

MEASURES FOR PREVENTING WRONG-WAY ENTRIES ON HIGHWAYS

by

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SUMMARY

An evaluation of the results of a two-year survey of incidents of wrong-way driving on Virginia highways revealed that the majority of them originated at diamond type interchanges. On-site investigations of a number of the interchanges at which instances of wrong-way driving had been noted suggested several improvements.

The report discusses measures for preventing wrong-way entries at interchanges and presents case studies of four of the interchanges visited. Some of the recommendations are given below:

- (1) Channelize the left lane of the exit ramp and remove the left end flare, preferably by providing a corner barrier. (The corner barrier will prevent the use of shoulders for a wrong-way turn.)
- (2) Properly locate signs based on the size of letters or symbols in the message and the cone of vision.
- (3) Provide intersection geometry information to the drivers entering a four-lane divided highway in the form of an information geometry sign.
- (4) As an aid to mentally impaired drivers, provide supplemental signs with pavement markings and spotlighting to make entry ramps conspicuous and exit ramps inconspicuous.

Specific techniques like the provision of double yellow lines without full openings, continuation of pavement edge lines across exit ramps, and bringing stop lines closer to pavement edge lines seem to pay off and are recommended for further evaluation.

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PURPOSE

The object of this investigation was to determine means for alleviating the problem of wrong-way driving on four-lane divided highways. The information considered in the investigation was obtained from (1) a 25-month survey of incidents of wrong-way driving on 2,000 miles of Virginia's divided highways, including interstates routes, conducted by the Virginia Highway Department and the Department of State Police, and (2) investigations of the physical aspects of sites at which wrong-way incidents occurred within the past 3 years.

EXTENT OF PROBLEM

Table 1 gives a comparison of accidents involving wrong-way driving with total accidents for the period covered by the 25-month survey. These data show that though accidents involving wrong-way driving are only 0.1% of the total accidents, the fatality rate per wrong-way accident is 30 times that for other types of accidents. This fact emphasizes the need for improvements that are not very expensive and also do not impede motorists other than the 0.1% wrong-way drivers.

The persons killed and injured per accident due to wrong-way driving were respectively 15.7 (1,570%) and 2.5 (250%) times the persons killed and injured due to other accidents on all roads. Wrong-way accidents on interstate highways were 0.4% of the total accidents on these type roads; and for each one, 0.47 and 1.18 persons were killed and injured, respectively; this means 27.4 (2,740%) and 2.81 (281%) times the persons killed and injured due to other types of accidents.

The table also shows that wrong-way accidents on arterial and primary roads are 0.1% of the total on these roads. Persons killed and injured per wrong-way accident on arterial and primary highways were respectively 2.8 (280%) and 2.2 (220%) times the persons killed and injured due to other types of accidents.

Wrong-way incident surveys carried out by California¹, Michigan², Missouri³, and Texas⁴ determined the same trend as for Virginia.

Table 1

Total Accidents Compared with Wrong-Way Driving Accidents

Accident Data	Interstate		Arterial & Primary		All roads	
	All Accidents 1970 & 1971 (24 months)	Wrong-way Accidents 25 mo. survey % of all accidents	All Accidents 1970 & 1971 (24 months)	Wrong-way accidents 25 mo. survey % of all accidents	All Accidents 1970 & 1971 (24 months)	Wrong-way accidents 25 mo. survey % of all accidents
Number of Accidents	14,862	55	72,812	83	133,065	138
Fatalities Per Accident	.016	0.47	0.017	0.048	.014	0.22
Injuries Per Accident	0.42	1.18	0.43	0.93	0.41	1.03
Incidents of wrong-way driving	—	140	—	331	—	471
						0.1
						1570
						250
						—

Source: Summary of Accident Data — States Highway Systems, 1970 and 1971, Virginia Department of Highways; and unpublished data compiled by the Department of Highways and Department of State Police.

EFFECT OF EFFORTS TO ALLEVIATE PROBLEM

Since the first wrong-way driving survey in 1970, the Highway Department's district traffic engineers have made improvements in signs and other facilities to prevent wrong-way entry. The effect of their efforts is indicated in Table 2. The period of January-May 1972 is not included in this table because there is no comparative January-May period for any other year.

Table 2

Numbers and Percentages of Wrong-Way Driving Incidents

Period of Survey	Time in Months	Incidents			
		Interstate		Divided Highways	
		Total	Per Month	Total	Per Month
July-Dec. '70	6	38	6.3	81	13.5
June-Dec. '71	7	38	5.4	114	16.2
June-Dec. '72	7	34	4.9	76	10.9

The table shows that on interstates in the three studies the incidents decreased from 6.3 to 5.4 to 4.9 per month for 1970, 1971, and 1972, respectively. On divided highways there was an increase in 1971 to 16.2 (being 13.5 in 1970) incidents per month but a decrease in 1972 to 10.9 per month.

EVALUATION OF THE WRONG-WAY DRIVING SURVEY

The parameters determined in the wrong-way driving survey of Virginia up to December 31, 1972 (hereinafter termed "the survey") were examined in detail. These parameters were driver's age, time, weather, day of week, time of day (day-light or darkness), and location of the wrong-way entry. The two most important observations from the data are discussed below.

- (1) Drunkenness and darkness: Darkness combined with drunkenness on the part of drivers accounted for 2 to 4 times the number of incidents that occurred during

the daytime (Table 3). California¹ and Michigan² have reported high rates of accidents caused by darkness and drunkenness. This is contrary to the pattern obtained in the case of non-drunken drivers, where the daytime incidents exceed the nighttime incidents (Table 4).

In considering these findings, it is helpful to keep in mind studies carried out by Michigan² and California⁵ which showed that the mental outlook and attitudes of the drivers (as indicated by their high rate of driving violations) may also be contributing causes.

- (2) Wrong-way entry generators: The evaluation showed that the majority of wrong-way entries occurred at interchanges.

The incidences of wrong-way driving on interstate highways were broken down into four major categories as shown in Table 5. This table shows that 47% of the cases of wrong-way driving resulted from entries at interchanges, the origins of 30% were unknown, 15% resulted from U-turns, and very few (none in the last survey period of 1972) originated at crossovers.

Table 6 gives data relating to incidences of wrong-way driving on divided arterial and primary roads.

Table 3

Day and Night Wrong-Way Incidents by Drunken Drivers

Time	Interstate		Divided Arterial and Primary	
	No.	Ratio	No.	Ratio
Daylight	22	1.0	23	1.0
Darkness	51	2.3	93	4.0

Note: Drunken drivers include drunken, drinking and drugged persons.

Table 4

Day and Night Wrong-Way Incidents by Non-Drunken Drivers

Time	Interstate		Divided Arterial and Primary	
	No.	Ratio	No.	Ratio
Daylight	24	1.0	112	1.0
Darkness	19	0.79	59	0.53
Note: Besides normal drivers, the non-drunken drivers category includes those sleepy, fatigued, in poor physical and mental condition, nervous, on medication, sick, senile, and feeble. Intentional wrong-way drivers are also included in this classification.				

Table 5

Number and Places of Wrong-Way Entries on Interstates

Total	Places of wrong-way entry			
	U-turns	Crossover	Interchange	Unknown
140	21	2	66	51
100%	15%	1%	47%	37%

Table 6

Places of Wrong-Way Entry
on Divided Arterial and Primary Roads

Driver Condition	Number of Wrong-Way Entries	Place of Wrong-Way Entry								
		Intersection with exit ramps from Interstate Highways	Intersection With Road	Business Area	Residential Area	Crossover	Median Crossing	U-turn	Beginning of Divided Section	Unknown
Drunken	121	1	59	16	3	6	2	5	2	27
Non-drunken	185	18	64	51	14	16	2	6	2	11
Unknown	25	0	9	9	1	0	1	1	2	3
Total	331	19	132	76	18	22	5	12	6	41
%	100	6	39	23	5	7	2	4	2	12

These data indicate that the places most in need of immediate attention are as follows:

- (1) Intersections: (a) With exit ramps. Of 19 such incidents, 18 were by non-drunken drivers. (b) With roads — This type of interchange was the point of origin for 39% of all the wrong-way incidents. The non-drunken driver rate was higher than that for the drunken driver.
- (2) Business Area: Non-drunken drivers account for more than three times the number of incidences of wrong-way driving in business areas than do drunken drivers. It is claimed that many of the non-drunken drivers intentionally drive the wrong way. Good examples are the two wrong-way exits from a gas station through a crossover on Route 207 near Carmel Church witnessed by this investigator within a half-hour period. Figure 1 shows a driver making a wrong-way exit.

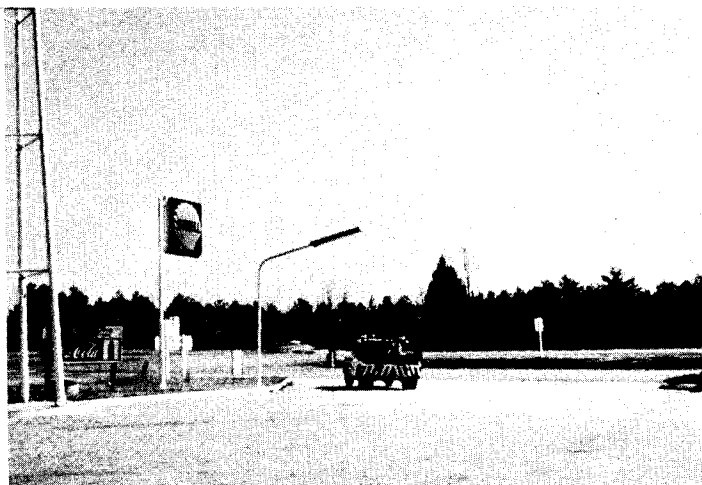


Figure 1. Example of an intentional wrong-way exit from a gas station. (Rte. 207 near Carmel Church.)

- (3) Crossovers and Residential Areas: Many of the cases of wrong-way driving from crossovers and in residential areas are considered to be intentional.

The above analysis indicates the need for engineering studies of (a) intersections with exit ramps from interstate highways, (b) intersections with roads, and (c) exits from business areas.

Study of the survey data further showed that most of the wrong-way entries were at partial interchanges* of the diamond type. Studies carried out by California⁶ and Michigan² also showed that the diamond type interchanges are more susceptible to wrong-way movements.

