Need To Stripe No-Passing Zones During Resurfacing of Lower-Volume Rural Roads

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The lack of no-passing zone markings during the resurfacing of two-lane highways may produce a hazard to the driving public. The objectives of the research were to evaluate the potential safety problems and to recommend a traffic volume at which there is a significant hazard associated with not having no-passing markings in place during a resurfacing project. Analytic models and simulation models were used to predict the number of passes, the potential for passing conflicts, and the number of delayed passes at various traffic volumes. Traffic volumes were also related to highway level of service and accidents in Missouri involving improper passing. Potential reductions in accident costs were related to the cost of temporary no-passing zones. Recommendations for marking no-passing zones were based on highway classification, average daily traffic, and terrain type.

It is common practice to place centerline markings on two-lane, two-way paved rural highways. The *Manual on Uniform Traffic Control Devices* (*MUTCD*) (*1*) recommends centerlines when the two-lane pavement is 16 ft wide or more and the prevailing speed exceeds 35 mph. If centerline markings are present, the MUTCD requires no-passing zone markings where sight distance is restricted.

During a pavement resurfacing project, a road generally remains in service to traffic. A temporary broken yellow centerline marking (of 4 ft dashes), without the associated no-passing markings, is generally placed during the paving operation. Note that this is clearly contradictory to the MUTCD. The permanent marking system, including no-passing markings, is placed later, often after completion of the entire project. The temporary nonconforming marking system could be in place for as long as 2 weeks.

A road with horizontal and vertical curves would generally have sections lacking adequate passing sight distance. The lack of no-passing zone markings may produce a significant hazard to the driving public. The extent of the hazard would be related to the number of passing maneuvers that typically occur on the road. The number of passing maneuvers is related to the traffic volume.

The objectives of the research were to

1. Evaluate the degree of safety hazard associated with not having no-passing markings in place during resurfacing operations and
2. Recommend a traffic volume at which there is a significant safety hazard associated with not having no-passing markings in place during a resurfacing project.

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Traffic volumes were related to the following indicators of potential hazard:

1. Passes per mile per hour,
2. Passes per mile per hour that would conflict with oncoming traffic if the passing vehicle ignored the presence of an oncoming vehicle,
3. Potential passing vehicles that are delayed because of the presence of oncoming vehicles,
4. Highway level of service (LOS), and
5. Accidents in Missouri involving improper passing.

A benefit-cost analysis was also used to relate potential reductions in accident costs to the cost of temporary no-passing striping.

PAST STUDIES

Glennon

Glennon (*2*) used a benefit-cost analysis to determine whether no-passing zones were appropriate for low-volume roads [average daily traffic (ADT) of 400 vpd or lower]. Glennon estimated that on roads with an ADT of 400 vpd the cost of striping would be three times the cost of accidents prevented.

The assumptions used in Glennon's analysis were as follows:

1. One-half of the roadway has restricted sight distance,
2. One-half of all head-on collisions involve passing, and
3. The presence of no-passing stripes reduces head-on accidents involving passing maneuvers in restricted sight distance areas by one-half.

Glennon estimated that the accident rate on roads with ADT values of 400 vpd was 0.367/mi-yr and that 13.7 percent of these accidents were head-on. The cost per accident was $9,500. The cost of striping 50 percent of the roadway was $176/mi-yr. The expected additional accident cost without striping was $60/mi-yr. If all accidents were fatal or involved injury, the additional cost would be $123/mi-yr.

Josey

The simulation model used by Josey et al. (*3*) predicted passing rates and passing conflicts that would occur if all drivers initiated passes without regard to the presence of conflicting vehicles. The simulation involved 1 hr of operation on 3 mi of road. The simulation runs indicated no passing conflicts when the volume was 80 veh/hr or lower. The simulation resulted in 1.25 conflicts/mi-hr for a volume of 90 veh/hr and 1.0 conflicts/mi-hr for a volume of 100 veh/hr. The least squares equation calibrated from the simulation runs indicate, for a 50–50 directional split, the following correlation:

Hourly Volume	*Conflicts/mi-hr*
60	0.32
70	0.50
80	0.72
90	0.99
100	1.33
120	2.20
140	3.36
160	4.86

When the volume on the two-lane highway became high enough, many passes were not completed because of the large number of opposing vehicles. Figure 1 shows the simulation results. At low volumes, passes are roughly proportional to the square of volume. At high volumes, the number of passes decreases because of the small number of gaps available for passing.

