Guidelines for Application of Selected Signs and Markings on Low-Volume Rural Roads

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Existing standards and guidelines for the application of signs and markings are unsuited and inefficient for use on low-volume rural roads (roads with less than an average of 400 vehicles/day). To alleviate this inadequacy, several potentially hazardous situations were evaluated to ascertain actual needs for signs and markings as they relate to economy and safety. These evaluations were based on recent research and on probability of conflict analyses with regard to the needs for signing and marking of intersections, horizontal curves, and sections of inadequate passing sight distance. The research revealed that more efficient intersection control can be attained from the careful application of stop signs and crossroad warning signs based on approach speed, sight distance, and combined intersecting volumes. Treatment of horizontal curves can be made more efficient through the application of more stringent guidelines without adversely affecting safety. Striping of no-passing zones was found to be very inefficient in most instances because the probability of conflict in these situations is virtually nil; guidelines for alternative treatments are presented. Overall, the authors felt that application of guidelines suited to the rural context would result in savings in time, money, and frustration on the part of responsible agencies.

Low-volume rural roads [roads with less than 400 vehicles/day of average daily traffic (ADT)] make up the bulk of the public roadways operated in this country. Their existence is essential to the various aspects of rural life. "Farm-to-market" and country roads provide accessibility for communities as well as perform as the major avenue of agricultural commerce. Forest roads and park roads are necessary for the operation, maintenance, and accessibility of national forests and parks.

Heretofore, application of traffic control devices on rural roads has been restricted to those guidelines and regulations contained in the Manual on Uniform Traffic Control Devices (MUTCD) (1). However, those guidelines, which were developed primarily for major highways and city streets, are easily recognized as impractical for application on low-volume rural roads. Adherence to existing MUTCD guidelines not only is unnecessarily expensive but also produces considerable visual clutter in the rural environment. Therefore, a reduction in the levels of signing and marking on low-volume rural roads has been given careful consideration. This paper contains the guidelines developed for the application of warning and regulatory signs on low-volume rural roads and the analyses that led to their development.

Of primary importance in the reduction of the level of signing and marking is the corresponding effect on safety. To assess this effect, three major potential hazard situations were analyzed—intersections, horizontal curves, and sections of insufficient passing sight distance, or no-passing zones. Two of the situations, intersections and no-passing zones, were analyzed by using a probability of conflict technique. Safety on horizontal curves was based on research by Ritchie and others (2) and field observations made during the course of this research.

One of the overriding concerns throughout the conduct of the research was development of guidelines that not only were easily understood and readily implementable but also were truly suited to the rural situation. Guidelines contained in the MUTCD may result in too little intersection control and too much horizontal curve and no-passing zone warning if applied in rural areas. Therefore, a combination of economic analysis, engineering judgment, and field observation was applied to produce the guidelines contained herein. The analyses presented are abridgments of the actual research. Detailed descriptions of the research may be obtained from the Texas Transportation Institute.

INTERSECTION CONTROL

The analyses and guidelines developed for treatment of low-volume rural intersections stemmed from the question, What is the probability of accident occurrence at a low-volume rural intersection?

Analysis

The initial step in determining the probability of an accident was the determination of the probability of conflict. From this determination, the expected number of accidents per year can be estimated.

For the purpose of analysis, eight assumptions are made.

1. Conflict is defined as that maneuver of vehicle B that makes the driver of vehicle A change speed or direction to maintain a comfortable clearance interval.

2. Average speed is 64 km/h (40 mph) or approximately 18 m/s (60 ft/s), and no intersection control or signing is provided.

3. Any two vehicles approaching the intersection from conflicting directions in such a way that the second vehicle would enter the intersection within 3 s after the first vehicle enters the intersection are said to be in conflict; that is, one or both vehicles must make a speed change maneuver to provide comfortable clearance.

4. Effects of sight distance are not considered in the analysis portion.

5. All vehicles arrive during a 12-h period from 7 a.m. to 7 p.m. (All vehicles probably do not arrive between 7 a.m. and 7 p.m., but, because this assumption covers the worst condition, it is used here.)

6. All arrivals are random; that is, they follow a Poisson distribution.

7. Only one arrival per approach is possible during one 3-s interval; that is, all approaches are single-lane approaches, and all headways are greater than three seconds.

