CASE STUDIES OF WRONG-WAY ENTRIES AT HIGHWAY INTERCHANGES IN VIRGINIA

N. K. Vaswani, Virginia Highway Research Council

An evaluation of a 2-year survey of wrong-way driving led to on-site investigations of a number of intersections and interchanges. The investigations showed a consistent pattern in wrong-way entry incidents that related to road geometrics, markings, and signs. Based on the findings of the investigations, five case studies were developed to show the effects of these variables. This paper discusses the results of the survey, some case studies, and measures for preventing wrong-way entries at selected interchanges. Some of the recommendations made are as follows: Channelize the left lane of the exit ramp and remove the left end flare; investigate the effectiveness of stop lines, the continuation of pavement edge lines across exit ramps, and the use of continuous double yellow lines; through the use of signs, provide intersection geometry information for drivers entering a 4-lane divided highway; and provide additional pavement marking and spotlighting to supplement signs.

•THE object of this investigation was to determine means for alleviating the problem of wrong-way driving on 4-lane divided highways. The information considered in the investigation was obtained from a 25-month survey of incidents of wrong-way driving on Virginia's divided highways and investigations of the physical aspects of sites at which wrong-way incidents had 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 the accidents involving wrong-way driving are only 0.1 percent of the total accidents. But for each wrong-way accident on Interstate highways, 0.47 and 1.18 persons were killed and injured respectively; these figures represent 27.4 (2,740 percent) and 2.81 (281 percent) times the deaths and injuries resulting from other types of accidents. These facts emphasize the need for highway improvements that are not very expensive and do not impede motorists other than the 0.1 percent wrong-way drivers.

Wrong-way driving surveys performed in California (1), Michigan (2), Missouri (3), and Texas (4) have observed the same trend as found in Virginia.

EVALUATION OF THE WRONG-WAY DRIVING SURVEY

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

Drunkenness and Darkness

Darkness combined with drunkenness of the driver accounted for 2.3 to 4 times the

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number of incidents that occurred during the daytime (Table 2). This is contrary to the pattern obtained in the case of non-drunken drivers, where the daytime incidents exceed the nighttime incidents (Table 3).

Partial Interchanges

The evaluation showed that on Interstate highways most of the wrong-way entries occurred at partial interchanges through an exit ramp from the Interstate onto the crossroad. [In a partial interchange (e.g., a diamond type with four ramps), although 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 interchange (e.g., cloverleaf).] No report in the survey showed that a wrong-way entry was made through the entry ramp, i.e., the ramp leading from the crossroad to the Interstate road.

The incidents of wrong-way driving on Interstate highways were broken down into four major categories, as given in Table 4. This table shows that 47 percent of the cases of wrong-way driving resulted from entries at interchanges, the origins of 37 percent were unknown, 15 percent resulted from U-turns, and very few (none in the last survey period of 1972) originated at crossovers.

The reason that exit ramps on partial interchanges generate wrong-way entries 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, 6). Because of this design, the three wrong-way entries shown in Figure 1 are possible.

Intersections With 4-Lane Divided Highways

The evaluation of the survey data on divided arterial and primary roads showed that 45 percent of the wrong-way entries were at their intersection with exit ramps or secondary roads. All such wrong-way entries were due to left-turning vehicles making an early left turn rather than turning around the nose of the median.

The data showed that, of 19 incidents at the intersections with exit ramps, 18 involved non-drunken drivers. For secondary roads, also, the non-drunken driver rate was higher than for drunken drivers. This finding stresses the need for improvement of highways rather than drivers.

Repeatability

The survey showed that repeated wrong-way entries from a given ramp are very rare, so it seems that any partial interchange is as prone to a wrong-way entry as any other. Therefore, the preventive techniques adopted should be sufficiently economical that they could be used for all interchanges.