* Partial Interchange: In a partial interchange (e.g. diamond-type with four ramps) though the cross-traffic at grade is eliminated, all or some of the left turn movements cross the path of other vehicles, as compared to no such crossing on a full or non-partial interchange (e.g. cloverleaf).

Except for a few cases, the survey reports do not give the place of the wrong-way entry from the crossroads into the interstate highways. Some reports give the place of wrong-way entry as being the exit ramp.* No report in the survey showed that the wrong entry was made from the entry ramp.** In this report, therefore, only the problem of wrong-way entries through the exit ramp is discussed.

EXIT RAMPS AS GENERATORS OF WRONG-WAY ENTRIES ON INTERSTATE HIGHWAYS

In considering exit ramps as prime generators of wrong-way entries on interstate highways, two questions come to mind:

- (1) Are some exit ramps designed so as not to strongly discourage wrong-way entries?
- (2) Why and how does an exit ramp generate a wrong-way entry?

To answer question (1) above, refer to Table 5, which showed that out of a total of 140 wrong-way incidents reported on interstate highways, 66 (47%) were due to the wrong-way entries at the interchanges. Of these 66 incidents, 48 could be evaluated from available information. These 48 entries took place from 36 interchanges, each of which has at least two exit ramps.

For repeatability of the wrong-way incidents, statistics were collected from the survey and are given in Table 7. These statistics show that there were only four exit ramps in Virginia that were the site of two wrong-way entries and one exit ramp that experienced three.

The table shows that normal as well as drunken drivers are liable to enter some intersections. In fact, on these five exit ramps, more cases involved non-drunken drivers than drunken ones.

* Exit Ramp: Sometimes known as off-ramp. It is the ramp for the exit of the traffic from the interstate highway onto the crossroad.

** Entry Ramp: Sometimes known as on-ramp. It is the ramp for the entry of the traffic from the crossroad onto the interstate highway.

Table 7

Exit Ramps Site of More Than One Wrong-Way Entry

Interstate No.	Date	Place of Entry	Direction of Travel	Driver Condition
81	7/11/71	Exit 53A Rockbridge County	N. in S. Lane	Drunken
	8/16/71		N. in S. Lane	Drunken
81	8/ 7/70	Exit 51 Rockbridge County	N. in S. Lane	Normal
	11/22/70		N. in S. Lane	Drunken
81	8/ 7/71	Exit 48 Botetourt County	S. in N. Lane	Drunken
	8/ 9/71		S. in N. Lane	Drunken
	8/31/72		S. in N. Lane	Normal
64	5/24/72	Richmond City	E. in W. Lane	Normal
	5/24/72		E. in W. Lane	Normal
85	10/15/70	Interchange with Rt. 1	S. in N. Lane	Drugged
	12/15/70		S. in N. Lane	Normal

Since repeated wrong-way entries from a given ramp are very rare and wrong-way entries continue to take place from different ramps onto the interstate highways, it seems that any partial interchange is as prone to a wrong-way entry as is any other. Therefore, the preventive techniques adopted should be sufficiently economical that they could be used for all interchanges.

The reason that exit ramps on partial interchanges generate wrong-way entries (question (2) above) is that these ramps, unlike the ones on non-partial interchanges that converge with right-hand traffic, meet the crossroad at about 90 degrees to accommodate both left and right turns. ^{5, 7}

The possible wrong-way entries from the crossroad into the exit ramp or from the exit ramp into the crossroad are as follows:

- (a) From an undivided crossroad into the exit ramp by left and right turns as shown by the arrows in Figure 2.

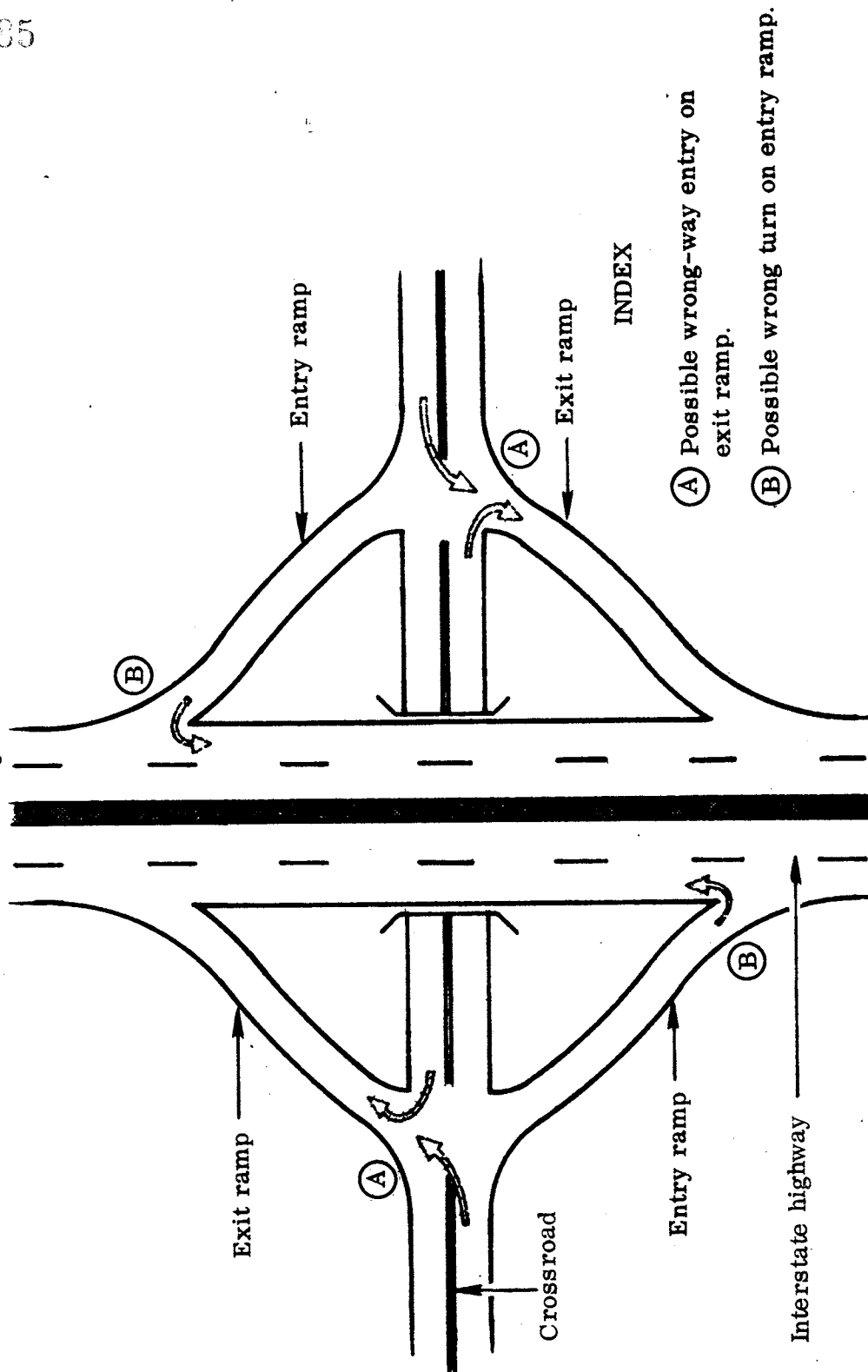


Figure 2. Location and direction of wrong-way entries on interstate highway.

- (b) From a divided crossroad into the left lane of the exit ramp as shown by arrows 1 and 2 in Figure 3.
- (c) From the Exit ramp (or its left lane if divided) into the wrong lane of a four-lane divided crossroad as shown by arrow 3 in Figure 3.
- (d) From the entry ramp of the interstate highway instead of the exit ramp into the wrong lane of a divided crossroad, as shown by arrow 4 in Figure 3.

MEASURES FOR PREVENTING WRONG-WAY ENTRIES

In this investigation visits were made to a number of interchanges on which wrong-way entries had been reported. Some interchanges for which wrong-way entries had not been reported were also visited. The objective was to review their engineering features.

The field study showed that in most cases signing has been the only means used to guide traffic at the interchanges, and that there was a need for more aids. The aids that seem to be necessary are discussed under the following subheadings and commented upon further in the section of the report titled CASE STUDIES.

- (1) Channelization,
- (2) signs,
- (3) intersection geometry information,
- (4) pavement markings,
- (5) physical barriers,
- (6) crossovers, and
- (7) junctions of entry ramps and exit ramps with crossroads.

1. Channelization

Channelization to prevent wrong-way entries involves four elements as follows:

- (a) Nonuse of flares.
- (b) Minimum width of the left lane of the exit ramp.

