impairment or emotional response of the driver. The following are factors which have previously been investigated with respect to the driver involved in wrong-way incidents:

1. Driver's use of alcohol
2. Willful or deliberate violation
3. Driver confusion and driver-expectancy

Table 4

ORIGINS OF WRONG-WAY MANEUVERS
ON CALIFORNIA EXPRESSWAYS*

Type of Wrong-Way Maneuver	Wrong-Way Maneuvers	
	Number	Percent
Entered at an intersection (median opening)	159	52.3
Turned wrong-way from undivided road transition or driveway (no median opening)	19	6.2
Drove across median divider	6	2.0
Drove through median opening (not at intersection)	52	17.1
Made U-turn in traffic lanes	57	18.8
Other	11	3.6
Subtotal (known maneuvers)	304	100%
Maneuver unknown	50	
Total incidents	354	

*Data for two 9-month studies conducted from 1962 to 1964.

Source: Reference (5).

The Drinking Driver - *"The use of alcohol by drivers and pedestrians leads to some 25,000 deaths and a total of at least 800,000 crashes in the United States each year."* This statement, from a 1968 report on Alcohol and Highway Safety to the U. S. Congress (18), emphasizes the enormous impact the drinking driver has on the national death toll. This report continues: *" . . . every competent investigation has demonstrated that the immoderate use of alcohol is a very major source of highway crashes, especially of those most violent. In fact, it contributes to about half of all highway deaths and to appreciable percentages of the far more numerous nonfatal crashes."*

The report to Congress noted that those drivers with blood alcohol concentrations of .10 percent and greater, who comprise one to four percent of the drivers on the road, account for about 50 to 55 percent of all single vehicle accidents in which drivers are fatally injured. The magnitude is similar for multiple vehicle accidents where the one to four percent of the driving population are involved in about 45 percent of the accidents.

Wrong-way driving has also been shown to be highly influenced by the drinking driver. Drinking drivers in the California studies (8), accounted for 43 percent of those involved in wrong-way accidents while Michigan (10) observed that 50 percent of all wrong-way accidents involved drinking drivers. In approximately four-fifths of the fatal wrong-way accidents studied in California in which the sobriety of the driver was known, the wrong-way driver had been drinking. Table 5 presents data

Table 5

SOBRIETY OF WRONG-WAY DRIVERS IN CALIFORNIA*

<u>Sobriety</u>	<u>Number</u>	<u>Percentage</u>
HBD** - obviously drunk	286	17.9
HBD - ability impaired	123	7.7
HBD - ability not impaired	207	12.9
HBD - impairment unknown	73	4.5
Had not been drinking	913	57.0
<u>Subtotal</u>	<u>1602</u>	<u>100%</u>
Not stated	136	
Total	1738	

*28 months of data for all phases of a three phase study.

**HBD - had been drinking

Source: Reference (8).

from the California study on the sobriety of drivers involved in wrong-way incidents.

Wilde and Curry (19) in a review of the drinking driver problem state:

"One reason that alcoholics and problem drinkers have not been removed from the highways is the general apathy of both public and police. If both were made aware of the disproportionate contribution of this group to both accident and fatality rates, it would make the realization of the elimination of this high risk group from the highways somewhat easier."

Willful Violation - A portion of the wrong-way driving problem is due to willful violations. Willful violations include the following different movements (2):

1. Drivers who missed or overdrove the desired exit and made a U-turn on the freeway lanes to return to the exit.
2. Drivers entering the freeway via a exit ramp and, after discovering their wrong-way maneuver, would continue down the freeway main lanes (in the wrong-way direction) until a suitable exit was reached.
3. Drivers who entered on an exit ramp or exited on an entrance ramp to reach a road that was not serviced by that interchange.

Tamburri (5) found that intentional wrong-way driving was mostly confined to taking short cuts. In response to an opinionnaire (3) many engineers and law enforcement personnel in Texas indicated that intentional short cuts and motorists attempting to reach facilities

not serviced by their roadway were the major reasons for willful wrong-way driving.