CASE STUDIES

In Virginia the longest and most heavily trafficked Interstate routes are I-95 and I-81. I-95 has more than 5 times the traffic of I-81 but has a history of fewer wrong-way driving incidents. Since the beginning of the wrong-way driving survey, more attention has been paid to reducing wrong-way entries on I-95 and I-81. The wrong-way entries on I-95 have varied between 6 and 8 for each 6-month period since 1970. On I-81 they have been reduced from 22 in 1970 to 14 in 1972 on a semiannual basis.

For this presentation, five interchanges on these two Interstate routes were chosen for case studies. These interchanges illustrate most of the design drawbacks noted on the various other interchanges for which wrong-way entries were reported. As a result of the on-site investigations of some interchanges for which no wrong-way incidents have been reported and some that have been modified since a wrong-way incident was reported, certain suggestions and recommendations for improvement have been made.

CASE STUDY 1: INTERCHANGE 43 ON I-81

Interchange 43 is of the diamond type and intersects a 2-lane crossroad. The cross-

Table 1. Total accidents compared with wrong-way driving accidents.

Category	No. of Accidents	Fatalities Per Accident	Injuries Per Accident
Interstate Roads			
All accidents, 1970 and 1971 (24 months)	14,862	0.016	0.42
Wrong-way accidents			
25-month survey	55	0.47	1.18
Percent of all accidents	0.4	2,740	281
All Roads			
All accidents, 1970 and 1971 (24 months)	133,065	0.014	0.41
Wrong-way accidents			
25-month survey	138	0.22	1.03
Percent of all accidents	0.1	1,570	250

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

Table 2. Day and night wrong-way incidents by drunken drivers.

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

Table 3. Day and night wrong-way incidents by non-drunken drivers.

	Interstate		Divided Arterial and Primary	
Time	No.	Ratio	No.	Ratio
Daylight	24	1.0	112	1.0
Darkness	19	0.79	59	0.53

Table 4. Places of wrong-way entries on Interstates.

Place of Entry	No.	Percent
U-turn	21	15
Crossover	2	1
Interchange	66	47
Unknown	51	37
Total	140	100

Figure 1. Wrong-way entry and egress on left lane of exit ramps.

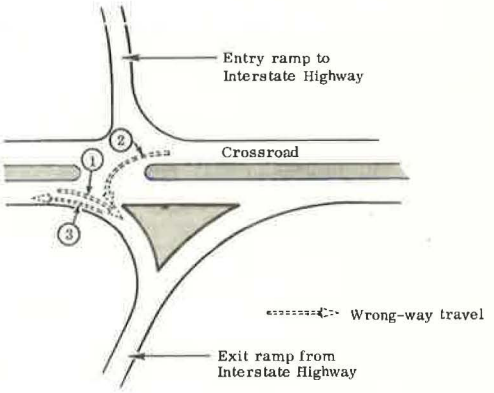


Figure 2. View from crossroad, with exit ramp on right, where wrong-way entry took place.

road carries about 6,000 vpd. All necessary "one way", "do not enter", "wrong way", and "no right turn" signs are provided on the exit ramps from I-81. Yet the wrong-way entry was made through an exit ramp and by a sober driver.

This interchange was chosen for study because it is typical of others for which wrong-way entries have been reported. It is similar to many others with respect to geometrics, signs, markings, and construction practices. The intersection of the exit ramp with the crossroad is shown in Figure 2. This photograph was taken from the crossroad and shows the left lane of the exit ramp (which the wrong-way driver entered) meeting the crossroad at a right angle.

As a result of inspections of this interchange and others like it, it is believed that they could be improved by three fundamental changes as discussed below.

Elimination of Unnecessary Flares

During this study it was observed that on almost all interchanges on which wrong-way entries had been made into the exit ramp or 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 a flared end is shown in Figure 2.

Such a flared end (termed "flare" hereafter) provides for a very easy but incorrect right-hand turn. 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 could be encouraged to make an improper left turn into the wrong lane of the crossroad. Again, a sharp, right-angled bend would not permit an easy left turn.

The site inspections showed that, 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 entry to or egress from exit ramps has been reported. It was also noticed that, on most interchanges with 4-lane divided crossroads that included flares, the flares had collected dust, which indicated their disuse by properly maneuvering drivers. (A good example of this is given in case study 3 where channelization to prevent wrong-way driving is discussed.)