8. The possibility of vehicles arriving on three approaches within a 3-s interval is negated because the probability of such an occurrence is a maximum of 2.01 $\times 10^{-5}$ for the volumes under consideration.

The probability that two vehicles will be in conflict is the product of the probability that either vehicle is in the conflict region during the interval Δt(3 s). Or

$$P(\text{conflict}) = P(\text{vehicle A in conflict region during } \Delta t) \times P(\text{vehicle B in conflict region during } \Delta t) \quad (1)$$

This probability of conflict analysis revealed that, on the average, 0.68 conflict/day could be expected on two intersecting roadways of 100 vehicles/day ADT each. ADTs were incremented by 25 vehicles/day on each facility to provide an expected number of conflicts E(C) for all ADT combinations up to 400 by 400 (800 vehicles/day ADT combined intersecting volumes). Expected number of conflicts ranged from 0.04/day for a combined ADT of 50 vehicles/day (25 by 25) to 10.67/day for a combined ADT of 800 vehicles/day. Selected values for E(C) given in Table 1 reveal that the highest expected number of conflicts for a given combined ADT occurs when the intersecting volumes are approximately equal. This indicates that the "worst case" condition may not be the intersection of a minor road with a major road but actually may be the intersection of two very similar roads.

Given, then, the expected number of conflicts, what is the probability of an accident? Data from a study by Perkins and Harris (3) indicated that about 33 accidents occur in every 100 000 conflicts for the situation in question, or

$$P(A,C) = 0.000\,33 \quad (2)$$

where P(A, C) = probability of an accident given a conflict. Other data indicated that P(A, C) ranges from 0.000 25 to 0.000 35. Therefore, to examine worst case conditions, a value of P(A, C) = 0.000 35 was chosen.

Then the probability of an accident P(A) is given by

$$P(A) = P(A,C) \times P(C) \quad (3)$$

Multiplying the probability of an accident occurrence in a given 3-s interval by the number of such intervals in a day yields the expected number of accidents per day. Thus multiplying by 365 yields the expected number of accidents per year E(A).

For the two intersecting facilities of 100 ADT each, E(A) = 0.087. From the selected values of E(A) given in Table 2, it can be seen that one or more accidents per year can be expected above a combined ADT of approximately 700 vehicles/day. However, the absolute number of expected annual accidents is not of sole importance. Of equal or greater importance is the estimated annual cost of accidents in the no-control alternative as it relates to the estimated annual cost of the two-way-stop-control alternative.

Estimated annual cost of accidents at a particular intersection is the product of estimated cost per accident and estimated number of accidents per year. The primary determinant in accident cost is severity. Results of a study by Burke (4) showed little variation in severity over the ADT range 0 to 400. However, as would be expected, severity (5) as well as the proportion of fatalities (6) was found to increase with speed. Combining the results of these two studies, we developed a weighted accident cost equation:

$$\text{Cost} = F_P(A) + F_I(B) + F_F(C) \quad (4)$$

where

F_P = proportion of property-damage-only accidents,
A = average cost of property-damage-only accidents [$318 (4)],
F_I = proportion of injury accidents,
B = average cost of injury accidents [$1955 (4)],
F_F = proportion of fatal accidents, and
C = average cost of fatal accidents [$13 781 (4)].

Combining the proportional factor for each type of accident with the average cost of that type of accident in the preceding equation resulted in a weighted average cost per accident for each speed group. For example, the weighted average cost of 32-km/h (20-mph) accidents would be found as follows:

$$\text{Cost/accident} = 0.750(\$318) + 0.248(\$1955) + 0.002(\$13\,781) = \$750 \quad (5)$$

These costs and the proportional factors from which they were derived are given in Table 3. Average yearly accident cost per intersection by speed for each ADT combination is given by the product of expected number of yearly accidents, E(A) (Table 2) and weighted average cost per accident (Table 3). These costs were compared with costs associated with the use of two-way stop control. Two-way-stop control costs included expected accident cost (approximately 20 percent of that of no control) and additional annual motor vehicle operating costs due to the stop control. Additional operating cost is the difference between the cost of continuing through the intersection at the approach speed and the cost of slowing to a stop from the approach speed and returning to the previous speed. As would be expected, the costs of stopping and regaining running speed increase with higher running speeds. Table 4 (7) gives additional operating costs for each speed group and the compilation of expected cost of two-way-stop control on a facility with an ADT of 100 vehicles/day.