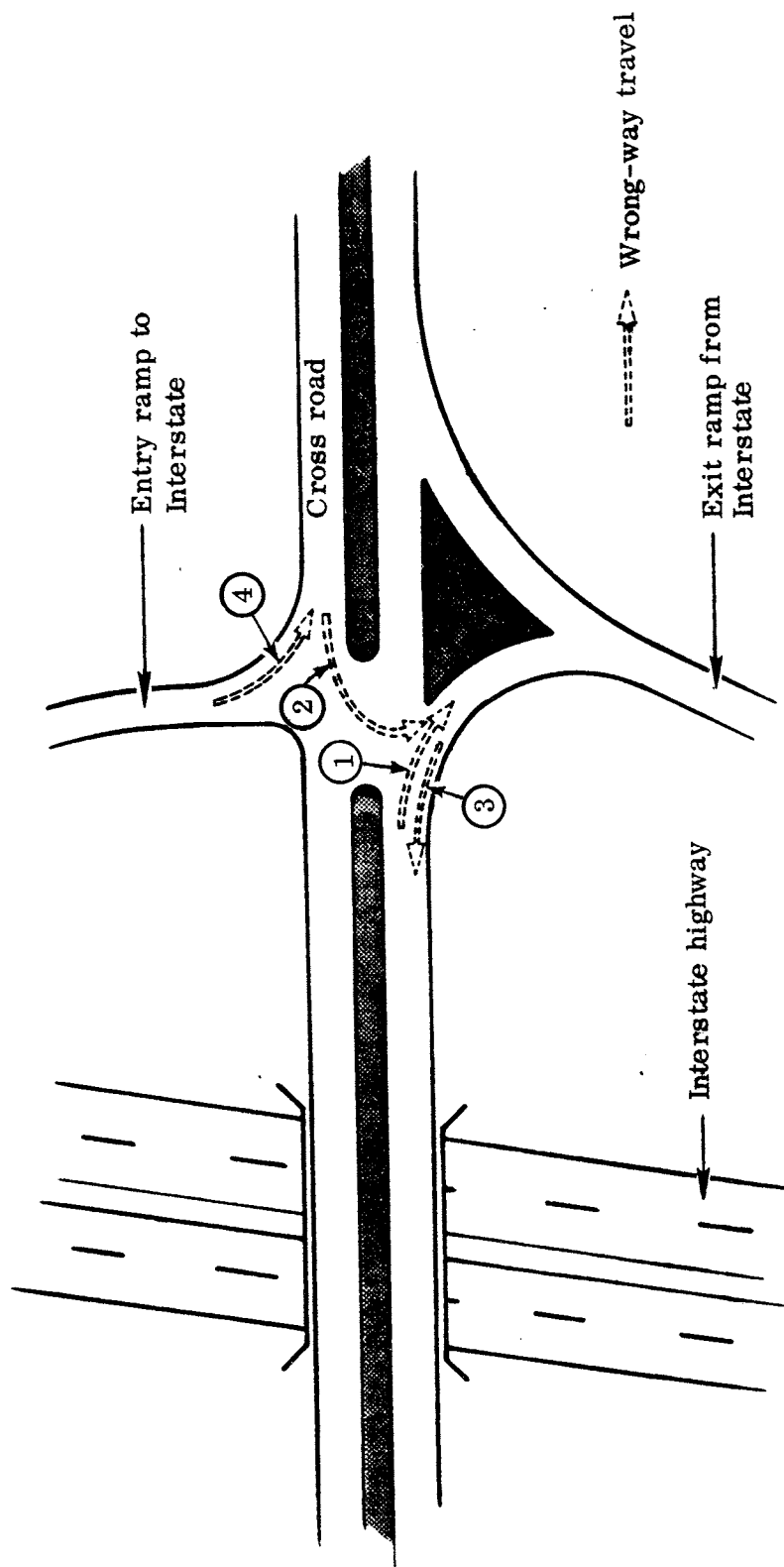


Figure 3. Wrong-way entry and egress on left lane of exit ramps.

- (c) Minimum width of the junction of the left lane of the exit ramp with the crossroad.
- (d) Physical barriers along pavement edge.

(a) Nonuse of Flares:

During this investigation it was observed that on almost all interchanges on which wrong-way entries had been made into the exit ramp and from the exit ramp into the crossroad, the left corner of the left lane of the exit ramp flared into the right pavement edge of the crossroad. An example of the flared end is shown in Figure 4 (a).

A flared end (termed "flare" hereafter) provides for a very easy right-hand turn out as compared to a sharp right-angled turn out. It is therefore possible that it would induce a driver to make a wrong-way entry from the crossroad into the exit lane. For a sharp, right-angled junction, the driver would have to reduce his speed and almost come to a stop before maneuvering into the exit lane.

Similarly, a driver coming upon the left flare from the exit ramp would tend to turn left with the flare into the wrong lane of the crossroad. Again, a sharp, right-angled bend would not permit such an easy left turn. A few examples of flares are given in Figures 4 (a), 5 (a), 6 (a), 6 (b), 7 (a), and 8 (b).

It was also observed that in the case of divided crossroads, some of the flares had collected dust, thus indicating their disuse. Examples are given in Figures 4 (a) and 5 (a). These flares may be either due to construction expediency or the design requirement for a left-turn curve from the exit ramp to the crossroad. When they have been provided to satisfy the left-turn curve designs, it is recommended that their designs be checked and the flares be removed or their use be prevented if they are not required. If these flares are found to be necessary, the following two alternative designs are suggested:

- (1) Provide pavement marking only or marking and rumble stripping over the flare such that the left edge of the left lane of the exit ramp makes a right angle with the pavement edge of the crossroad. This will discourage cars and other light vehicles — which for the most part are those involved in wrong-way entries — from using the flares. An example of flare marking is shown in Figure 4 (b).



Figure 4(a). Present condition — view from crossroad of exit ramp where wrong-way entry took place.

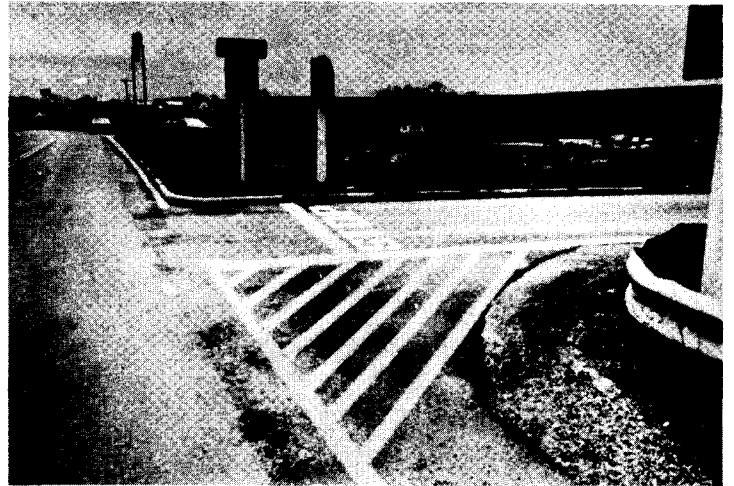


Figure 4(b). Suggested improvement of exit ramp shown in Figure 4(a) by marking pavement in flared corner and providing a stop line.



Figure 4(c). Further improvement of exit ramp over that shown in Figure 4(b) by continuing pavement edge line (broken) across exit ramp junction and adding an arrow.

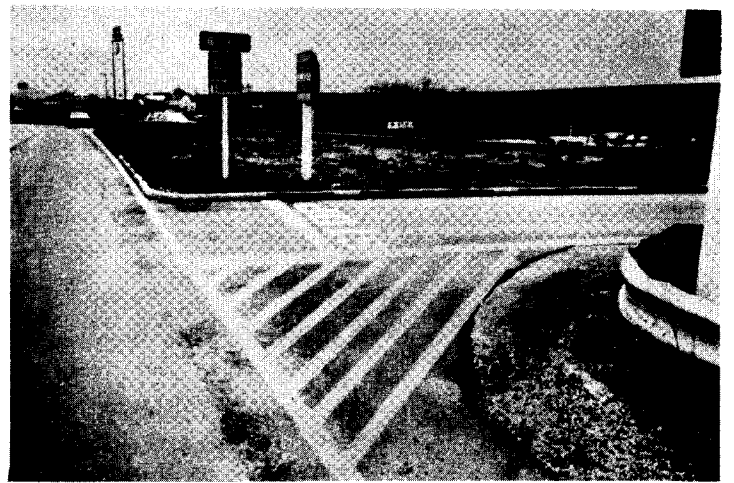


Figure 4(d). Continuation of pavement edge line (solid) across exit ramp junction would be an improvement on dotted line shown in Figure 4(c).

Figure 4. Interchange 43 on I-81 north. Example of improvement by pavement marking. Site of wrong-way entry to interstate by non-drunken driver.

- (2) Alter the present design to eliminate the flares. A new design based on a partial S curve (convex-concave type) or any other type could be adopted. Figure 9 (A) shows a concave curve which needs a flare, but with the introduction of a partial S curve as shown in Figure 9 (B) the flare could be removed.

(b) Minimum width of the left lane of the exit ramp:

A wide pavement at the junction of the exit ramp with the crossroad makes wrong-way entry onto or egress from the exit ramp easy; narrow pavements will discourage them. Some of the lanes of the exit ramps could be narrowed considerably, as shown in Figure 5 (a). This figure shows the excess width has collected dust, indicating disuse.

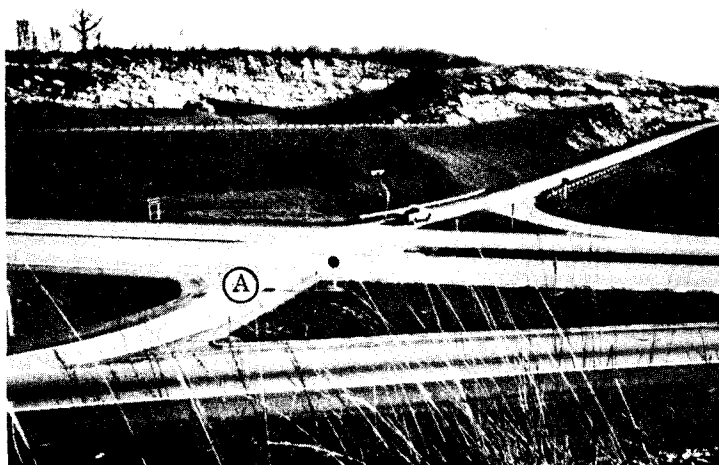


Figure 5(a). Present condition — elevated view of exit ramp with its left lane and junction with crossroad, marked 'A'. Note (1) the dark patches of unused pavement at flare and left edge, and (2) one-way, do not enter, and wrong-way signs are not provided for the crossroad.

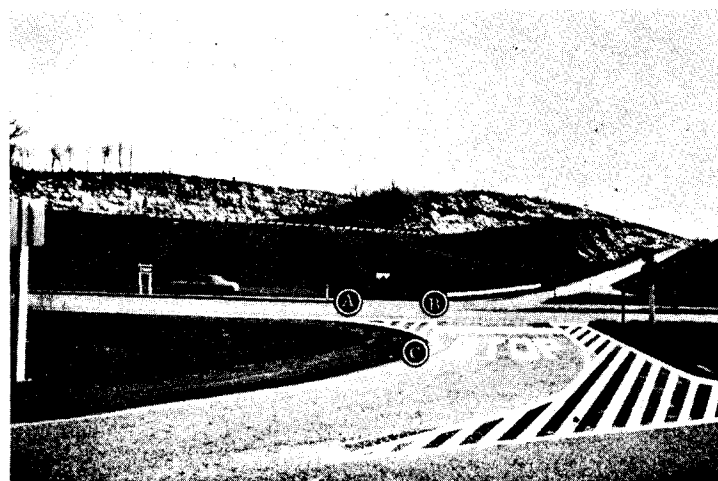


Figure 5(b). Suggested improvements — (1) channelize left lane by marking or by providing physical barrier along ABC and reducing pavement width, (2) provide stop line, (3) continue pavement edge line of crossroad across exit ramp, (4) provide missing signs, (5) provide geometry sign shown in Figure 13(b).