The conclusion of the report (*3*) stated, "The probability of passes and emergency indicators (conflicts) approaches zero as traffic volumes decline below a value of 100 vehicles per hour." A conclusion derived from this study was that no-passing zones should be provided when the volume exceeds 1,000 veh/day.

RESEARCH APPROACH

The number of vehicle overtakings and potential passing conflicts were related to traffic volumes by three methods:

1. Glennon's (*2*) formulation,
2. Wardrop's (*4*) formulation,
3. Simulation by ROADSIM (*5*).

The *Highway Capacity Manual* (*6*) was used to describe LOS for various traffic and roadway conditions. Accident experience involving improper passing was evaluated using 1988 Missouri accident data (*7*).

OVERTAKING MODELS

Analytical Models

Glennon (*2*) developed a method to estimate expected number of passes, probability of an oncoming vehicle being in conflict with the passing vehicle, and expected number of passing conflicts. The expected number of passes is based on an assumption of random vehicle headways. At a given point in time, two vehicles with a headway of 1 sec or less are assumed to be engaged in a passing maneuver. The expected number of passes per unit length per unit time are extrapolated from this headway assumption. The number of passes is a function only of flow rate and is independent of the mean speed or the speed distribution.

The probability of an oncoming vehicle's being in conflict with a passing vehicle is based on Poisson (random) arrivals of vehicles at a point. The probability of a conflict increases with the flow rate in the opposing direction and the time period required to complete the pass.

$$P(A) = 1 - P(0) = 1 - e^{-Vt/3{,}600} \tag{1}$$

where

$P(A)$ = probability of a passing vehicle encountering a conflict,
$P(0)$ = probability of a passing vehicle encountering no opposing vehicles,
V = flow rate in the opposing direction (veh/hr),
t = time period in which passing vehicle is vulnerable to a conflict (sec), and
3,600 = number of seconds per hour.

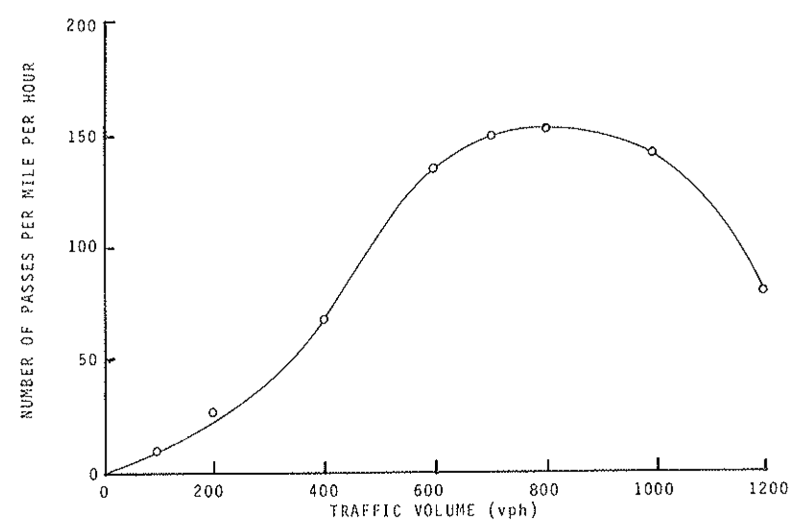

FIGURE 1 Number of passes versus two-way hourly volume for higher flow rates.

The expected number of passing conflicts per unit time per unit length would be the expected number of passes multiplied by the probability of a conflict.

Wardrop (4) developed an expression to determine the frequency with which vehicles overtake one another. If speed normally distributed and every driver chooses to pass when a slower vehicle is encountered, then the number of overtakings (N) per unit length per unit time for vehicles traveling in one direction is as follows:

$$N = \frac{Q^2\sigma}{\bar{v}^2\pi^{1/2}} = \frac{0.56\ Q^2\sigma}{\bar{v}^2} \qquad (2)$$

where

Q = one-way flow rate,
σ = standard deviation of speed, and
$\bar{v}$ = space mean speed.