Driver Confusion - The results of a multi-state diagnostic study of highway visual communications systems reported by Woods, et. al., (11) indicated that motorists frequently experience difficulty in locating entrance ramps to freeways. Also, drivers are often confused when there are several side roadways intersecting in close proximity to the interchange area. This confusion may result in wrong-way driving. Tamburri's studies (5) found that many older drivers and drinking drivers had no idea whatsoever where their wrong-way trip began. Woods, et. al., (11) suggest that more efficient use could be made of "positive" signing techniques in guiding motorists to the freeway entrance ramp and thus discouraging the motorist from possible wrong-way maneuvers.

Driver Expectancy - The concept of driver expectancy refers to the repetitive process that conditions a motorist to respond to a traffic situation in a predetermined manner. The role of driver expectancy has been established as a primary problem in the effectiveness of highway visual communications systems. When a conflict exists between the expected situation and the information presented to the driver by his view of the roadway, including informational or regulatory signing, an undesired driver response, such as a wrong-way maneuver, may occur (12).

Wrong-Way Maneuvers and the Driving Environment

The results of the California studies (5,8) revealed that a majority (56.9 percent) of the wrong-way movements studied occurred during the hours of darkness or reduced visibility. Wrong-way drivers who had been drinking were involved in more incidents during the hours of darkness than during the daylight hours. Michigan (10) reported that 37 of 44 wrong-way accidents recorded in 1966 occurred in dark hours. The high frequency of nighttime as well as weekend wrong-way incidents seemed to be related to the drinking driver.

Woods, et. al., (11) found that many drivers feel the roadway geometrics situation ahead is a principle source of information for accomplishment of the driving task and drivers are especially concerned with the view of the pavement surface at points where decisions are to be made regarding turning maneuvers. From this, it might be assumed that locations where highway structures, land use, natural growth or lighting conditions are such that adequate notice of right-way maneuver points is not sufficient, wrong-way maneuvers may occur.

Studies (5,10) have shown that high volume traffic on urban freeways may give a clue to the driver that he is driving incorrectly, and thus may act as a deterrent to wrong-way driving. Conversely, low volume traffic on rural freeways may not alert the driver to the mistake of a wrong-way maneuver. However, the high volumes on urban freeways may, at times, make it impossible or difficult for the driver to take corrective action before a collision occurs.

PREVENTIVE MEASURES FOR WRONG-WAY DRIVING

Methods that have been used or could be used to reduce the number and severity of wrong-way incidents are discussed in this section. Preventive measures can be classified into the following elements:

- . Ramp and roadway geometry
- . Signing and pavement marking
- . Warning and detection devices and vehicle arresting systems

The material herein focuses on standard design practices, practices which have resulted from various studies to reduce wrong-way driving, and methods which may have application in this area.

Ramp and Roadway Design

The previous section of this report has indicated some of the problems of wrong-way driving associated with the geometric design aspects of the highway. Although it has been observed that some ramp types and roadway configurations have higher rates of wrong-way violation than others, it is significant to note that few conclusions have been reached correlating specific geometric details and traffic control measures to the rate of wrong-way entry at freeways and expressways.

Ramps to Redirect or Snare Wrong-Way Vehicles - Goodman (13) suggests the provision of a divergent roadway on a ramp to redirect the wrong-way driver into the normal flow of traffic. He suggests that this may be accomplished by the installation of an "ear"

roadway, as shown in Figure 1. The theory assumes that in spite of signing, some drivers will enter the ramp. It also assumes that the majority of drivers would continue to keep to the right with the "ear" roadway providing a safe exit. The loop could also serve as a means of escape for those entering the actual ramp roadway. Signing on the "ear" roadway would serve to eliminate driver confusion. Possible uses of an "ear" roadway as suggested by Goodman are shown in Figure 2. Although not indicated in the reference, this design may actually encourage wrong-way maneuvers and could be modified to provide the divergence a short distance up the ramp.