Selected values of costs associated with no control and two-way-stop control are compared in Tables 5, 6, and 7.

Careful examination of the estimated cost tables reveals that, up to combined volumes of 200 vehicles/day, the expected annual accident costs associated with no control are less than the accident and operating costs associated with two-way-stop control. At higher ADT values, these expected costs become equal; as the ADT values become higher still, the no-control alternative becomes more expensive. As a result of increased running speeds, this breakpoint between the economic justification of the two control alternatives increases as the speed on the intersecting roadways increases. These analyses showed that the no-control alternative was more economical up to the following combined ADT (1 km/h = 0.61 mph):

Speed (km/h)	Combined ADT	Speed (km/h)	Combined ADT
32	300	80	700
48	520	96	720
64	650		

The calculation of these breakpoints is derived by equating the costs of the no-control alternative and the cost of the two-way-stop-control alternative as represented in the following equation:

$$E(A) \times C_A = (ADT \times 365 \times C_S) - 0.2[E(A) \times C_A] \quad (6)$$

which can be simplified to

$$0.8[E(A) \times C_A] = T_Y \times C_S \quad (7)$$

where

$E(A)$ = expected number of yearly accidents with no control [for equally split traffic volumes (Table 2)],
C_A = weighted average cost per accident (Table 3),
T_Y = yearly traffic volume = ADT × 365, and
C_S = additional motor vehicle operating cost with two-way-stop control (Table 4).

Thus, for each approach speed there is a point below which stop control is not economically justified. However, as mentioned previously, economy is not the only necessary consideration. Although two-way-stop control may not be economically justified, adequate visibility of a crossing roadway is vital in the absence of signing. Because it is highly likely that a situation will arise in which stop control is not justified and cross-road visibility is inadequate, a standard crossroad warning sign (W2-1 in MUTCD) is necessary. Criteria for the use of a crossroad sign were based on sight distance requirements specified by American Association of State Highway and Transportation Officials (7). The inclusion

Table 1. Expected number of conflicts per day.

Facility B ADT	Facility A ADT 100	200	300	400
100	0.68	1.36	2.03	2.70
200	1.36	2.70	4.04	5.37
300	2.03	4.04	6.04	8.03
400	2.70	5.37	8.03	10.67

Note: Values are in vehicles per day.

Table 2. Expected number of accidents per year.

Facility B ADT	Facility A ADT 100	200	300	400
100	0.087	0.174	0.259	0.345
200	0.174	0.345	0.516	0.686
300	0.259	0.516	0.772	1.026
400	0.345	0.686	1.026	1.363

Note: Values are in vehicles per day.

Table 3. Weighted average cost per accident by speed.

Speed (Km/h)	Proportional Factors F_P	F_I	F_F	Weighted Average Cost/Accident ($)
32	0.750	0.248	0.002	750
48	0.720	0.277	0.003	812
64	0.660	0.322	0.008	969
80	0.580	0.400	0.020	1242
96	0.410	0.783	0.077	1733

Note: 1 km/h = 0.621 mph.

Table 4. Expected annual costs associated with two-way-stop control.

Approach Speed (km/h)	Operating Cost/Stop ($)	Stops/Year	Annual Operating Cost ($)	Average Cost/Accident ($)	Expected Number of Accidents	Expected Annual Accident Cost ($)	Expected Annual Cost of 2-Way Stop[a] ($)
32	0.0022	36 500	81	750	0.0174	13	94
48	0.0040	36 500	145	812	0.0174	14	159
64	0.0059	36 500	216	969	0.0174	17	233
80	0.0083	36 500	302	1242	0.0174	22	324
96	0.0116	36 500	422	1733	0.174	30	452

Notes: 1 km/h = 0.621 mph.
Operating cost per stop is based on Cleveland (5).
[a]Annual operating cost plus expected annual accident cost.

Table 5. Accident costs per year for no control and two-way-stop control at 32-km/h approach speeds.