Figure 5. Interchange 53 on I-81 south. Site of two wrong-way entries on crossroad, both by non-drunken drivers.

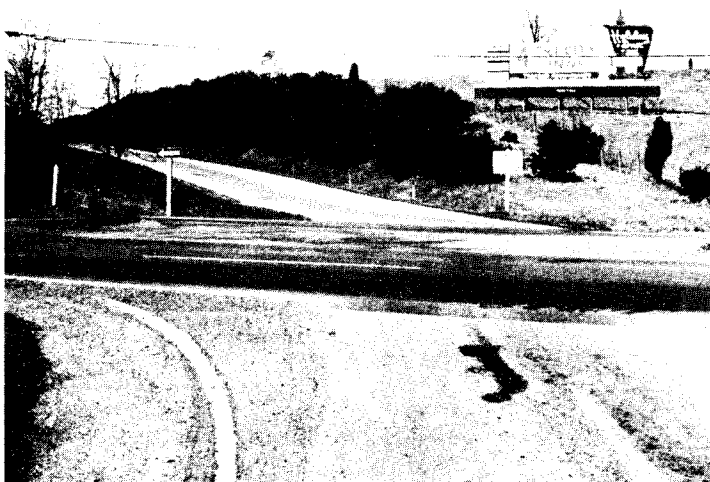


Figure 6(a). Interchange 7 — view from I-81 south exit ramp onto Route 140 south. Site of wrong-way entry from the crossroad by a non-drunk driver. Remove flare by pavement marking.



Figure 6(b). Interchange 9 — view from I-81 north exit ramp onto Route 11. Site of wrong-way entry by drunken driver from the crossroad. Channelize left lane by eliminating flare on left and dividing island on right.

Figure 6. Examples of flares at the junctions of exit ramps and crossroads.



Figure 7(a). Condition after accident — view from crossroad of right exit ramp and left entry ramp. Note stop sign on crossroad and low height of no right turn sign.



Figure 7(b). Same signs as in Figure 7(a). No right turn sign not visible due to vehicle interference.

Figure 7. Interchange 49 on I-81 south. Example of improvement in signing and marking. Site of wrong-way entry from crossroad by drunken driver. Two killed, five injured.



Figure 7(c). View from the exit ramp of the same interchange. The signs have been changed and pavement marking provided. The stop sign and stop line are now on the exit ramp.



Figure 7(d). Same interchange as in Figure 7(c). View from crossroad. Note the location of the no right turn sign on the extreme edge of the right shoulder.



Figure 7(e). View from crossroad closer to the junction with the exit ramp on right and entry ramp on left.



Figure 7(f). The interchange could be further improved by (1) providing left turn arrow on exit ramp in addition to straight arrow as shown on the right, (2) providing left turn arrow on crossroad, (3) placing no right turn sign closer to the pavement edge at x.

Figure 7. Continued.

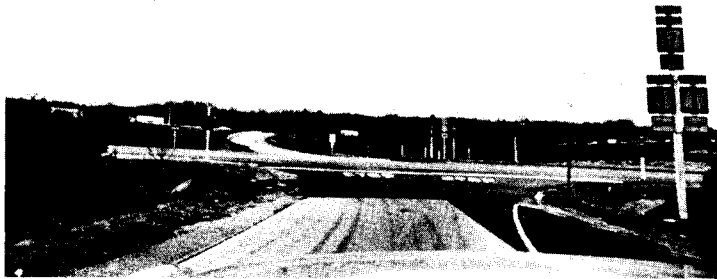


Figure 8(a). Present condition — view of Route 1 crossroad from I-95 south exit ramp.



Figure 8(b). Closer view from I-95 south exit ramp.



Figure 8(c). Use of intersection geometry sign. Either replace sign in Figure 8(a) by the sign shown above or provide sign in Figure 13(b) on left corner as shown by x in Figure 8(d).



Figure 8(d). Improvement by (1) improving sight distance for left turns, (2) providing intersection geometry sign at x, (3) moving stop line closer to edge of crossroad, (4) marking left corner flare, (5) decreasing width of cross-over, (6) providing median nose delineators, and (7) bringing signs on median closer to nose.

Figure 8. Interchange of I-95 South with Route 1. Example of improvement. Place of six wrong-way entries on crossroad by non-drunken drivers.

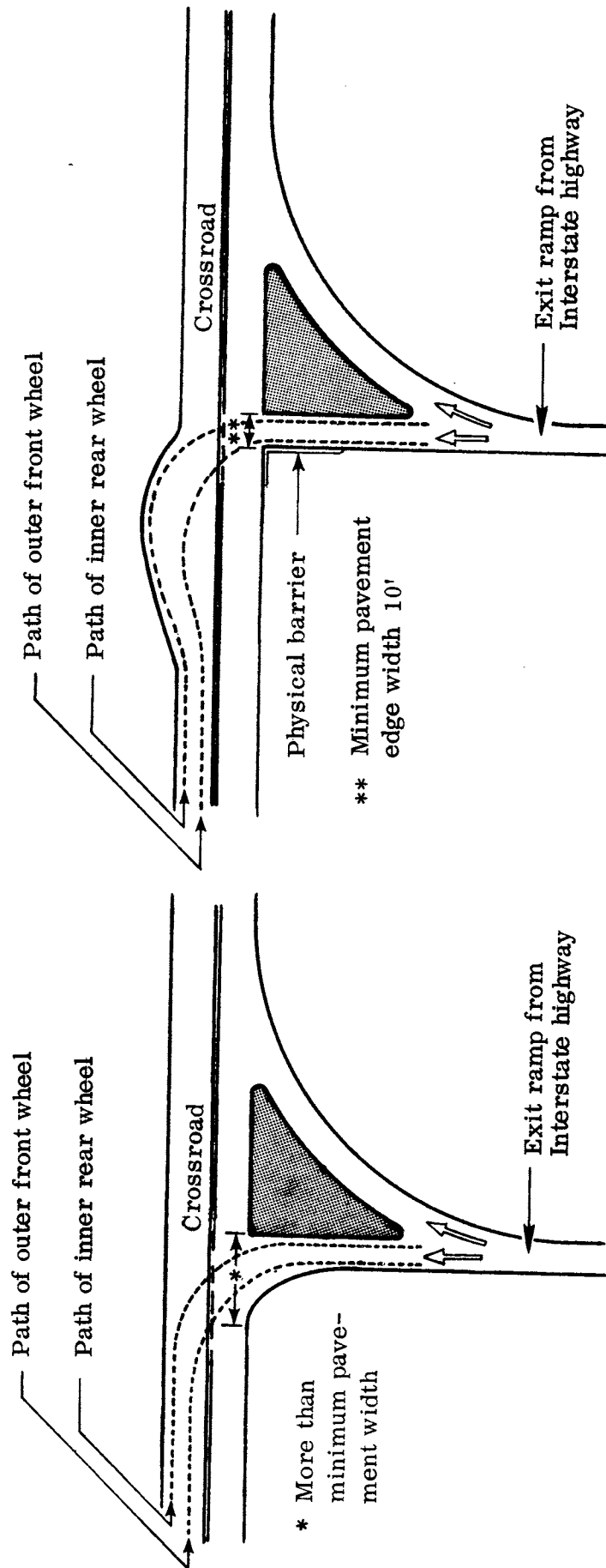


Figure 9. Two-lane crossroad. Suggested improvement to prevent flare at the junction of exit ramp and crossroad.

In places where the flare is not provided and the left lane of the exit ramp and the passage through the median are channelized, no wrong-way entries to or exits from the interstate have been reported. Two examples of such channelized intersections are shown in Figure 10 (a) and 10 (b). By comparing Figure 10 (b) with Figure 5 (b) one can see that there is less possibility of wrong-way incidents with non-flared ends and channelized left lanes than with flared ends and non-channelized left lanes.

(c) Minimum width of the junction of the left lane of the exit ramp with the crossroad:

A right-angled junction of the left lane of the exit ramp with the crossroad, without a flare, would reduce wrong-way entries and exits. This design would provide a minimum width of the left lane of the exit ramp and make it difficult for a driver from the right lane of the crossroad to maneuver onto the left lane. Most of the left lanes are at right angles with the crossroads; hence after the flare is removed, the minimum width would automatically be obtained. An example is shown in Figure 9 (B).

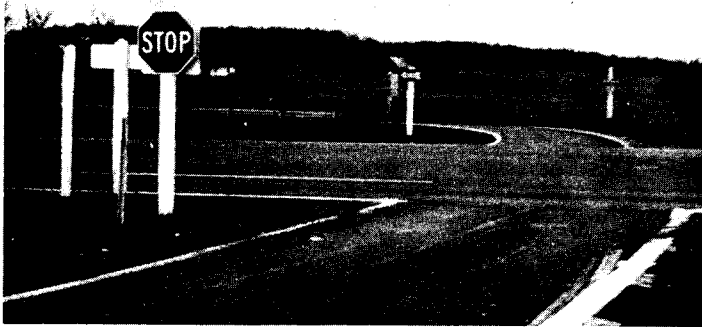


Figure 10(a). Interchange 32 on I-81 south — view from exit ramp. Right-angled intersection and conspicuous one-way median crossing on 4-lane crossroad. Compare channelization and pavement marking with median crossing in Figure 16(a).

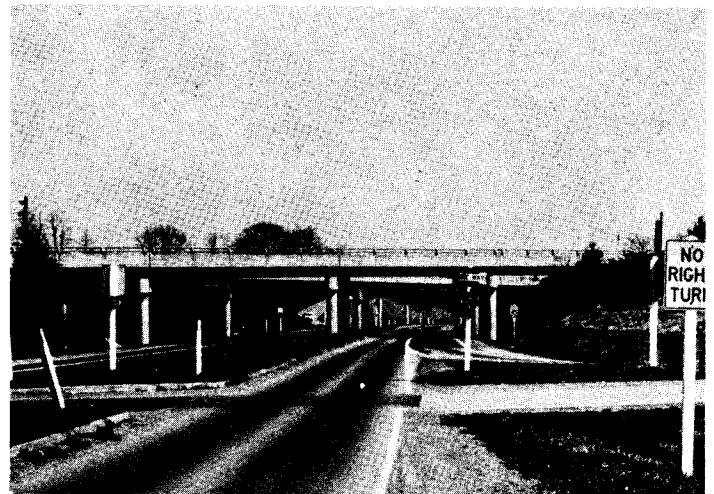


Figure 10(b). Interchange 7 on I-81 north — view from crossroad of exit ramp on right. Right-angled intersection with conspicuous median on 2-lane crossroad. Compare with Figure 6(a). The no right turn sign is close to intersection. Compare location of sign with those in Figures 7(c) and 7(d).