These flares may have been provided either as a matter of construction expediency or the design requirement for a left-turn curve from the exit ramp to the crossroad. It is recommended that the designs be checked and the flares be removed or their use be prevented when they have been provided to satisfy the left-turn curve requirements.

To discourage this type of wrong-way entry, pavement marking at the corner of the left lane of the exit ramp could be provided as shown in Figures 3 and 4. To make this turn difficult to negotiate, or to prevent the use of the shoulder, a physical barrier could be provided along lines AB and BC in Figures 3 and 4.

Stop Line

The exit ramp has one-way traffic and on all partial interchanges the traffic must stop at 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 involved in wrong-way entries onto the crossroad or the Interstate highway did not have stop lines at the junctions.

The stop line probably has the following two advantages: First, more drivers tend to stop for a stop line and a stop sign than for a stop sign only; while stopped, the driver is likely to observe the signing and road layout before entering the crossroad. Second, the stop line also may discourage a driver from the crossroad from entering the exit ramp. It is recognized that these two 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 (7). This is an improvement because the line is clearly visible at a considerable dis-

Figure 3. Suggested improvements of exit ramp shown in Figure 2 by marking pavement in flared corner, providing a stop line, and continuing the pavement edge line across the exit ramp junction.

Figure 4. Suggested improvements of exit ramp shown in Figure 2 by marking pavement in flared corner and providing a very thick line—minimum of 24 in. (0.6 m)—with its outer edge in line with the pavement edge line.

Figure 5. View of crossroad from exit ramp from which six wrong-way entries were made onto the crossroad.

Figure 6. Suggested improvements on exit ramp and crossroad shown in Figure 5 by improving sight distance for left turns, providing intersection geometry sign at X, moving stop line closer to edge of crossroad, marking left corner flare, decreasing width of crossover, providing median nose delineators, and bringing signs on median closer to nose.

Figure 7. Recommended striped median.

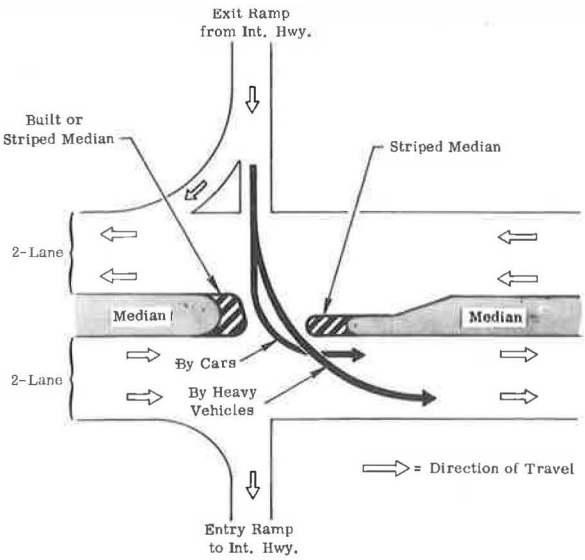


Figure 8. Suggested improvement on exit ramp shown in Figure 5 by use of intersection geometry sign.

tance from both lanes of the crossroad. If the stop line is brought up to the edge of the crossroad and in line with the edge line of the crossroad (as discussed below), it might completely deter drivers from entering the exit ramp. If such a stop line is provided, it should be at least 24 in. (0.6 m) wide with a stop marking to provide enough clearance between vehicles on the crossroad and vehicles stopped at the line.

Continuation of Pavement Edge Line Across Exit Ramp Junction

Drivers have now become so accustomed to pavement edge lines that they subconsciously use them as a guide. It is felt that if the edge line were continued across the junction of the crossroad with the exit ramp it would make the exit ramp less conspicuous to a driver on the crossroad for the following reasons: First, 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 if the edge line follows the flare into the exit ramp, as is sometimes the case, an impaired driver would follow the edge line so scrupulously that he would 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 ramp. Second, 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.