Facility B ADT	Type of Control	Facility A ADT 100	200	300	400
100	None	65	130	194	259
	2-way stop	94	107	120	133
200	None	130	259	387	514
	2-way stop	107	213	238	264
300	None	194	387	579	770
	2-way stop	120	238	357	395
400	None	259	514	770	1022
	2-way stop	133	264	395	526

Notes: 1 km/h = 0.621 mph.
Values are in dollars.

Table 6. Accident costs per year for no control and two-way-stop control at 64-km/h approach speeds.

Facility B ADT	Type of Control	Facility A ADT 100	200	300	400
100	None	84	169	251	334
	2-way stop	233	250	266	283
200	None	169	334	500	665
	2-way stop	250	499	532	565
300	None	251	500	748	994
	2-way stop	266	532	798	847
400	None	334	665	994	1320
	2-way stop	283	565	847	1129

Notes: 1 km/h = 0.621 mph.
Values are in dollars.

of the crossroad warning sign as part of low-volume rural intersection control was, in our opinion, a necessary safety measure in the absence of stop control and adequate sight distance. Although the erection of four crossroad signs is more expensive than two stop signs, the savings in motor vehicle operating costs over the life of the signs more than offset the additional capital cost of the crossroad signs.

Guidelines

The analyses coupled with engineering judgment and many hours of field observation in rural areas resulted in certain recommended guidelines for safe and economic low-volume rural intersection control. Stop signs should be on low-volume rural roads (paved or unpaved) that intersect paved highways provided that the low-volume road

1. Serves 10 or more residences,
2. Has an ADT of 50 vehicles or more, or
3. Is 8 km (5 miles) long or longer.

Two guidelines should be followed unless two things can be shown.

1. The combined ADT for the two intersecting roadways is less than the following for the corresponding lower approach speed of the two facilities (1 km/h = 0.621 mph):

Approach Speed (km/h)	Combined ADT	Approach Speed (km/h)	Combined ADT
32	300	80	700
48	500	96	720
64	640		

2. The sight distance on each approach is at least the same as the following for the corresponding approach speed (1 km/h = 0.621 mph; 1 m = 3.28 ft):

Approach Speed (km/h)	Sight Distance (m)	Approach Speed (km/h)	Sight Distance (m)
32	27	80	66
48	39	96	78
64	54		

Sight distance is defined here as a triangle of clear visibility with legs of a length equal to the distance shown for the corresponding speed. This triangle shall apply from all directions of approach. For example, approach speeds on two intersecting facilities are 80 km/h (50 mph) and 64 km/h (40 mph) respectively. A driver approaching the intersection on the 80-km/h (50-mph) facility must, 66 m (220 ft) from the intersection, have clear visibility throughout a cone of vision extending 54 m (180 ft) in each direction along the crossing roadway (Figure 1).

For intersections that meet the ADT requirements for no control but do not meet the sight distance requirements, a standard crossroad sign, W2-1, may be used in advance of the intersection instead of two-way-stop control.

The requirements for intersection control just given can be determined from Figure 2. The procedure includes three steps.

1. Enter combined ADT in part A and project horizontally to intersect with lowest approach speed. If the intersection of these two lines is above the curve (shaded area), stop here and install stop signs on the minor approach or approaches.
2. Enter combined ADT in part A and project horizontally to intersect with lowest approach speed. If the intersection is below the curve, project intersection point downward into part B.
3. Enter shortest sight distance on lower speed approach and project horizontally to intersect line drawn in step 2. If this intersection point lies below the line, no control is needed. If the intersection point lies above the line (shaded area), a standard crossroad sign is needed on all approaches.

HORIZONTAL CURVES

Aside from the elements of geometric design, use of warning signs is one of the primary methods of improving safety on horizontal curves. In an effort to provide guidelines for the application of curve warning signs on low-volume rural roadways, existing practices, recent research, and subjective data obtained in this study were assimilated. Recommendations based on these elements were developed.