Figure 10. Examples of excellent right-angled junctions with no wrong-way entries.

(d) Physical barriers along pavement edge:

If a narrow left lane without a flare is provided, the junction could be made further foolproof by providing a physical barrier as shown in Figure 11. If such a barrier was provided, to make a wrong-way maneuver a driver could not make an easy right turn into the exit ramp, but would have to negotiate a very sharp turn over a right angle. In order to do the latter, he would have to come to an almost complete stop before maneuvering his vehicle into the exit lane. Such a barrier would greatly discourage a driver from turning in the wrong lane or using the shoulder for an easy wrong-way entry into the exit ramp, or turning from the exit ramp into the crossroad.

2. Signs

During this investigation the signing systems at interchanges were very carefully observed. It was assumed that all signs are reflectorized as specified in the Virginia manual.⁸ The provision of signs was excellent, except in some cases there was a slight congestion. Attention was drawn to the following: (1) Absence of signs, (2) improperly located signs, (3) the height of signs, and (4) signs not within the cone of vision. They are discussed below.

(1) Absence of signs:

A few examples of missing signs are shown in Figures 5 (a), 12 (a), and 12 (b).

(2) Location of signs:

Figure 12 (c) shows a crossroad on which the "no right turn" sign is placed before the bridge underpass, while the exit ramp is after the underpass. The Virginia manual shows that this sign is to be placed on the exit ramp side of the bridge or underpass. Proper placements for this sign would be on the right corner of the exit ramp as shown by an arrow in Figure 12 (d) or on the sign post holding the "one way" sign at the exit ramp. Similarly, it is felt that the "no right turn" sign as shown in Figure 7 (c) would prove to be more effective if moved as shown in Figure 7 (f).

(3) Height of sign:

Figure 7 (b) shows that due to interference from a car, the driver approaching a T-junction is unable to read a "no right turn" sign, shown in Figure 7 (a). Such signs need to be elevated, as shown in Figure 7 (d).

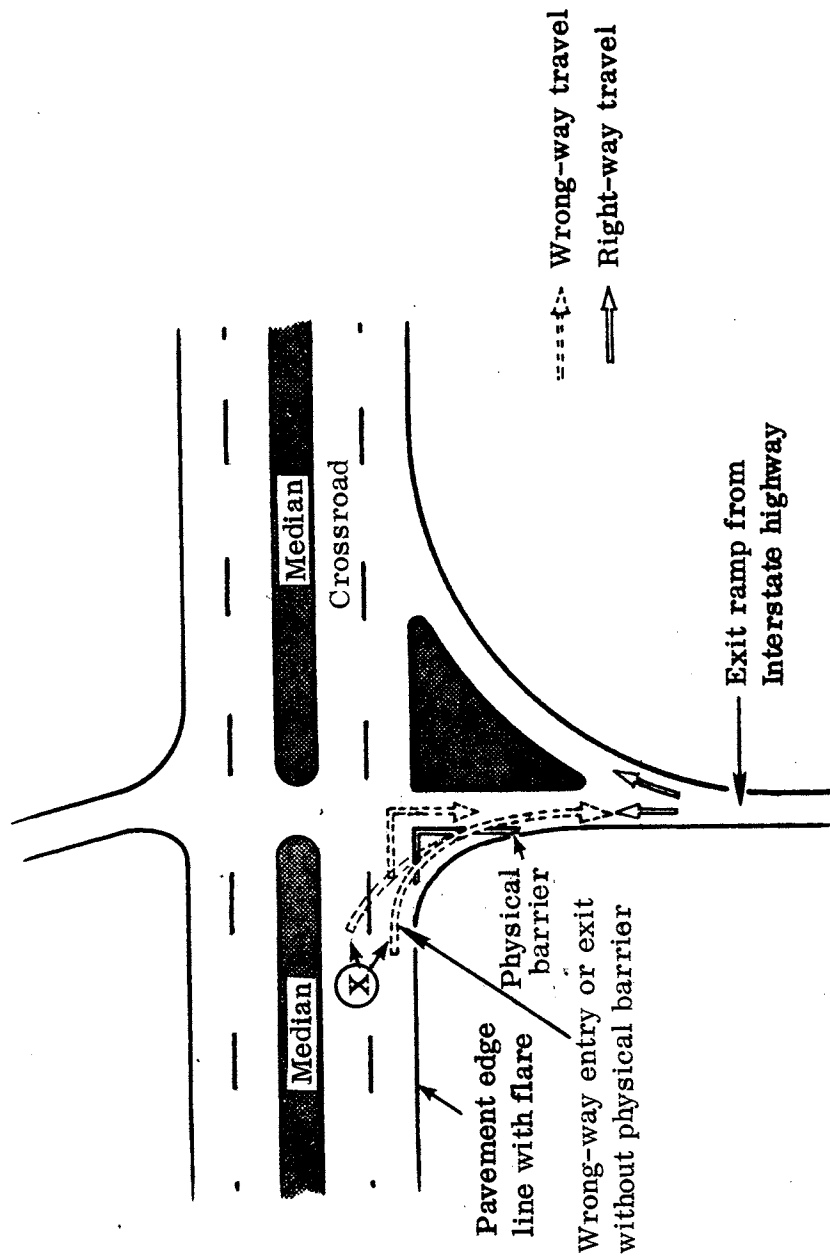


Figure 11. Location of physical barrier to prevent wrong-way entry into the exit lane.

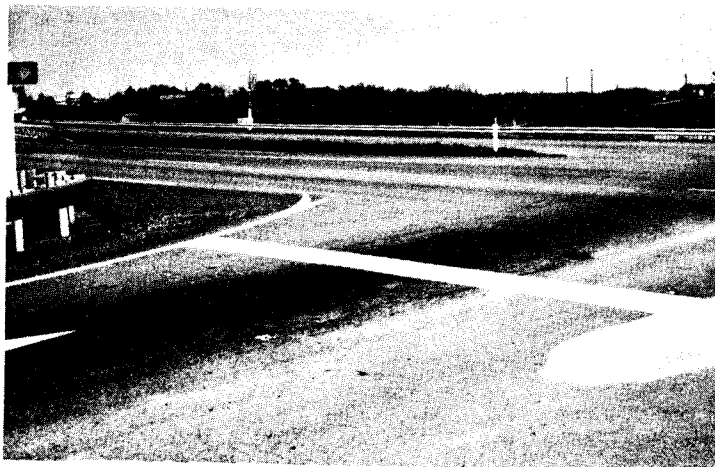


Figure 12(a). Interchange at I-64 West and Rte. 340 — view from exit ramp. One-way, do not enter, and wrong-way signs not provided on median of crossroad. No accident so far.

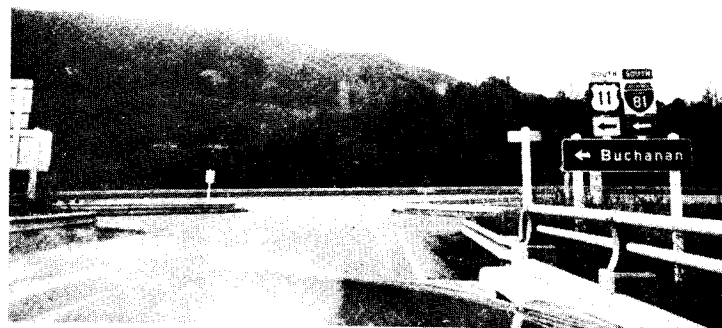


Figure 12(b). Interchange 48 on I-81 — view from crossroad with exit ramp on right. Site of two wrong-way entries by drunken drivers. No right turn sign missing. Other exit ramp of same interchange had one wrong-way entry (by normal driver). No right turn sign missing here also. No lane separation marking provided.



Figure 12(c). Interchange 53A on I-81 — view from crossroad with exit ramp on right across the bridge underpass. Site of two wrong-way entries from crossroad both by drunken drivers. No right turn sign improperly placed. Should be as shown in Figure 12(d). No lane separation marking provided.

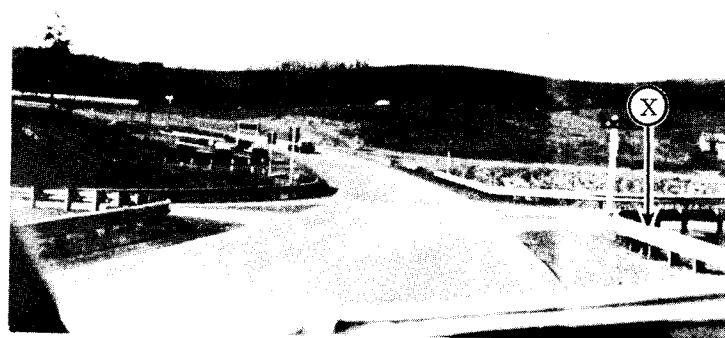


Figure 12(d). Interchange 53A and 81 south exit ramp on right. Site of two wrong-way entries. The arrow shows a better location of no right turn sign. See Figure 12(c). No lane separation marking provided.

Figure 12. Examples of missing or improperly placed signs.

(4) Signs not within the cone or range of vision:

During this investigation some signs were found to have been placed so far beyond the range of vision and some outside the cone of vision that it is doubtful they are observed by the drivers when needed.

Examples are the "Do Not Enter" and "Wrong Way" signs placed in the medians of four-lane divided highways to warn drivers entering a crossroad from an exit ramp. In many cases these signs are placed so far from the nose of the median that they can be observed by a driver only after he has entered the wrong way. An example of the poor location of signs is shown in Figure 8 (d). These signs would give better results if placed nearer to the nose of the median.

The signs placed on the shoulders of crossroads probably follow the specification that they should not be placed less than 8 feet nor more than 15 feet from the edge of the pavement. The effectiveness of a sign depends upon its location within the angle of vision and its legibility distance.