A proposed vehicle disabling sand trap on a divergent roadway (14), as shown in Figure 3, follows the concept of Goodman's "ear" roadway. As before, a driver is encouraged to keep to the right on a path off of the ramp. He is then guided into a sand pit and does not remain a hazard to normal ramp traffic. Raised reflective pavement markers (reflective in the wrong-way direction) used in conjunction with a "KEEP RIGHT" sign may be used to guide the driver into the sand trap. Although no documented uses of such a roadway were found in the literature review, it seems that this design would be beneficial in preventing the drinking driver from continuing his trip and insuring that a wrong-way vehicle does not remain a hazard to right-way traffic.

Freeway Frontage Roads - Diagnostic evaluations reported by Woods, et. al., (11) have indicated that two-way frontage roads are generally unsatisfactory to motorists. The intersection of ramps with

PROPOSED RAMP DESIGN TO ELIMINATE WRONG WAY ENTRY

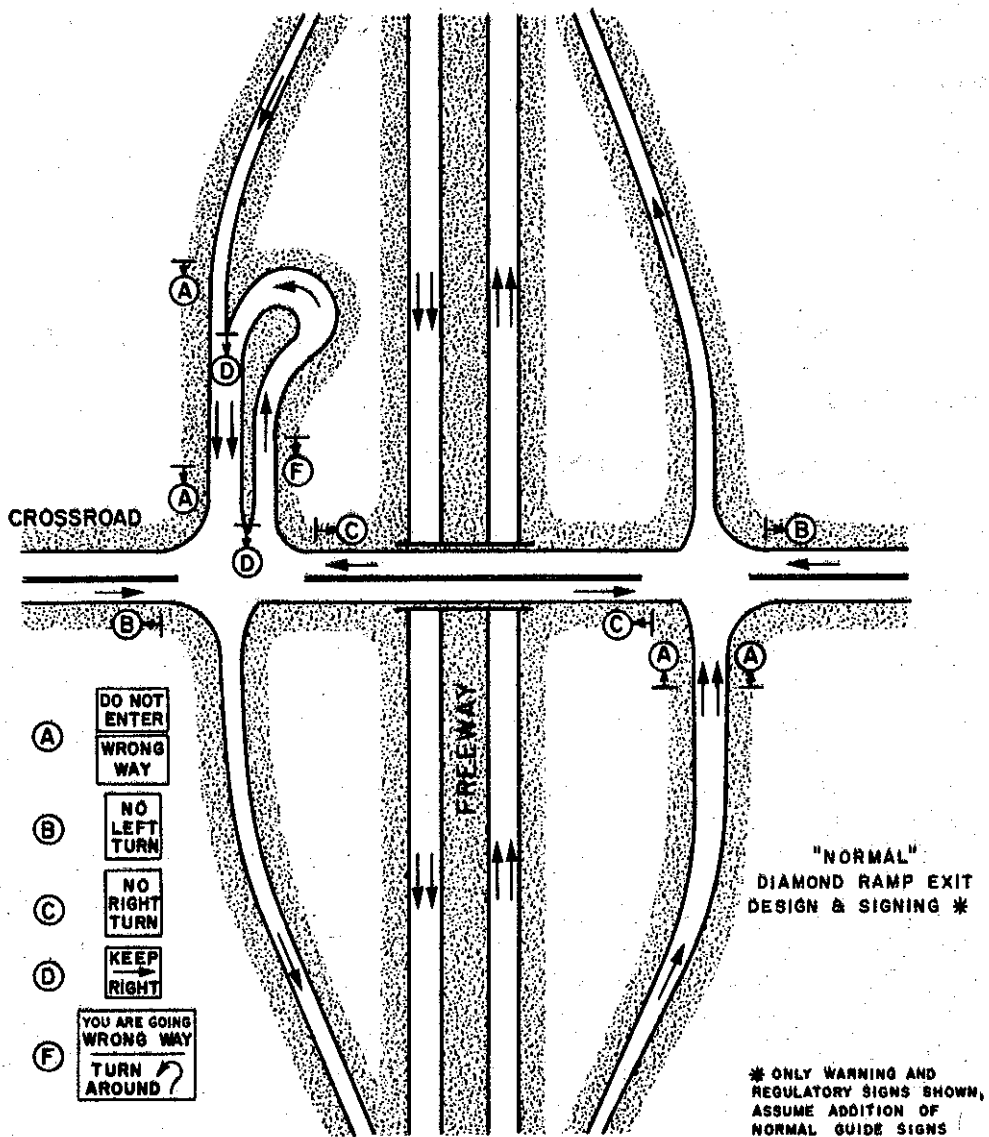
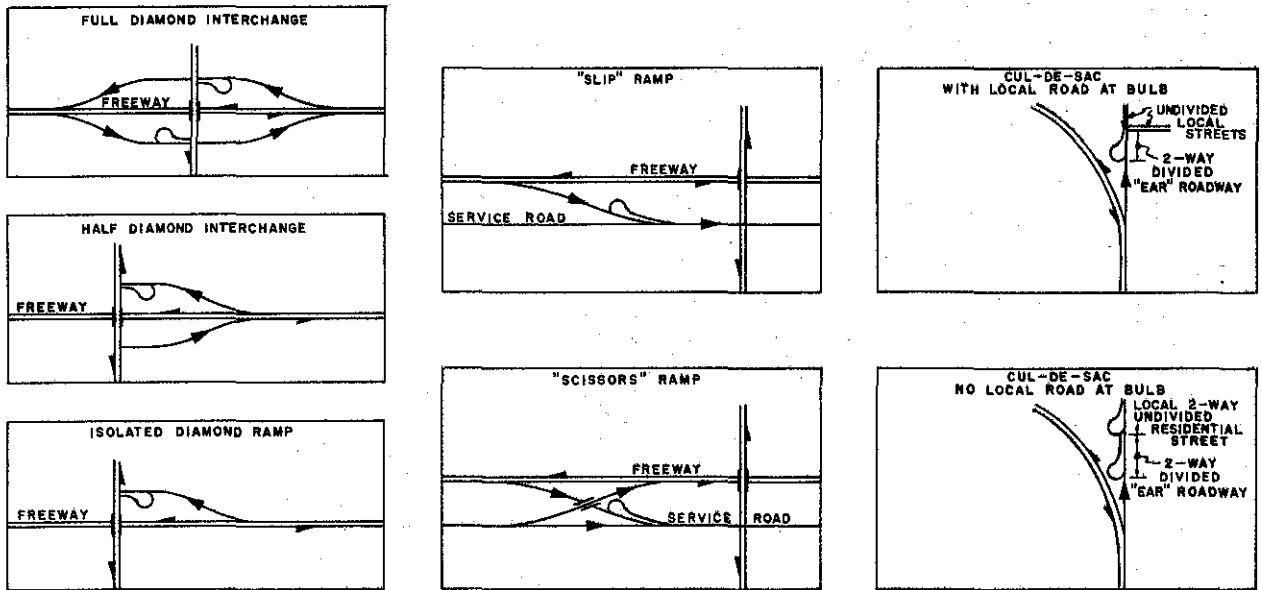