Analysis

The MUTCD provides minimal guidelines for the application of curve signs and advisory speed plates. Several states have developed specific warrants for curve signs within the requirements of the MUTCD. These warrants require the availability of ball bank indicators or detailed curve data. The objective of this endeavor was to establish guidelines for curve signing in lay terms to permit ready application. The primary assumption made was that supplemental driver information (signs, markings, and the like) is more critical in night driving than in day driving. Using the equation

$$S = 0.277V_1T + \left\{[0.277^2(V_1^2 - V_1^2)]/2a\right\} \quad (8)$$

where

S = required deceleration distance in meters,
T = perception-reaction time,
V_1 = approach speed in kilometers per hour,
V_2 = safe curve speed in kilometers per hour, and
V_3 = deceleration rate in meters per second^2

required distances for deceleration to safe curve speed that were calculated assuming an average deceleration rate of -2.1 m/s^2 (-7 ft/s^2). The addition of a perception-reaction time of 2 s yielded the minimum distance at which a driver must be aware of an impending situation. These distances are shown for various combinations of approach and curve speeds in Figure 3.

For certain combinations of approach and curve speed, the roadway itself generally provides adequate information for proper vehicular maneuvers. High beam visibility distance [about 90 m (300 ft)] was assumed to be the upper limit at which the roadway provides adequate information. A line was drawn on Figure 3 through the 90-m (300-ft) contour. Distances to the upper left of the contour line require advance supplemental information; distances to the lower right do not. Calculated data points were compared with field observations. A close correlation was found between calculated critical speed differentials and those curves observed to be hazardous.

In general, at approach speeds greater than 48 km/h (30 mph), a differential of 16 km/h (10 mph) between approach speed and safe curve speed required perception-reaction-deceleration distances necessitating advance warning. This advance warning can be provided through the use of standard (W2-1) curve signs. Speed differentials of 24 km/h (15 mph) are characteristic of more severe curvature and should be identified with a curve sign (W2-1) and an advisory speed plate (W13-1).

The relative degree of risk associated with this reduced level of signing on curves can be evaluated based on driver characteristics in a curve maneuver. The important question to be answered is whether the reduced level of signing (fewer or no signs) contributes to potentially hazardous operations. To determine the effect of signing level, Ritchie and others (2) conducted a study in 1968 that involved the relationship between forward velocity and lateral acceleration in curve driving. In a subsequent study, the previous research was expanded to determine the driver's choice of curve speed as a function of curve and advisory speed signs (2).

The study was based on the actions of 50 subjects negotiating sections of roadways containing 162 curves that required deceleration from normal operating speed. Four levels of signing were evaluated: (a) no signs, (b) curve signs, (c) curve signs with advisory speed plaques, and (d) curve signs without advisory speed plaques. In addition, all curves were lumped together to obtain an overall condition. The significant results of the study were as given in Table 8 (2).

1. As forward velocity increased, lateral acceleration decreased, indicating that, at higher speeds, drivers tend to provide themselves with a greater margin of safety on curves.
2. Drivers were more cautious on curves without signs than on curves with signs. Mean lateral accelerations on curves with signs ranged from 0.280 to 0.159 *g*; on curves without signs, they ranged from 0.259 *g* to 0.124 *g*.
3. Except at very low speeds, greater lateral acceleration (0.268 to 0.161 *g*) was produced on signed curves with advisory speed plaques than on signed curves without advisory speed plaques.
4. Below 64 km/h (40 mph), posted advisory speeds were exceeded more often than above 64 km/h (40 mph).

The conclusion of Ritchie and others was that the experimental data do not support the hypothesis that the roadway signs are responsible for the inverse relationship between speed and lateral acceleration. Roadway signs serve to reduce uncertainty and increase the confidence with which the driver proceeds. Therefore, the reduced level of signing on curves on low-volume rural roads can be effected without appreciable decrease in level of safety.

Guidelines

Based on the foregoing analyses and associated assessment of relative degree of risk and on engineering judgment founded on field observations, guidelines were developed.

1. Curve signs (W1-2) should be placed in advance of all curves with intersecting angles of 45 deg or more on paved roadways and 60 deg or more on unpaved roadways unless it can be shown that the posted speed limit is 55 km/h (35 mph) or less or that the combination of normal approach speed and safe curve speed requires a perception-reaction-deceleration distance of less than 90 m (300 ft) [the combination of the speeds produces a point to the lower right of the 90-m (300-ft) contour line in Figure 3].
2. Advisory speed plates (W13-1) should be used in conjunction with curve warning signs when the safe curve speed is 8 km/h (5 mph) below that speed warranting a curve sign (the combination of the speeds produces a point to the upper left of the appropriate line in Figure 3).