For optimum viewing conditions, one assumes a need for one inch of letter height for each 50 feet of viewing distance.⁹ Thus a 4-inch high letter would be legible from a distance of 200 feet. Then, taking 10 degrees as the cone of vision (i. e. 5 degrees to each side of center line) the 4-inch letter sign placed 8 feet from the right edge of a pavement having 12-foot lane width can be read by a driver at 200 feet and will go out of his cone of vision after he has travelled 25 feet (he can read the sign for a period of 0.57 second at 30 mph). The 4-inch letter sign placed at 15 feet from the edge of the pavement will not come within the 10 degrees cone of vision of the driver. A sign placed at 10 feet from the pavement edge would be visible to the driver for a period of less than the wink of an eye. An example of how far from the pavement edge the signs are sometimes being placed is shown in Figure 7 (c).

It is recommended that specifications for the placement of signs, based on the above discussion, be developed and adhered to.

3. Intersection Geometry Information

Arrow 3 in Figure 3 shows the type of wrong-way entry onto a crossroad a driver turning left from the exit ramp is likely to make. The same problem exists on intersections where four-lane divided roads intersect other roads. This type of maneuver accounts for about 32% of the wrong-way entries in Virginia.

The Information Decision Action (IDA) sequence developed by Taylor and McGhee¹⁰ shows that for a left turn nine actions are needed. In order to execute these actions the driver needs the following information: (1) destination/direction, (2) advance warning of intersection, and (3) intersection geometry. Preferably, this information should be given to the driver during his first action, i. e. in the "approach vicinity of the intersection". In the present system of signing, the driver is unaware of the intersection geometry, and while taking the third action, "entering the appropriate lane", some drivers make a faulty maneuver and enter the wrong lane. It is therefore necessary that the driver be supplied information on the intersection geometry before he takes the third action. Two signs that supply this information are shown in Figure 13.

The sign shown in Figure 13 (a) could replace the road intersection sign of Figure 8 (a) as shown in Figure 8 (c). Another alternative is to provide a sign such as shown in Figure 13 (b) at the left corner of the exit ramp as shown in Figure 8 (d).

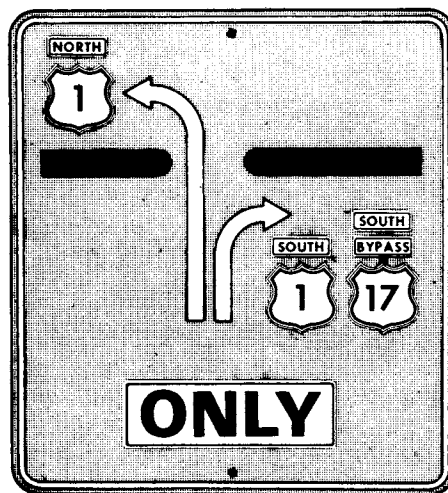
4. Marking

During the site investigations it was observed that signing has been almost the only means of guiding drivers at the interchanges. The importance of pavement marking has become recognized in recent years and is now considered one of the most effective means of guidance. Its use as an additional aid is therefore recommended. Based on the results of this investigation the following markings are recommended: (a) Double yellow lines on two-lane undivided crossroads, (b) stop lines on exit ramps, and (c) continuation of the pavement edge line over crossroads. These markings are discussed below.

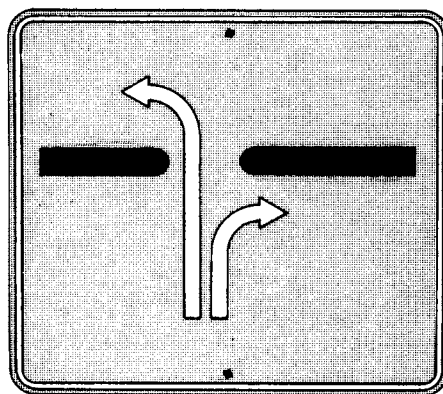
(a) Double yellow lines on two-lane undivided crossroad:

Many two-lane undivided crossroads at interchanges have been provided with double yellow lines. In the design of these the factor of wrong-way entries by left turns seems not to have been considered.

Exit 33 on I-81, the site of a recent accident in which six people were killed, might be improved through a change in pavement marking. At this exit, an opening was made in the double yellow lines, probably to enable drivers coming from I-81 via the right lane of the exit ramp to go back to the same lane of the interstate via the entry ramp. An opening is provided to the left lane too. Figure 14 shows this opening. A drunken driver coming from the gas station went through this opening into the right lane of the exit ramp as shown by the arrow in Figure 14 (b). To discourage wrong-way driving provision of about a 24" wide stop line and continuation of the yellow lines as shown in Figure 14 (c) is recommended.

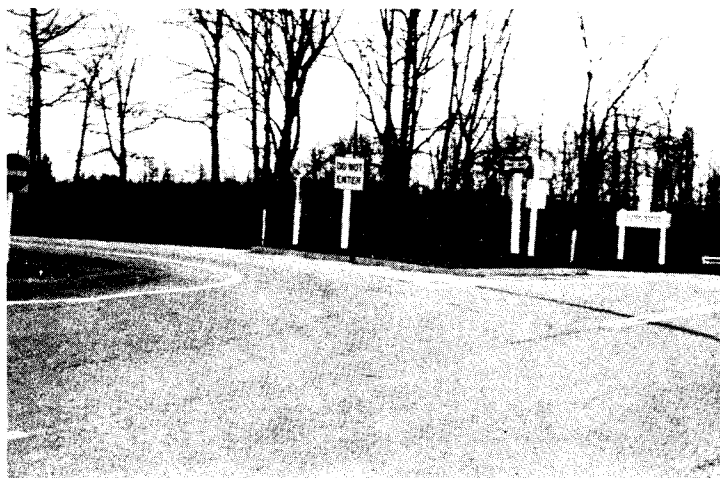


(a)



(b)

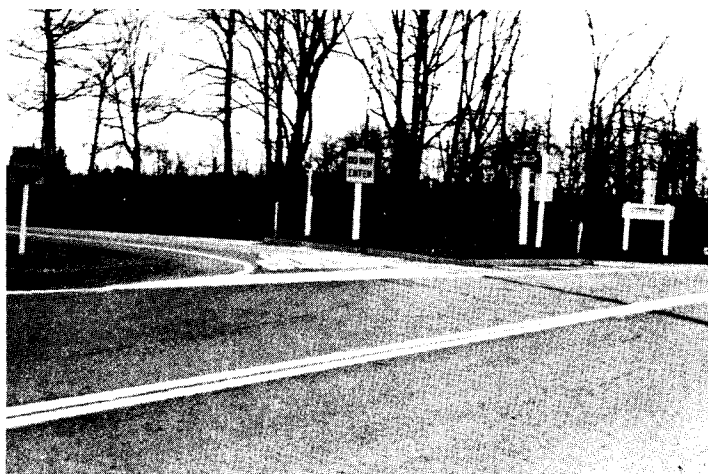
Figure 13. 'Geometry' signs for installation on exit ramps.



(a) View of the exit of the right turn lane of I-81 south exit ramp, as seen from across the road while coming out of a service station. Notice the opening in the double yellow lines dividing the two lanes.



(b) The driver went through the opening in the double yellow lines and entered the wrong way through the right lane of the exit ramp as shown by the arrow. Recommended improvements are: (1) Provision of yellow lines and pavement edge lines as shown in Figure 15; and (2) provision of stop lines.



(c) Suggested improvement on the exit ramp shown in Figure 14 (a), and also the other one on the same exit by continuing the yellow lines and providing about a 24-inch wide stop line.

Figure 14. Exit 33 on I-81 — Site of wrong-way entry by a drunken driver. Six persons killed.

A scheme for the use of double yellow lines to discourage wrong-way entries by a left turn from the crossroad into the exit lane is shown in Figure 15, where only two entries are provided for left turns. The openings made for these entries extend up to a point facing the center of the left lane of the exit ramp. In the opening provided, only one line is broken for the left turn while the second line is solid. Yellow lines thicker than the normal width would increase the effectiveness of the markings. If provision is to be made in the yellow lines for direct connection between the exit and the entry ramp across the crossroad, a slight adjustment in the position of the broken yellow line might sometimes be necessary.

(b) Stop line:

The exit ramp has one way traffic and on all partial interchanges the traffic must stop on a stop sign and/or a stop line before entering the crossroad.

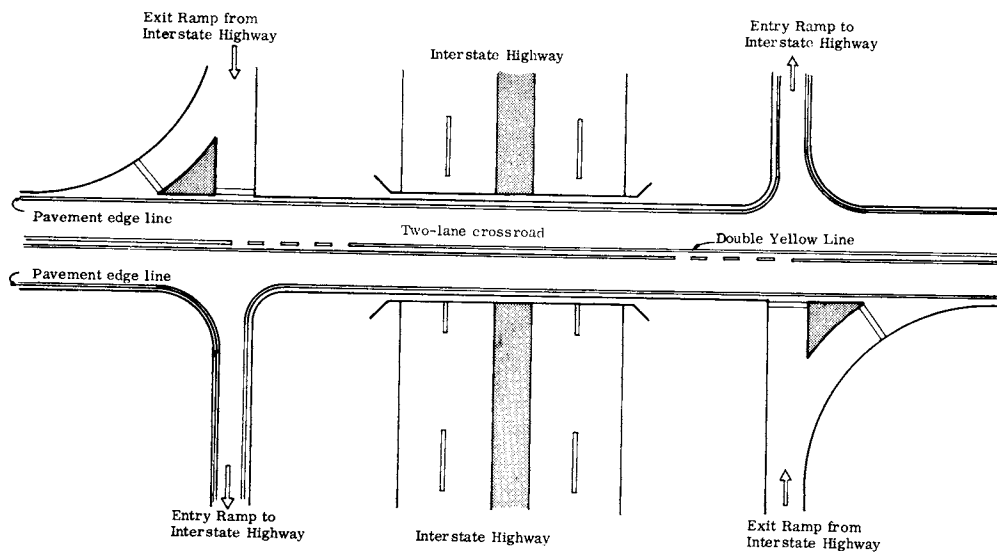
During the site investigations it was observed that many of the exit ramps which were involved in wrong-way entries on the crossroad or the interstate highway did not have stop lines at their junctions with the crossroads. The exit ramps shown in Figures 4, 5, 6 (a), 7 and 14 did not have stop lines and all experienced wrong-way entries.