FIGURE I. EAR ROADWAY (13)



(TWO-WAY RAMPS)

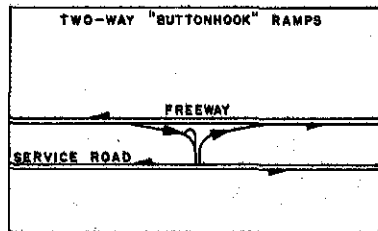
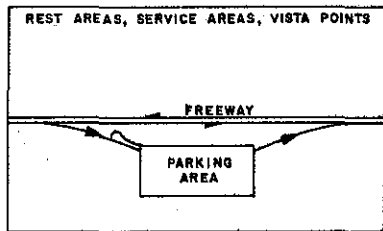
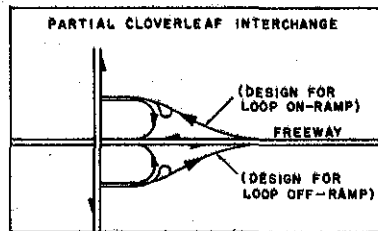
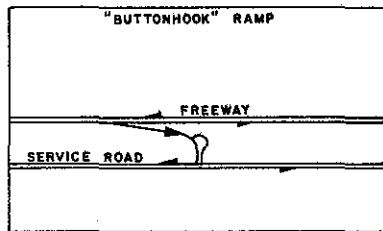