NO-PASSING ZONES

Because most low-volume rural roads follow the existing horizontal and vertical curvature of the terrain, there can be a considerable amount of inadequate passing sight distance. Treatment of this condition, with respect to the MUTCD, requires the use of standard no-passing-zone stripes on all such sections. Because this practice may be unnecessarily expensive, an evaluation of the need for such a practice is necessary. The probability of conflict technique was again employed for this determination.

Analysis

For analysis purposes, all passing maneuvers were assumed to be undertaken without regard for oncoming vehicles (as soon as a driver overtakes a slower vehicle, he or she pulls out to pass). This assumption produces unrealistic results that will be adjusted later.

In the basic situation for development of probability of conflict, a driver in vehicle A traveling at 80 km/h (50 mph) overtakes vehicle B traveling at 64 km/h (40 mph). Without regard for safe passing sight distance, the driver in vehicle A pulls into the opposing traffic lane to pass vehicle B. Before vehicle A can return to the right lane, vehicle C, traveling in the opposite direction, comes into conflict with vehicle A. The necessary determination in this evaluation is the probability of occurrence of this situation. To begin with, the probability of vehicles A and B being in this passing situation is the probability of simultaneous arrival (within a Δt of 2 s) of two or more vehicles, which is given by

$$P(x) = 1 - [P(0) + P(1)] \quad (9)$$

Based on the maximum low-volume rural road ADT of 400 vehicles (200 vehicles in each direction), the probability of such an occurrence in any 2-s interval is 4×10^{-5}. Over an entire day, the expected number of potential passing situations is 0.864.

Assuming that the following vehicle passes at a constant speed of 80 km/h (50 mph), the length of time that vehicle A is encroaching on the opposing lane is determined as follows:

$$t = d/0.277v \quad (10)$$

where

t = time left lane occupied,
d = distance traveled in left lane in meters, and
v = average speed in kilometers per hour.

For an assumed speed of 80 km/h (50 mph), the duration of encroachment on the opposing lanes is approximately 11 s. Therefore, if an opposing vehicle arrives during that 11-s interval, there will be a conflict. The probability of such an arrival P(A) in the opposing lane is 0.049 65. The probability that the passing maneuver will occur during the 11-s critical interval is

$$[(P)(11/2)] \times 0.000\,04 = 0.000\,22 \quad (11)$$

The probability that both events will occur and thus cause a conflict is the product of the respective probabilities.

$$P(C) = P(P) \times P(A)$$
$$= 0.000\,22 \times 0.049\,65$$
$$= 1.09 \times 10^{-5} \quad (12)$$

Over the course of a year, the expected number of conflicts would be 15.6, or about one conflict every 3 weeks. However, this figure is based on total disregard for passing sight distance.

Table 7. Accident costs per year for no control and two-way-stop control at 96-km/h approach speeds.

Facility B ADT	Type of Control	Facility A ADT 100	200	300	400
100	None	151	302	449	598
	2-way stop	452	482	512	542
200	None	302	598	894	1189
	2-way stop	482	965	1024	1083
300	None	449	894	1338	1778
	2-way stop	512	1024	1536	1624
400	None	598	1189	1778	2362
	2-way stop	542	1083	1624	2162

Notes: 1 km/h = 0.621 mph.
Values are in dollars.

Figure 1. Required sight distance triangle for no intersection control.

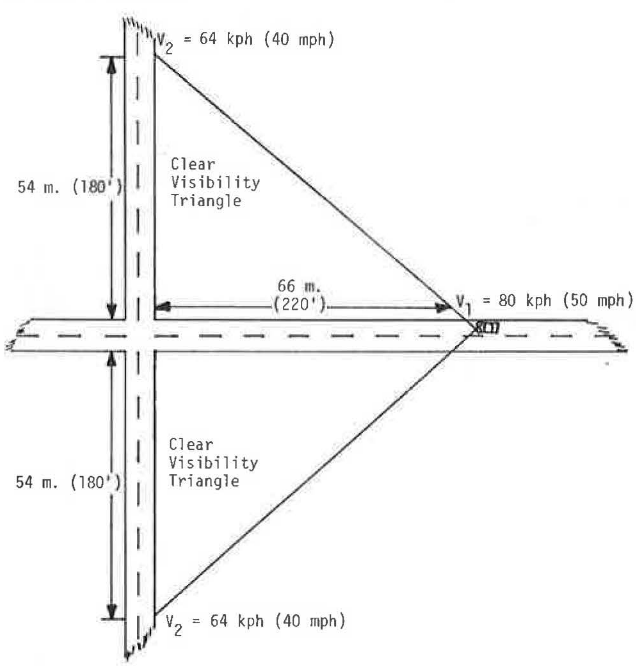

Figure 2. Intersection signing needs diagram.