If there is interference with overtaking because of oncoming traffic, this expression might be taken to be the number of desired overtakings. For a given distribution of speeds (mean and standard deviation), the number of desired overtakings increases with the square of flow.

Matson et al. (8) described a model that was based on similar assumptions. The model involved the summation of overtakings between vehicles within different speed groups. The model yields results identical to the Wardrop formulation.

Simulation: ROADSIM Model

ROADSIM (5) is a two-lane highway simulation model developed by the FHWA during the 1980s. An earlier version of this model (TWOWAF, developed by Midwest Research Institute) was modified and used by the Texas Transportation Institute to develop the two-lane highway procedure for the 1985 edition of the *Highway Capacity Manual* (6). The version of ROADSIM used for the research reported here has a November 1987 revision date and runs on a microcomputer. It was obtained from the FHWA's Traffic Safety Research Division in October 1989.

RESULTS OF OVERTAKING MODELS

Analytical Results

The Glennon (2) and Wardrop (4) methods were used to predict the number of passes as a function of hourly volume. The probability of a passing vehicle's encountering an opposing vehicle was determined from the Poisson distribution (assuming random vehicle arrivals in the opposing direction).

The following assumptions were used to predict passing demand for the Glennon formulation:

1. Two vehicles within 1 sec of each other are engaged in a passing maneuver, and
2. Nine seconds are required for the passing maneuver.

For the Wardrop formulation, the following assumptions were used to predict passing demand:

1. Space mean speed = 45 mph and
2. Standard deviation of speed = 5 mph.

Figure 2 shows the number of passes per mile per hour derived from the two analytical models.

To predict potential conflicts, the distance traveled by the passing vehicle plus the distance traveled by the opposing vehicle in 5 sec was taken as the conflict distance. If an opposing vehicle was within this 10-sec window, then a potential conflict would occur. The implicit assumption is that all passes are initiated without regard to the presence of opposing vehicles, and the presence of an opposing vehicle within a 10-

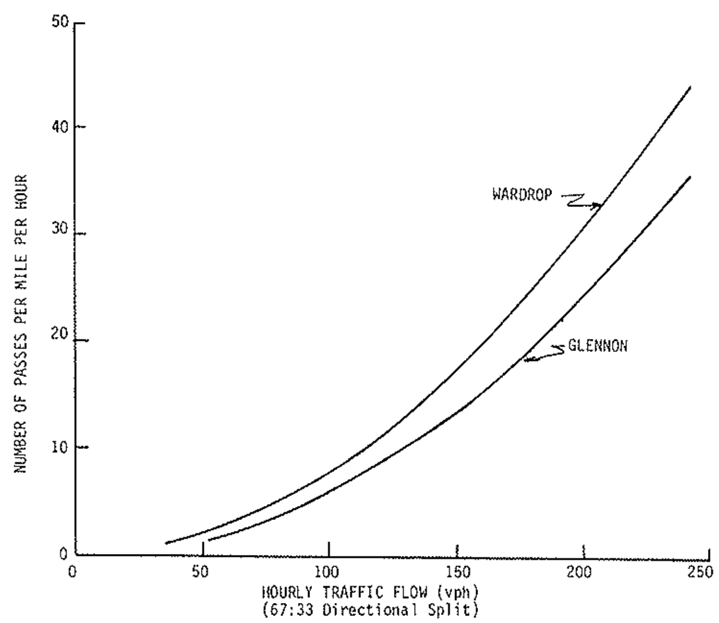

FIGURE 2 Number of passes versus two-way hourly volume.

sec window results in a conflict. Figure 3 shows the number of passing conflicts per mile per hour for each of the analytical models.

The Glennon (*2*) formulation depends on the assumption of random vehicle arrivals at a point without regard to speed or the standard deviation of speed. The Wardrop (*4*) formulation explicitly considers speed characteristics. The more variation in speed (the higher the standard deviation of speed), the higher the number of passes that will occur. For that reason, the Wardrop formulation was considered preferable to the Glennon formulation for predicting number of passes.