FIGURE 2. APPLICATIONS OF EAR ROADWAYS (13)

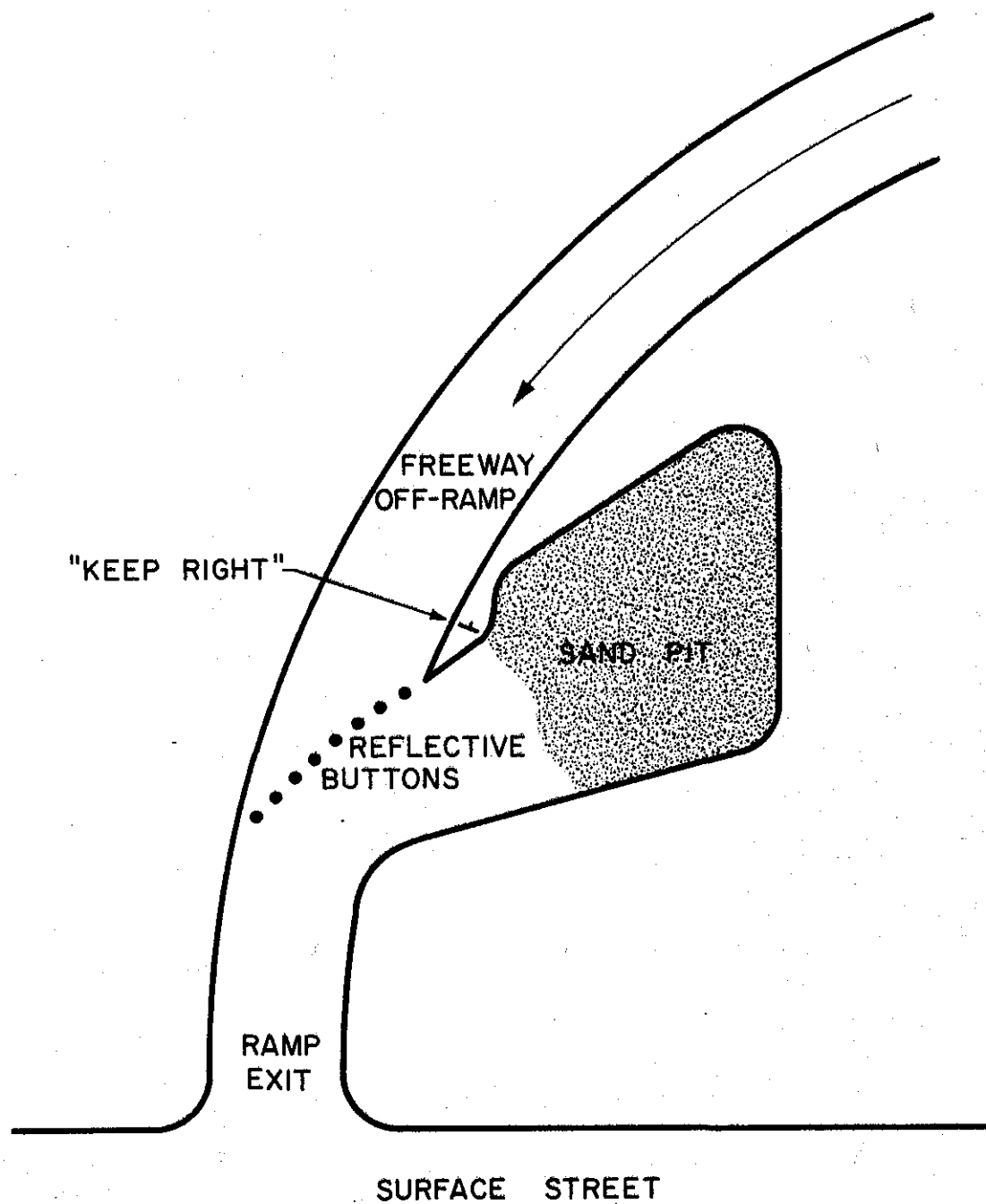


FIGURE 3. DIVERGENT RAMP ROADWAY AND SAND PIT TO TRAP WRONG-WAY VEHICLES (14)

the frontage road tend to confuse the driver and may invite him to enter the exit-ramp. The visual picture presented to the driver when a slip ramp intersects a two-lane frontage road appears to be very similar to the transition from a two-lane, undivided roadway to a four-lane divided section. The resulting confusion may lead to a wrong-way movement.