Hilton (8) also recommends continuing the edge marking across intersections adjacent to bridges, even though the traffic is both ways across such intersections.

It is therefore recommended that continuation of the pavement edge line—as shown in Figure 3—be tried. Continuation of the pavement edge line of the crossroad across the exit ramp would conform with the principle followed in continuing it across the deceleration and turning lanes from primary, arterial, and Interstate highways.

CASE STUDY 2: INTERCHANGE OF I-95 SOUTH AND ROUTE 1

The junction of I-95 South and Route 1 is a diamond interchange linking an Interstate highway with a 4-lane divided crossroad that has two additional left-turning lanes. The crossroad carries about 5,000 vpd.

This interchange was chosen because it is the only one in Virginia that had as high as six wrong-way entries onto the crossroad reported in the survey. Two of these six incidents happened between 10:30 and 11:30 a.m., and the other four during hours of darkness. All the entries were made by sober drivers, all were made from the same exit ramp, and all resulted from the drivers making their turns before rounding the nose of the crossroad median. As mentioned before, this type of maneuver accounts for 45 percent of the wrong-way entries in Virginia. The photograph of this intersection, shown in Figure 5, was taken from the exit ramp meeting the crossroad at its right.

In addition to the many geometric features that might be involved, it is possible that low visibility and a restricted sight distance may have contributed to the numerous wrong-way entries. The crossroad has a curve on the left of the exit ramp and the exit ramp is in a deep cut. To increase the sight distance up the crossroad from the exit ramp, the stop line should be brought closer to the edge of the crossroad, as recommended in case study 1. Figure 6 shows a suggested revised location of the stop line and the marking of the flared end at this junction.

The "do not enter" and "wrong way" signs, as can be seen in Figure 6, are placed very far from the ends of the medians of the 4-lane divided crossroad and are not easily read from the junction. Figure 6 also shows the setback of the nose of the medians (not considering the extension marked in white) from the exit ramp. This setback, and hence the width of the crossover, seems to be too long and should be reduced to minimum requirements. If this width cannot be reduced, pavement nose markings as shown in Figure 6 (by a white mark) and in Figure 7 would help. The nose markings should be applied to provide the minimum width of crossover needed for lighter vehicles, which form a large percentage of the total traffic.

The information-decision-action (IDA) sequence developed by Taylor and McGhee (9) shows that, for a left turn, nine actions are needed. In order to execute these actions the driver needs the following information: (a) destination/direction, (b) advance warning of intersection, and (c) 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, drivers are unaware of the intersection geometry, and while taking the third action, i.e., "entering the appropriate lane", some 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. Figure 8 shows one example of an intersection information sign to replace the direction sign shown in Figure 5. An enlarged view of this intersection information sign is shown in Figure 9. An alternative arrangement is to provide a sign such as shown in Figure 9 at the corner of the exit ramp shown by X in Figure 6.

The possibility of spot illumination of the far lane to help drivers make a left turn could also be considered. An example of such spotlighting is shown in Figure 10. This spotlighting would also illuminate the entry ramp junction and thus make it more conspicuous so as to reduce the likelihood of its being missed by normal as well as impaired drivers.

CASE STUDY 3: INTERCHANGE 53 ON I-81 SOUTH

Interchange 53 is of the diamond type and connects I-81 with a 4-lane divided crossroad. The crossroad carries about 2,000 vpd on the north side and about 4,000 vpd on the south side. Two wrong-way entries (both by sober drivers) have been made onto the crossroad from the exit ramp by drivers turning too early rather than turning around the nose of the median.

The interchange was chosen mainly to emphasize the need for channelization on the left lane of the exit ramp. In this case, as shown in Figure 11, "do not enter", "one way", and "wrong way" signs—to discourage wrong-way entry from the exit ramp for left-turning vehicles—are not provided on the median.

Channelization to prevent wrong-way entries involves four elements: (a) elimination of flares, (b) minimum width of the left lane of the exit ramp, (c) minimum width of the junction of the left lane of the exit ramp with the crossroad, and (d) physical barriers along the pavement edge.