The stop line probably has the following two advantages:

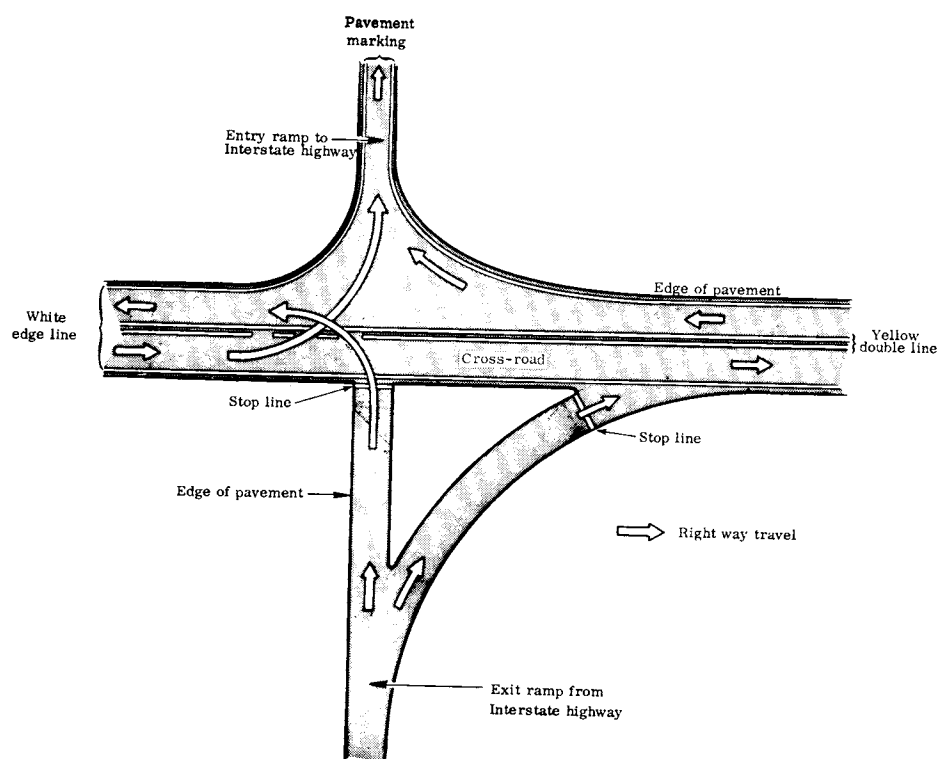
- (1) More drivers tend to stop for a stop line and a stop sign than for a stop sign only. While stopped the driver has to observe the signing and road layout before entering the crossroad.
- (2) The stop line also probably discourages the driver from the crossroad from entering into the exit ramp.

It is admitted that the above observations do not provide conclusive evidence that the provision of stop lines would discourage wrong-way entries and that further consideration of this subject is needed.

During the investigation it was found that at two intersections the stop line was closer to the edge of the crossroad than the minimum distance specified in the Virginia manual. This is an improvement because the line is clearly visible from a considerable distance in both the lanes. An example of this is shown in Figure 7 (e).



(a). System of marking.



(b). Detail of marking on each side of bridge, also showing the right-way travel.

Figure 15. Recommended edge and center line marking on undivided crossroad.

As discussed in the following paragraph, if this stop line is brought up to the edge of the crossroad and in line with the edge line of the crossroad, it might completely deter drivers from entering the exit ramp. If such a stop line is provided, then it should be at least 24 inches wide to provide enough clearance between crossroad vehicles and vehicles stopped at the line.

(c) Continuation of the pavement edge line on crossroad across the exit ramp junction:

Investigations have proved that the pavement edge line guides the driver within the lane. In fact drivers are now so much accustomed to this pavement edge line that they subconsciously use it as a guide. It is felt that if this edge line was continued across the junction of the crossroad with the exit ramp, it would make the exit ramp inconspicuous to the driver on the crossroad because of the following two reasons:

- (1) A person whose attention to the driving task is impaired might as a matter of habit still use the edge line for guidance and thus not cross it for a wrong-way entry onto the exit ramp. In fact, it is possible that an impaired driver will follow the edge line so scrupulously that he will turn with it into the exit ramp. A normal driver will have less chance of doubling his mistake by crossing the edge line and getting into the exit lane.
- (2) If it is true that the stop line discourages drivers from entering the exit ramp from the crossroad, the continuation of the pavement edge line would prove to be more effective because it would be nearer the driver.

It is therefore recommended that continuation of the pavement edge line — either broken or solid — as shown in Figures 4 (c) and 4 (d) be tried. It is obvious that the solid line should be more effective than the broken one.

Continuation of the pavement edge line of the crossroad across the exit ramp would conform with the principle followed in continuing it across the turning lane at the exit ramp on the interstate highway. In fact, a bold step would be to try a wide (at least 24 inches) stop line with its edge on the crossroad side in line with the inner edge of the crossroad edge line.

Figure 4 (c) shows the provision of an arrow for traffic guidance. Arrows are being tried in Virginia but their advantages and disadvantages are not yet known. Tamburri,⁶ in his phase III report, concluded that the pavement arrows he used were of no benefit. However, they still seem to be worth trying.

5. Physical Barriers

The high incidence of wrong-way driving by impaired drivers and those with poor driving attitudes has led to the idea of erecting physical barriers across exit ramps. Various proposals to impound or disable wrong-way vehicles have been made, but because of the inherent problems in the systems proposed, most such proposals have been shelved.

In this investigation, only systems offering guidance to drivers have been considered. The only barrier type elements suggested are as follows.

- (a) A barrier could be installed at the corner of the edge of the left lane of the exit ramp and the right edge of the crossroad, as shown in Figure 11, to prevent the use of the shoulder or flare by the wrong-way driver to enter the exit ramp. This barrier would make it very difficult for the driver to make a right turn from the crossroad into the exit lane, as has been discussed previously in this report under physical barriers for channelization.
- (b) A physical barrier (e.g. a small-width raised median) could be used in place of the double solid yellow lines proposed earlier to eliminate wrong-way entries by a left turn.

6. Crossovers

As previously shown, most of the wrong-way incidents on a four-lane divided highway (whether at the crossroad of an interchange or at an intersection) result from left turns before the drivers pass the nose of the median.

Usually two types of crossovers are used in Virginia to connect exit ramps to the far side of the divided highways. They are either one-way crossovers with a narrow width as shown in Figure 10 (b), or nosed crossovers with either narrow or wide widths. An example of a nosed crossover with a narrow width is shown in Figure 6 (a); ones with wider widths are shown in Figures 8 (b) and 5 (a).

When kerbed and painted yellow, narrow width crossovers are very conspicuous. Because of their narrow width, their edges are in the direct vision of the driver.

Compare the narrow width crossover with kerb and painted ends in Figure 10 (b) and 6 (a) respectively, with the one in Figure 16 (a), which does not have kerbs nor even the pavement edge markings around the nose of the median. The crossover in Figure 16 (a) is inconspicuous and a slightly impaired driver may ignore it. Delineation of the nose of the median by kerb and paint is therefore very important. The crossover as shown in Figure 16 (a) is very inconspicuous in winter when there is no grass in the median. It becomes conspicuous in spring and summer when grass grows in the median. This indicates a need for contrast in colors.

In Figure 8 (b) no delineators are provided at the nose of the median, and the nose seems to be quite far from the left turn path of a vehicle. The design of the median space should be checked and decreased if possible; otherwise nose marking should be provided.

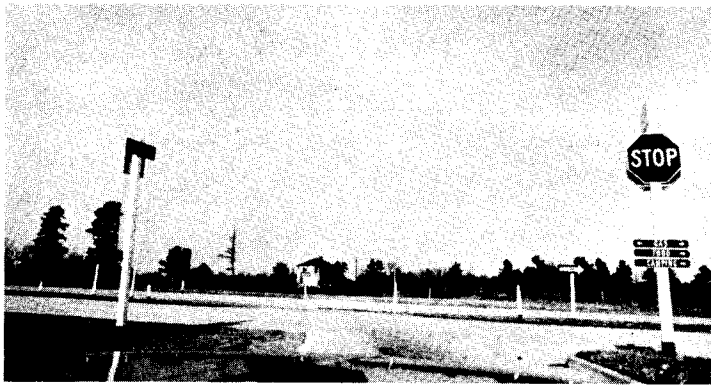


Figure 16(a). Exit ramp of I-85 to Rte. 460 and Rte. 1. Cross-over for left turn is one-way, has gravel nosed median and hence hardly visible, even at stop sign. Pavement marking around nose or concrete nose painted yellow might prevent possible wrong-way incident. No wrong-way incident reported so far.



Figure 16(b). Exit ramp of I-95 south and Rte. 1 median. Site of six wrong-way incidents. Left median nose needs to be delineated and median opening reduced as shown in Figure 8(d).

Figure 16. Example of poor median design.

The operation manual of the Traffic and Safety Division¹¹ states that crossover widths greater than 70 feet often lead to confusion and accidents. This investigation has indicated that crossovers with wide widths might be one of the major causes of wrong-way entries into crossroads.

Based on the above discussion the following are recommended:

- (a) Crossovers should be as narrow as possible with their noses within the direct vision of the driver making a left turn.
- (b) To make the crossover very conspicuous, its nose should be painted yellow and it should be provided with delineators. If the left nose is not in the direct vision of the driver, pavement marking should be applied at the nose.
- (c) Where doubt exists concerning safety, the width of the crossovers should be checked and the space between the medians reduced by extending the raised medians or applying pavement markings such that the width between the markings satisfies the design for lighter vehicles, which form a very large percentage of the total vehicles.

These recommendations, if applied to the median of Route 1 at the interchange with I-95 South, where six incidents of wrong-way entry have been reported (Figure 8 (d)), might prove beneficial.

5. Making entry ramps conspicuous and the exit ramps inconspicuous from the crossroad.

On diamond interchanges, for a right-hand turn, the entry ramp should be so conspicuous that neither normal nor impaired drivers are likely to miss it. If they do not miss it, there is no chance of them making a wrong entry. For a left-hand turn, the junctions of the entry ramps are opposite the junctions of the exit ramps. If the exit ramps are very inconspicuous and the entry ramps very conspicuous, both normal and impaired drivers will have their attention drawn more to the entry ramp.

Entry ramps could be made more conspicuous to a driver on the crossroad by (1) providing flatter angles of entry for the right-hand turn, (2) applying pavement markings, and (3) spotlighting the ramp as shown in Figure 17. Spotlighting of the entry ramp junction could also help in illuminating the lane for the driver turning left from the exit ramp into the crossroad.