Sight Distance - As previously mentioned, sight distance considerations are important in conveying information to both the potential wrong-way driver and right-way driver. Sight distance limitations due to adverse alignment, piers, abutments, slopes, natural growth, and land use should be considered. Tamburri (6) found that sixty percent of fatal and injury wrong-way accidents in California occurred where sight distance was restricted to 1200 feet or less.

Signing

The primary information source of the motorist that warns him of a wrong-way maneuver is the roadway or ramp geometry itself. This often does not convey an adequate message and signs then become the primary mode of driver communication. Design considerations for signing include, size, contrast, colors, shape, composition of the message, and lighting or reflectorization. Placement of the sign must assure that it is within the cone of clear vision of the road user and that it is positioned with respect to the point, objective,

or situation to which it applies. Use of oversized signs and reflectorization may be needed in locations where the motorist is apt to disregard the warning.

The Special AASHO Traffic Safety Committee made the following recommendations for wrong-way signing and marking on freeway and expressway exit ramps (1):

1. "ONE WAY" signs, Turn Prohibitions signs, and Sign assemblies consisting of a "DO NOT ENTER" sign above a white-on-red "WRONG-WAY" sign should be in place where an exit ramp intersects a crossroad, if the exit movement is sufficiently separated from an entrance movement to avoid confusion as to the intent of such signing. In addition, "WRONG-WAY" signs may be placed, as required, at locations along the exit ramp away from the crossroad.
2. Arrow pavement markings should be placed in each lane of an exit ramp in advance of a crossroad.

The following recommendations were made by the Committee for freeway and expressway entrance ramps:

1. To minimize the possibility of wrong-way travel on entrance ramps a "NO TURNS" sign should be placed in advance of the entrance ramp intersection. A "ONE-WAY" sign on the opposite side of the through roadway should be visible to traffic on the ramp entering the through lanes. In at least two States legal opinions have been rendered stating the inadequacy of lack of signing at these locations.
2. Route markers and directional signs adequate in size and suitably positioned (overhead if necessary) should be in place at an intersection of an entrance ramp and a crossroad. "FREEWAY ENTRANCE" signs should be used to supplement these guide signs where appropriate.
3. Arrow pavement markings should be placed in each lane where an entrance ramp joins a through roadway.

The Committee also stated that "at-grade intersections of divided highways present as many, if not more, opportunities for wrong-way

travel and adequate signs similar to those used at exit ramp terminals should be employed where appropriate to avert these movements."

The most common sign to warn motorists of attempted wrong-way maneuvers is the standard black letters on white background "DO NOT ENTER." Texas uses the message "DO NOT ENTER-RAMP" at the intersection of exit-ramps and two-way frontage roads (Figure 4) to inform the motorist that the restriction applies to the ramp (15). The 1970 Manual on Uniform Traffic Control Devices has recently changed the "DO NOT ENTER" sign to the modified European design - a 30-inch white square inscribed with a 30-inch diameter red circle with a white band placed horizontally across the center of the circle with the words "DO NOT" above the band the the word "ENTER" below the band (20). This sign, shown in Figure 5, is the new standard according to the 1970 Manual and has no alternate design.

Studies reported by Woods, et. al., (11) indicate that more "positive" type signing techniques can help minimize driver confusion at freeway interchanges. "Positive" signing indicates the correct path or turning maneuver to the motorist rather than a restriction. Examples would include route markers, trailblazers, and the "FREEWAY ENTRANCE" sign that positively designates an entrance to the freeway.