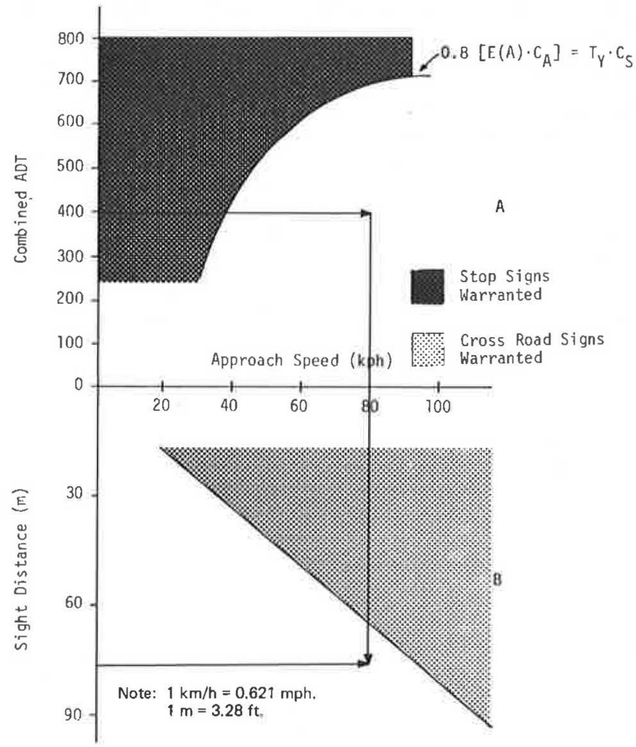

Figure 3. Required deceleration distances on horizontal curves.

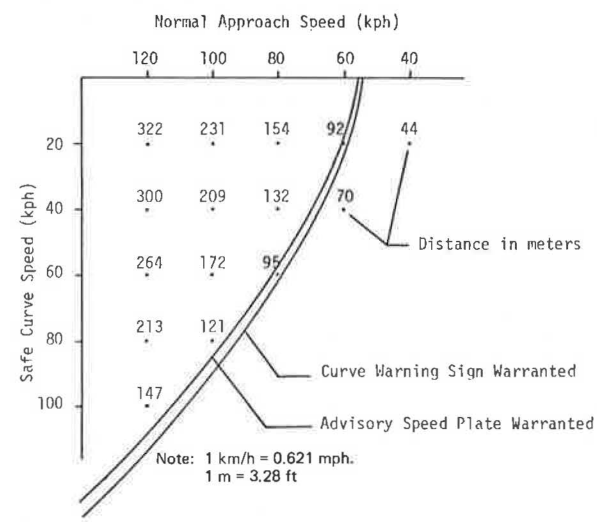

Table 8. Lateral acceleration in gravitational units as a function of forward velocity and type of roadway sign.

Forward Velocity (km/h)	All Curves N	Mean	σ	With Signs N	Mean	σ	Without Signs N	Mean	σ	With Advisory Speed N	Mean	σ	Without Advisory Speed N	Mean	σ
<32	9	0.264	0.055	2	0.280	0.024	7	0.259	0.062	1	0.263	0	8	0.264	0.059
32 to 40	6	0.257	0.070	5	0.270	0.071	1	0.193	0	4	0.268	0.081	2	0.234	0.059
40 to 48	11	0.228	0.061	6	0.257	0.061	5	0.193	0.043	6	0.257	0.061	5	0.193	0.043
48 to 56	16	0.201	0.051	10	0.222	0.053	6	0.165	0.021	10	0.222	0.053	6	0.165	0.021
56 to 64	20	0.212	0.042	13	0.223	0.035	7	0.192	0.048	12	0.224	0.037	8	0.195	0.045
64 to 72	28	0.172	0.051	21	0.183	0.051	7	0.140	0.139	19	0.185	0.053	9	0.146	0.035
72 to 80	35	0.142	0.043	18	0.159	0.037	17	0.124	0.042	13	0.161	0.043	22	0.130	0.039
80 to 88	37	0.129	0.041	4	0.174	0.028	33	0.124	0.040	3	0.169	0.032	34	0.126	0.041

Note: 1 km/h = 0.621 mph.