Elimination of Flares

The disadvantages of flares were discussed in case study 1. The present case study shows that on 4-lane divided crossroads the flares are not in use and have been found to collect dust. Figure 11 shows at A the left lane of the I-81 exit ramp. A dark patch in the flared corner shows the collection of dust, which exemplifies its disuse.

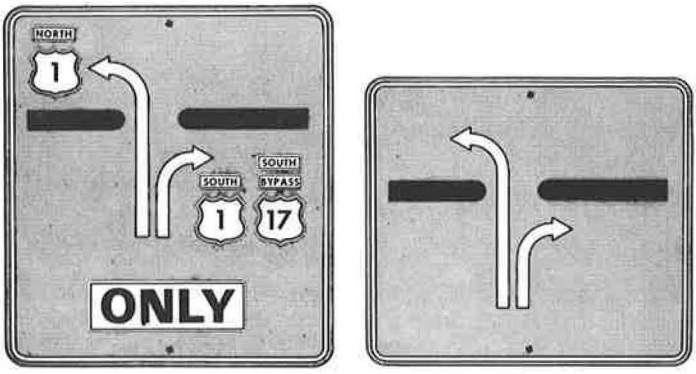
Minimum Width of Left Lane of Exit Ramp

Generous widths of the exit ramp at its junction with the crossroad make wrong-way entry onto or egress from the exit ramp easy; narrow pavement widths will discourage such entries. Figure 12 shows an excess width by the dark patch on the right side of the lane. This patch has collected dust, which indicates its disuse. Such excessive widths could be striped to discourage their use for wrong-way entries.

Minimum Width of Junction of Left Lane of Ramp With Crossroad

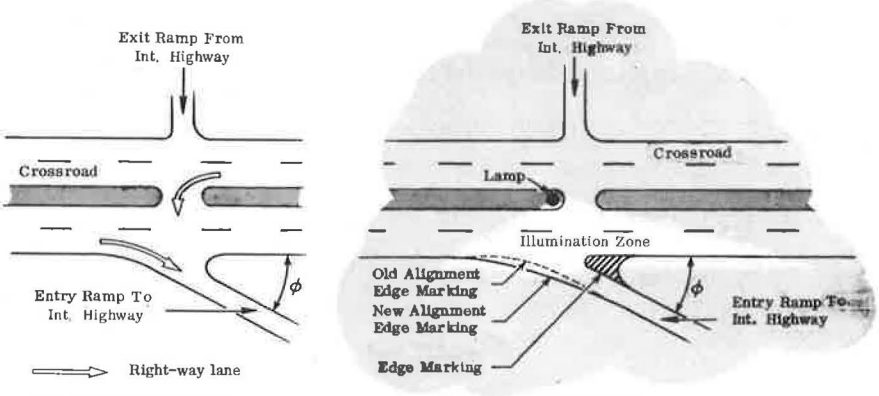
A right-angled junction of the left lane of the exit ramp with the crossroad, without a flare, would reduce wrong-way entries and exits. This design would provide a minimum width of the left lane of the exit ramp and make it difficult for a driver from the right lane of the crossroad to maneuver onto the ramp. 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 12.

Figure 9. Recommended geometry signs for installation on exit ramps to 4-lane divided crossroads; provide sign (b) on left corner as shown by X in Figure 6.



(a) (b)

Figure 10. Recommended improvement of an entry ramp.



(A) Before improvement. (B) After improvement.

Figure 11. View of exit ramp with its left lane and junction with crossroad, marked A. Note the dark patches of unused pavement at flare and left edge and absence of one-way, do not enter, and wrong-way signs for the crossroad.

Figure 12. Suggested improvements of left lane shown in Figure 11 by channelizing left lane by marking or by providing physical barrier along ABC and reducing pavement width, providing stop line, continuing pavement edge line of crossroad across exit ramp, providing missing signs, and providing geometry sign shown in Figure 9(b).