Pavement Markings

Markings painted on the roadway may be used to assist motorists in avoiding wrong-way movement at interchange ramp terminals and at connections with frontage roads. Tamburri (6) indicated that a white

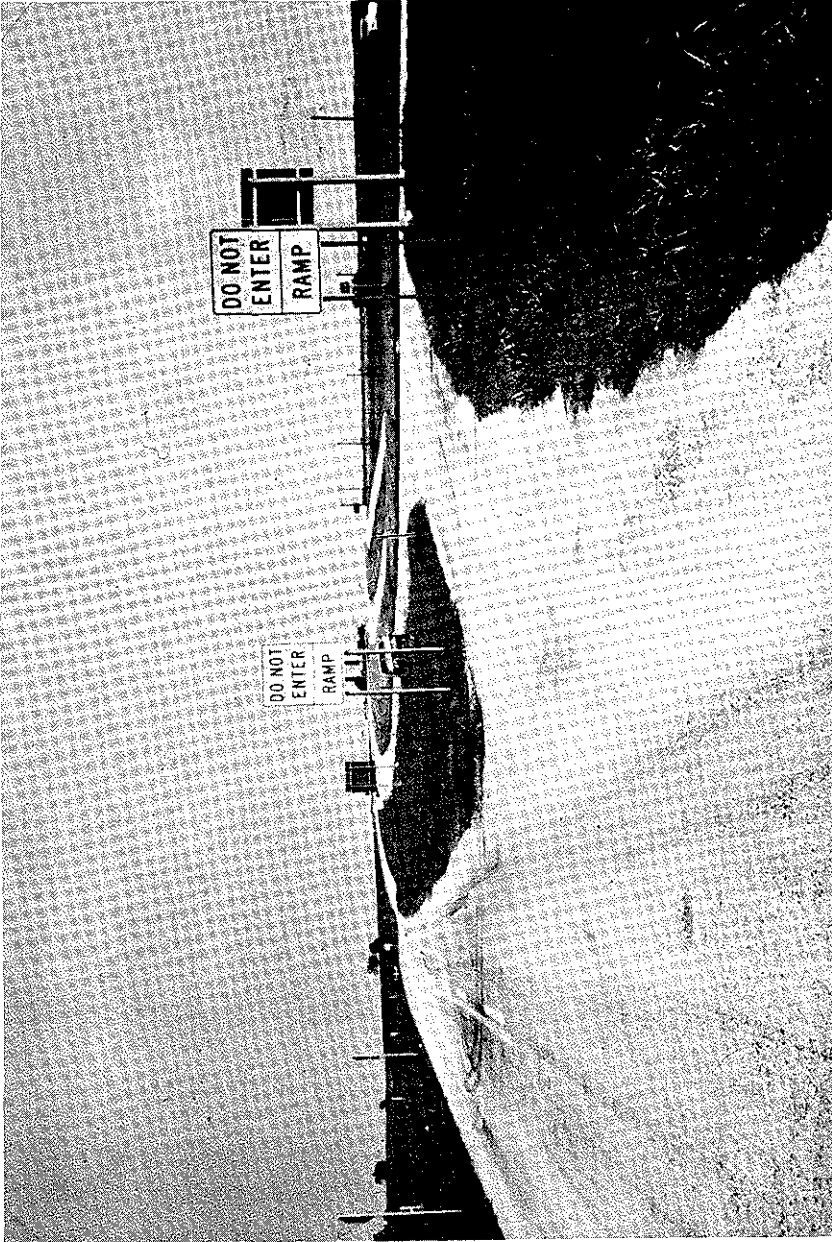


FIGURE 4 - "DO NOT ENTER-RAMP" SIGN TO PROHIBIT ENTRY ONTO THE EXIT RAMP



**FIGURE 5 - THE 1970 STANDARD FOR THE
"DO NOT ENTER" SIGN (20)**

pavement arrow placed at all off-ramps pointing in the direction of the right-way movement can be effective in reducing the number of wrong-way maneuvers.