Assuming that about 30 percent passing sight distance was on our example roadway and that the ordinary prudent driver would take advantage of this visibility, the expected number of conflicts per year is reduced by 30 percent to about eleven. Although this number may seem a bit high to be tolerable, it applies to the worst case—400 vehicles/day and total disregard for safety on sections on inadequate passing sight distance by all drivers. Because a majority of dirvers probably would not attempt a passing maneuver without at least marginal sight distance, the actual number of conflicts is more likely 2 or 3/year. Yet this figure is applicable only for 400 vehicle/day facilities. The average facility examined (about 150 vehicle/day) would produce over the long term only about one conflict every 3 or 4 years.

This analysis indicates that there may be inefficient striping of no-passing zones on low-volume rural roads according to MUTCD requirements. MUTCD-recommended striping might prevent a conflict every few years, but there is no reason to believe that every conflict will result in an accident. Conceivably, a paint stripe would not prevent any accidents throughout the entire life of the paint.

Guidelines

Although the probability of conflict in a passing maneuver has been shown to be minute, the elimination of all signs and markings relative to passing does entail some risk. Yet the degree of risk involved does not appear to justify the expense of standard MUTCD striping. The following alternatives are offered as a substitute for MUTCD striping.

A PASSING HAZARDOUS warning sign should be used to indicate extended sections of inadequate passing sight distance on all unmarked paved roadways and all unpaved roadways. Such signs should have attached to them supplementary plates indicating the length of the section. Subsequent PASSING HAZARDOUS signs and supplementary plates should be erected beyond the intersections with paved roadways. The distances on these subsequent supplementary plates should indicate the number of kilometers remaining in the section from that point.

If centerline definition is desired on paved roadways with insufficient passing sight distance, a double narrow line may be used instead of the PASSING HAZARDOUS signs. The double narrow line consists of two 3.8-cm (1.5-in) yellow lines separated by a 2.5-cm (1-in) space. This line should be used only for extended sections of insufficient passing sight distance; intermittent sections of restricted sight distance within which striping is deemed necessary should be striped according to current MUTCD guidelines. Because vehicle wheel paths on roadways less than 6.1 m (20 ft) wide tend to overlap the centerline and obliterate painted pavement markings, such roadways should not be striped.

SUMMARY

The results of this research indicate that considerable benefit can be derived from a reevaluation of the needs for signs and markings on low-volume rural roads. These benefits include not only obvious monetary savings from reduced levels of signing and marking but also considerable savings in time and frustration on the part of the engineer responsible for the operation of these roadways. Guidelines presented in this paper were developed solely for the rural context and are thus more readily applicable to that environment than are the guidelines offered in the MUTCD. Although the recommendations presented by no means cover all control devices or all situations, they do provide guidance in three most crucial areas—intersections, horizontal curves, and no-passing zones.

1. Low-volume rural intersection control can be efficiently achieved through guidelines based on an economic analysis. Primary variables governing the application of regulatory-warning devices are approach speed, ADT, and sight distance. Below 200 vehicles/day combined entering volume, stop control is inefficient and should not be used except in rare cases. Crossroad signs are advocated for use instead of stop signs at certain locations described in the guidelines.
2. Existing signing practices produce more curve warning signs than are necessary. The guidelines presented describe a more efficient and pragmatic technique for signing of horizontal curves. This reduced level of signing was shown not to adversely affect safety because drivers tended to be more cautious on unsigned curves.
3. Guidelines were developed that are more efficient than existing standards for traffic control in sections of inadequate passing sight distance. Analyses showed that the potential for accidents in no-passing zones is virtually nil on these roadways. Recommendations contained in this paper would virtually eliminate standard striping of no-passing zones and replace that practice with a PASSING HAZARDOUS sign or a more economical double narrow line.

We found, in general, that standard practices for signing and marking of highways are inefficient and unsuited to the rural environment. The recommended guidelines should provide for a much more orderly, pragmatic, and efficient application of control devices on low-volume rural roads.

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