CASE STUDY 4: INTERCHANGE 49 ON I-81 SOUTH

Case study 4 involves a diamond interchange over a T-junction. The crossroad carries about 2,000 vpd. No marking is provided to divide the two lanes of the crossroad. At the time of the wrong-way entry, the crossroad had a stop sign for vehicles turning into the entry ramp and the exit ramp did not have a stop sign at its junction with the crossroad, as shown in Figure 13. This stop sign system is unusual.

This interchange was chosen for study for two reasons: First, placement of the stop sign on the crossroad instead of the exit lane is unusual, and second, provision of the flare encourages a right-hand turn for a wrong-way entry from the crossroad into the exit ramp. (It is noted that in the accident resulting from the single wrong-way incident at this intersection, two people were killed and five injured.)

Figure 13(a) shows the plan of the T-junction at the time of the accident. At that time there was no pavement marking and the "no right turn" sign was so low that it could be hidden by a car coming from the exit ramp on the right across the field of vision of the driver intending to turn left onto the entry ramp for the Interstate highway.

The signing system has since been changed and pavement marking provided as shown in Figure 13(b). This junction is now less likely to be the scene of wrong-way entries.

Provision of arrows is recommended as an improvement on the modified marking system as shown in Figure 13. The recommended improvement of the modified system also includes the provision of the "no right turn" sign within the cone of the driver's vision and in such a place that the driver sees it at the time he can most effectively utilize the information it imparts. There appears to be a need for a revision of the specifications for the location of signs in the Virginia Manual (7). The revised specifications should be based on the cone of vision and the size and effectiveness of the sign.

CASE STUDY 5: INTERCHANGE 33 ON I-81

Interchange 33 is also of the diamond type. It connects I-81 with a 2-lane crossroad that carries about 1,700 vpd. The lanes on the crossroad are separated by double yellow lines that have openings for left turns and for through traffic from the exit ramps to the entry ramps. The crossroad and the exit ramps are fully furnished with the necessary "one way", "do not enter", "wrong way", "no right turn", and "no left turn" signs. Both the exit ramps and entry ramps are divided into right and left lanes by islands at their junctions with the crossroad. Except for the signs, the details, including pavement markings, are shown in Figure 14.

This interchange was chosen for two reasons: (a) the need for modifications in the use of double yellow lines and (b) the need for emphasizing stop lines. It should be noted that in the accident resulting from the single wrong-way incident at this intersection, six people were killed and one was seriously injured.

Figure 14 shows a photograph of the junction of the right-hand lane of the exit ramp and the crossroad, with the opening between the yellow lines. A drunken driver coming from a gas station went through this opening into the right lane of the exit ramp as shown by the arrow superimposed on the photograph.

If there had been no gap in these yellow lines the driver may not have crossed them. Further, if a stop line were provided at the junction of the right lane of the exit ramp and the crossroad it might have further discouraged this driver from entering the exit lane. The yellow line and white line are shown in Figure 15.

The following improvements are recommended.

Double Yellow Lines on 2-Lane Undivided Crossroad

Many 2-lane undivided crossroads at interchanges have been provided with double yellow lines to separate the lanes. Whenever these lines have been provided on the crossroad of an interchange, openings in the lines like the one shown in Figure 14 have also been provided to guide turning or crossing vehicles. It seems that when providing these openings the possibilities of wrong-way entries were not considered.

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 16, where only two entries

Figure 13. Original and modified marking and signing at Interchange 49: (a) at the time of the accident; (b) after the accident; (c) recommended improvement in the modified marking and signs.