Texas (15) uses raised, retro-reflective plastic pavement markers placed in an arrow pattern to indicate the right-way direction of travel. These "wrong-way arrows" are placed on a one-way exit ramp or one-way frontage road at its intersection with a crossroad. The motorist traveling in the correct direction sees a non-reflective white arrow while the wrong-way driver sees a red reflective arrow pointing in his direction.

Detection and Warning Devices and Vehicles Arresting Systems

Directional Detection - In order to determine the extent of wrong-way maneuvers at any specific exit ramp, a directional detector would be required (4). A directional detector used to accomplish this objective must have the capability to detect vehicles traveling in the wrong-way direction and must function properly over a wide range of vehicle speeds. Many commercially available detectors, including the pressure sensitive, magnetic, inductive loop, and radar types, have directional capabilities. California (16) has used induction loop directional detectors. These were found to be reliable although adjustments were often necessary because certain truck and trailer combinations caused occasional false alarms.

Warning Devices - California extensively investigated the use of a wrong-way vehicle detection and warning device. The warning device

consisted of a white-on-red reflective background sign with the message "GO BACK -- YOU ARE GOING -- WRONG WAY." Visual impact was increased by automatic illumination of the sign only when the directional detector was actuated by a wrong-way vehicle. A standard 12" red signal head was also used and operated in the steady mode when actuated. Audio warning also accompanied the visual warning and was accomplished by two electric horns, one continuous and the other pulsating. The entire device was actuated by a vehicle moving the wrong-way on an exit-ramp through an inductive loop directional detector. Data on wrong-way movements were recorded by using a camera that was actuated at the same time as the warning device.

It was found that with the addition of the warning device and directional signing changes, the incidence of wrong-way entry to the freeway at the off-ramp was reduced by 54 percent. An estimated 89 percent of the drivers who actuated the device, stopped, backed up or turned around when they saw and/or heard the automatic sign-horn device. There is some indication that this device might be effective in stopping drunk or confused drivers as a result of the sensory impact (16).

Vehicle Arresting Systems - As previously discussed, the possibility of a divergent ramp roadway to guide a wrong-way vehicle into a sand pit is a method of disabling a vehicle outside the path of normal traffic. Another possibility is the use of a spike barrier at exit ramps, such as are installed at some self service parking lots and drive-in theatres. These spike barriers are designed to puncture tires of a

wrong-way vehicle thereby disabling it. Experiments in California (17) however, found them to be unsatisfactory. The primary inadequacy of the spike barriers is that they do not immediately disable an errant vehicle, and thus the possibility remains that the vehicle can reach the freeway main lanes. In addition, it is not possible for the motorists to recognize the direction that the spikes are pointing and, therefore, the possibility of right-way driver panic exists.

DISCUSSION

Wrong-way drivers may be classified into three groups, namely, 1) drunk drivers, 2) sober drivers who intentionally make wrong-way maneuvers, and 3) sober drivers who unintentionally make wrong-way maneuvers. Drunk drivers impose an enormous impact on the national death toll. The drinking driver appears to be one of the major factors in the frequency of wrong-way maneuvers, accidents, and fatalities. It appears that legislation and enforcement offer the greatest promise for reducing wrong-way driving accident and fatality statistics due to the drinking driver. Electronic detection and alerting systems may be a means by which the drunk wrong-way driver could be controlled; however only limited development and testing of such devices has been accomplished to date.

Sober drivers who intentionally make wrong-way maneuvers are responsible for a portion of the wrong-way driving problem. These intentional maneuvers may be due to errors in navigation such as missing an exit or to the fact that no convenient access is provided to the desired destination. Where access is not provided, the driver is tempted to take a short-cut that includes a wrong-way maneuver to reach his destination. It is doubtful that electronic warning devices would reduce the frequency of intentional wrong-way maneuvers. Better surveillance and continued enforcement appear to be the key factors in controlling deliberate wrong-way driving.

It would appear that preventive measures such as the use of divergent roadways on exit ramps and electronic sensing and warning devices

could be of use in preventing unintentional wrong-way maneuvers by sober drivers. Such maneuvers by this group of drivers generally result from confusion or negligence and thus, these preventive measures may be an effective means to correct their driving mistakes.

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