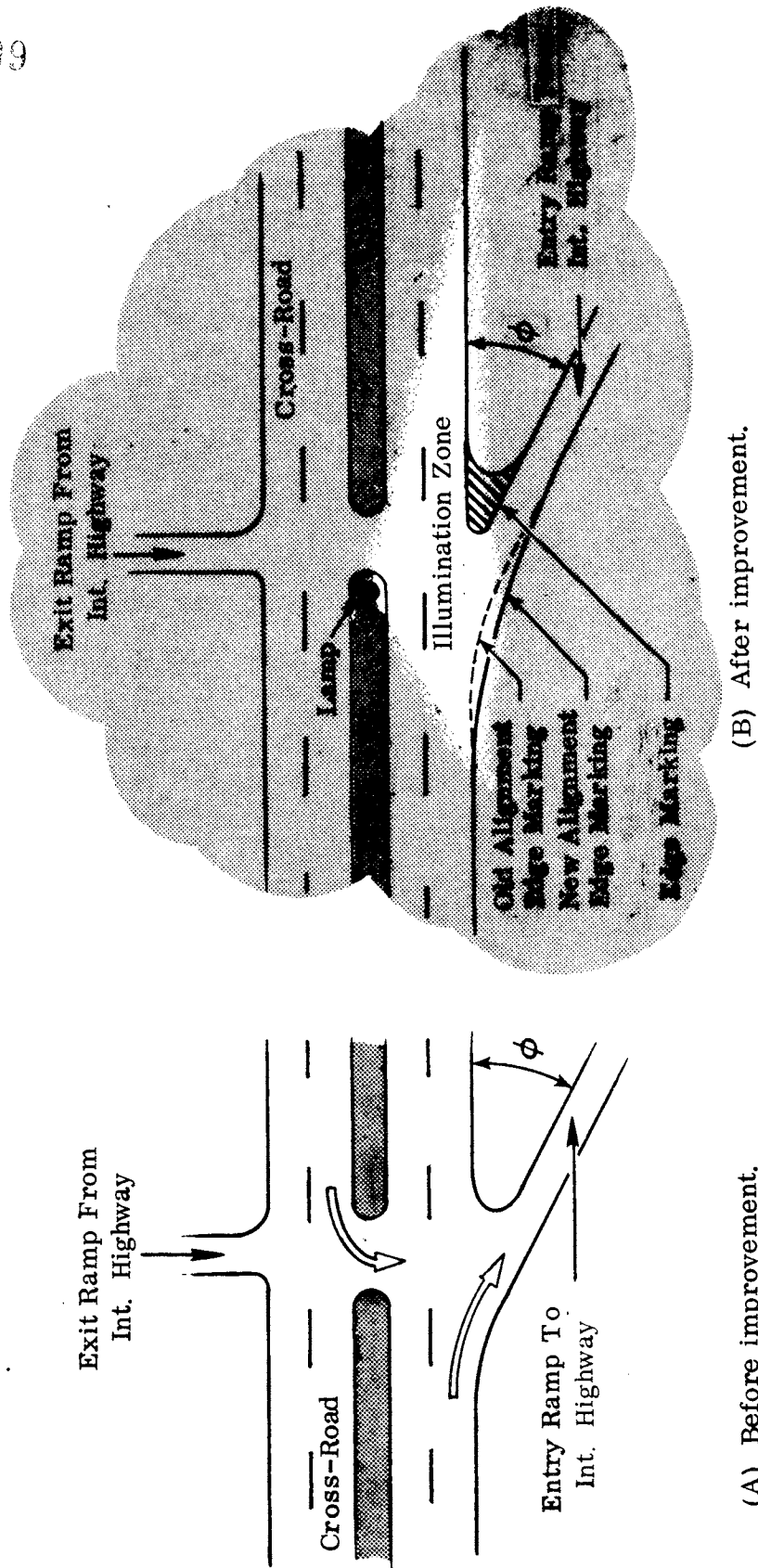


Figure 17. Improvement on entry ramp.

Exit ramps could be made inconspicuous from the crossroad by (1) providing a minimum width of exit ramp (or minimum width left lane of the exit ramp if traffic-dividing islands are provided), (2) continuing the crossroad pavement edge line across the exit ramp as previously discussed, (3) providing a thick stop line across the exit ramp, also previously discussed, and (4) not lighting the exit ramp junction. Additionally, the topography and plantings may be used to obscure the ramps.

CASE STUDIES

Of the sites examined in this investigation and referred to in the preceding sections of this report, the following four were used for case studies.

1. Interchange 53 on I-81 South. At this diamond interchange two wrong-way entries (both by non-drunken drivers) had been made onto the crossroad from the exit ramp. The following deficiencies were noted:
 - (a) The left lane of the exit ramp, marked A in Figure 5 (a), has its left corner flared into the crossroad, and thus encourages wrong entries onto the crossroad. Note the dark patch in the flare where dust and stone have collected from disuse.
 - (b) The left lane of the exit ramp is unnecessarily wide. Note the dark patch on the right side of this lane — Figure 5 (a) — which also is not used.
 - (c) The median of the crossroad, as seen in Figure 5 (a), has no signs to discourage wrong entries from the exit ramp onto the crossroad.
2. Interchange 49 on I-81 South. At this diamond interchange with a T-junction, one wrong-way entry was made onto the interstate highway by a drunken driver. Two persons were killed and five were injured. The site was visited immediately after the accident and again after about three months. The photographs shown in Figures 7 (a) and 7 (b) show the geometry and the signs after the accident and before any changes were made. Three months later the photographs in Figures 7 (c), 7 (d), and 7 (e) were taken, which show the changes made in signs and the provision of pavement marking.

Note that the stop sign initially was on the crossroad (Figure 7 (a)) rather than the exit ramp, which is unusual. Also note that the sign is so low that it is not visible due to interference from a car, as shown in Figure 7 (b).

The signing system was changed and pavement marking provided as shown in Figures 7 (c), 7 (d), and 7 (e). This change is a good example of the use of signs and pavement marking. However, a few more changes could further improve the interchange. They are shown in Figure 7 (f).

When leaving the exit ramp the driver could go left or go straight. The pavement arrows should therefore indicate both the left and straight directions and not the straight only shown in Figure 7 (c). A left turn arrow is needed as shown in Figure 7 (f). To guide the left turn only from the crossroad, a left turn arrow marking should be provided. The sign shown in Figure 7 (d) is not within the direct vision of the driver and hence should be brought closer to the edge of the crossroad and also closer to the junction as shown by X in Figure 7 (f).

3. Interchange of I-95 South with Route 1. At this diamond interchange six wrong-way entries (all by non-drunken drivers) had been made onto the crossroad from the exit ramp. See Figures 8 (a) and 8 (b).

Two of these six occurrences happened between 10:30 and 11:30 a. m. and four during hours of darkness. In addition to many geometric features that need to be examined, it is possible that low visibility and restricted sight distance may have contributed to the occurrences. The crossroad curves on the left side of the exit ramp and the exit ramp is in a deep cut. Recommendations for improving the site are shown in Figures 8 (c) and 8 (d).

- (a) The need for the intersection geometry sign has been discussed.
- (b) To increase the sight distance up the crossroad from the exit ramp, the height of the cut beyond the left corner of the exit ramp needs to be lowered and/or the stop line brought closer to the edge of the crossroad.
- (c) The width of the crossover between the medians should be checked and the space reduced to minimum requirements. If this width cannot be reduced, pavement nose marking as shown in Figure 8 (d) would help. This marking should be such that the width between the pavement markings satisfies the design for lighter vehicles, which form a large percentage of the total traffic.
- (d) The one way, do not enter, and wrong way signs on the left median are so far from the junction that a driver probably could not see them. These signs should be brought closer to the nose of the median.

- (e) The possibility of spot illumination of the far lane to help drivers making a left turn could be considered.
- 4. Interchange 33 on I-81 North. At this diamond interchange one wrong-way entry was made by a drunken driver onto the right lane of the exit ramp from the crossroad, killing six people. See Figures 14 (a) and 14 (b).

The signing system was good except for a slight congestion of sign posts on the dividing island of the exit ramp. The deficiencies are (1) the opening in the yellow lines as shown in the figures, and (2) no stop line is provided on the right lane of the exit ramp before entry into the crossroad. Recommendations for improving the intersection are given in Figure 14 (b).

In addition, for new designs, the need for a dividing island at the end of the entry ramp in junction with the crossroad should be carefully examined, and this dividing island should be omitted if it is not needed. In fact, there seems to be no need for the dividing island at this entry ramp.

These recommendations for I-81 North are also applicable to I-81 South.

SUMMARY OF RECOMMENDATIONS

Though the wrong-way entry survey was analyzed for all interstate and four-lane divided highways and most of the wrong-way incident sites were investigated, this report discusses the details of and makes recommendations for diamond interchanges only.

- 1. The left lane of the exit ramp should be channelized by (a) not using the left flared end (Figures 4 and 5 (b)), (b) providing a minimum width left lane (Figure 5 (b)), and (c) providing a minimum width left lane at the junction with the crossroad.

2. A physical barrier should be provided at the left corner of the exit ramp and the crossroad to prevent use of the shoulder of the crossroad or a flare to make a wrong entry to or exit from the left lane of the exit ramp (Figures 5 (b) and 11).
3. Continuous vigilance should be maintained to assure that all signs are provided.
4. Specifications for the location of signs based on their size and the cone of vision should be developed and incorporated in the manual on uniform traffic control devices.
5. "Intersection geometry" (diagrammatic) signs would considerably help drivers maneuver around the nose of the median when making a left turn from an exit ramp into a four-lane divided highway.
6. At interchanges, pavement markings and spotlighting at night could be used as driver aids.
7. Further evaluations should be made of the effectiveness of stop lines and continuation of the pavement edge line across the exit ramp. In fact, the provision of a very wide (24-inch minimum) stop line with its edge on the side of the crossroad in line with the crossroad pavement edge line is very much recommended.
8. For two-lane crossroads, the use of double yellow lines without openings should be evaluated.
9. Crossovers could be channelized or made narrow, and provided with nose markings and delineators to make them more conspicuous. Some of the crossovers with very wide widths could be modified by very simple methods given in the report.
10. Entry ramps should be made very conspicuous and exit ramps very inconspicuous through use of the methods discussed in the report.
11. Techniques should be developed for evaluating signs, marking, and other driver aids used at interchanges.

ACKNOWLEDGEMENTS

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