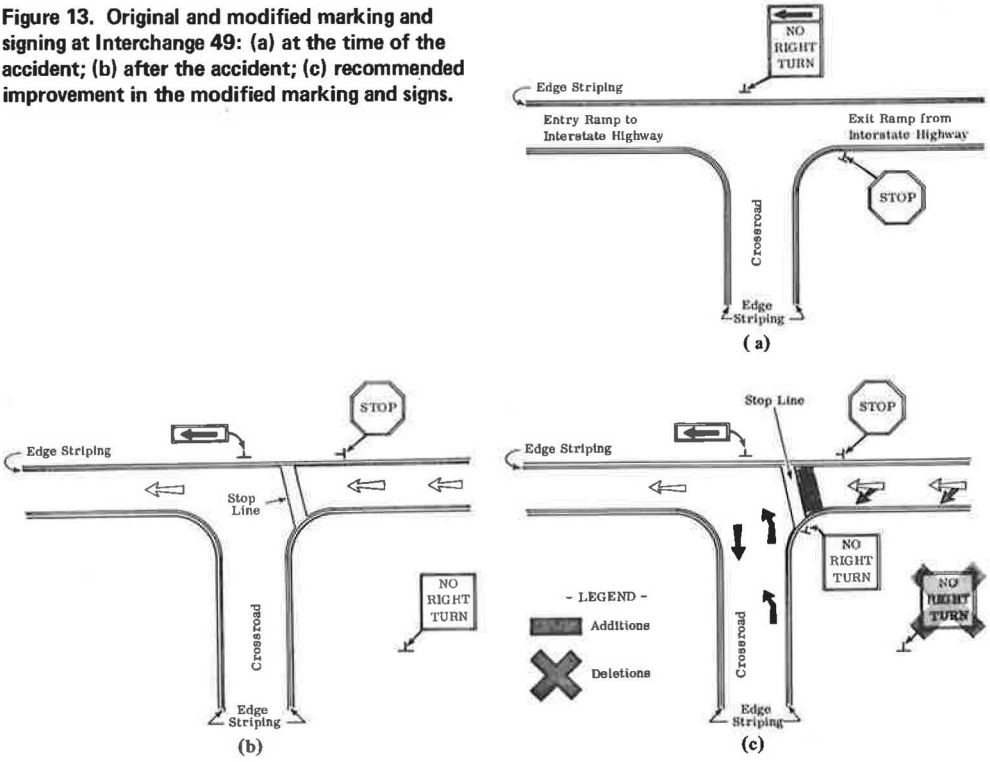


Figure 14. The driver went through the opening in the double yellow lines and entered the wrong way through the right lane of the exit ramp as shown by the arrow.

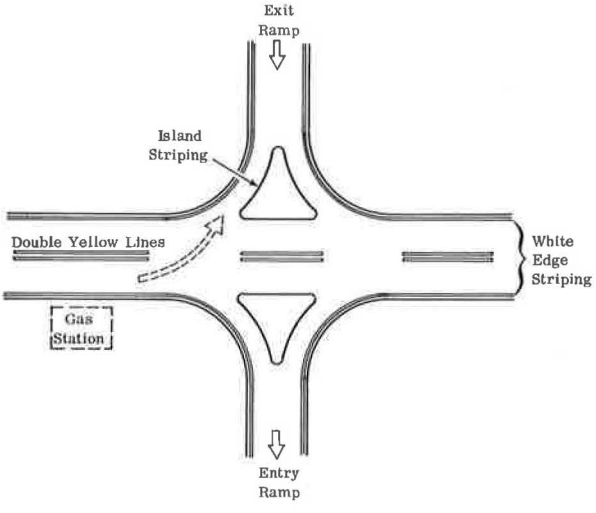


Figure 15. Suggested improvement on the exit ramp shown in Figure 14 by continuing the yellow lines and providing about a 24-in.-wide stop line. The island at the entry ramp is unnecessary.

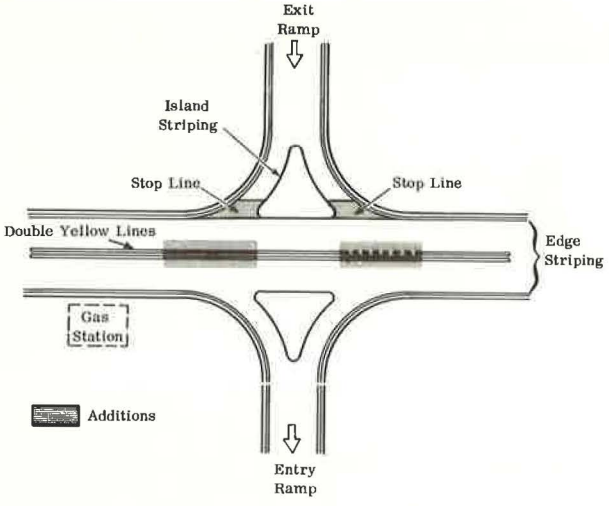
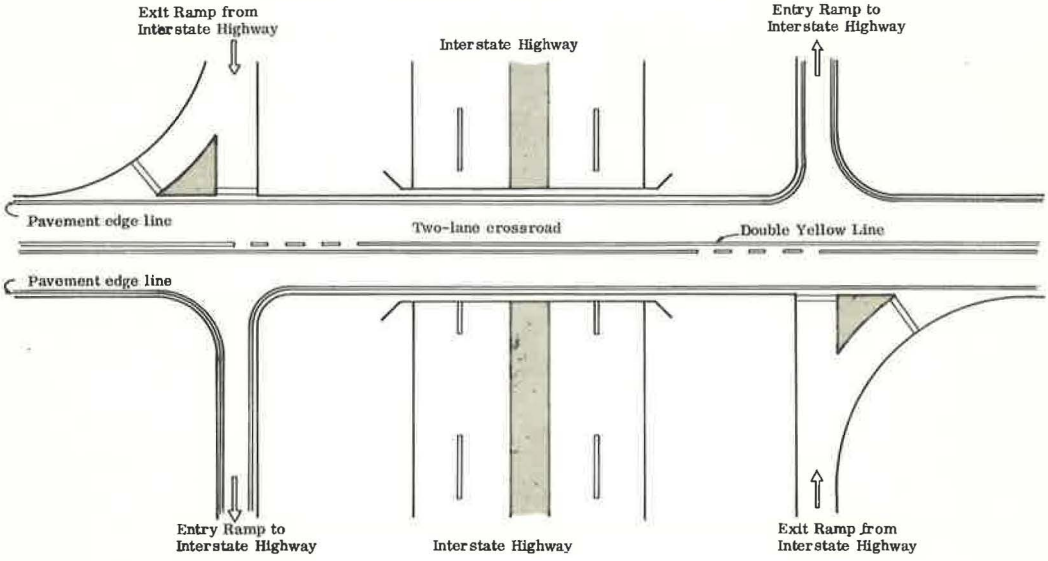


Figure 16. Recommended marking on undivided crossroad.



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 might 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.

For new designs, the need for a dividing island at the junction of the entry ramp with the crossroad should be carefully examined.

FINDINGS

The following findings are based on visual observations and evaluations of several interchanges and intersections on highways in Virginia:

1. Aids in addition to signs are necessary on crossroads and their junctions with exit and entry ramps.
2. Since non-drunken drivers were involved in most of the wrong-way entries by left turns from the exit ramps onto the divided highway, improvements at such junctions are needed to guide normal drivers.
3. Use of flared corners at the junction of the left side of the left lane of the exit ramp with the right edge of the crossroad should be discouraged or prevented.
4. Evaluations should be made of the effectiveness of stop lines and continuation of the pavement edge lines across exit ramps. In fact, the provision of a very wide (24-in. minimum) stop line with its edge on the side of the crossroad in line with the crossroad pavement edge line is recommended for evaluation.
5. "Intersection geometry" signs might considerably help drivers maneuver around the nose of the median when making a left turn from an exit ramp into a 4-lane divided highway.
6. At interchanges, spotlighting at night could be used as a driver aid.
7. The left lane of the exit ramp should be channelized by (a) providing a minimum-width left lane and (b) providing a minimum width at the junction of the left lane and the crossroad.
8. Specifications for the location of signs based on their size and the cone of vision should be developed and incorporated in the Virginia Manual.
9. Continuous vigilance should be maintained to ensure that all signs are provided.
10. For 2-lane crossroads, the use of double yellow lines without openings to divide the lanes seems to be necessary.
11. 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 simple methods given in this paper.

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