The Wardrop results for potential conflicts per day as a function of ADT are presented in Table 1. An average day was assumed to consist of 1 hr at 15 percent of ADT, 3 hr at 10 percent of ADT, and 11 hr at 5 percent of ADT. Each hour has a 67–33 directional split.

TABLE 1 POTENTIAL PASSING CONFLICTS PER DAY VERSUS ADT BY WARDROP (*4*) FORMULATION WITH 67-33 DIRECTIONAL SPLITS IN EACH HOUR OF THE DAY

ADT	Potential Conflicts/day[a]
225	0.08
400	0.43
600	1.44
800	3.37
1,000	6.49
1,200	11.1
1,400	17.5
1,600	26.4
1,800	37.2

[a]The potential conflicts reported in this table are based on the assumptions that (a) all drivers are willing to pass when adequate sight distance is not available, and (b) passing sight distance is never available.

Simulation Results

ROADSIM was first used to determine the number of passes that would be initiated in one direction of traffic flow if there were no opposing traffic to restrict the passing maneuvers. Two-way flow simulations were then run to determine how opposing traffic affects the passing pattern.

Simulations were conducted for one-way flow rates ranging from 25 to 175 veh/hr. Two-way simulations were run for flows rates ranging from 50 to 255 veh/hr. The range of hourly flow rates was selected to evaluate a range of ADT volumes from 400 to 1,700 veh/day. The upper value of hourly flow rates (255 veh/hr) is 15 percent of 1,700 veh/hr. Twenty-five vehicles per hour is the lowest nonzero value the simulation model will accept.

Because it was desired to determine the maximum number of passes that would likely occur for a given flow rate, the simulation runs were conducted on an ideal roadway. A 4-mi-section of straight and level roadway was used. At each end of the simulated roadway there was a half-mile section in which no passing was allowed. ROADSIM requires these end sections, over which no data is collected, because of the car-following logic used. For the simulated roadway, data were collected on the number of passes initiated in each 1-mi section. Three miles was selected as the length of roadway over which to collect data because this length was considered to be a typical length of road on which there would be few vehicles entering or leaving a typical rural, low-volume, two-lane Missouri highway. The ROADSIM model puts vehicles into the roadway only at the ends.

Simulation runs were made for 1 hr. A speed distribution with an average of 45 mph and a standard deviation of 5 mph was selected as input to ROADSIM. Only passenger cars were included in the simulated traffic stream. The assumption of no trucks (other than pickup trucks) was considered reasonable for typical low-volume rural roads of the collector and local functional classes in the state of Missouri.

Two direction distributions were used, 67–33 and 50–50. The average number of passes per mile (total in both directions) initiated in the two-way flow simulations (over the range

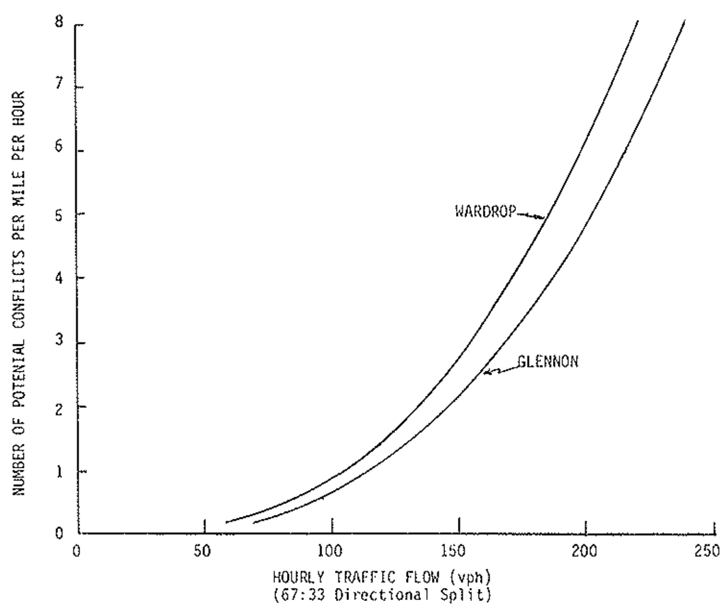

FIGURE 3 Passing conflicts versus two-way hourly volume.

of flows from 50 to 255 veh/hr) was found to be independent of the direction distribution of the traffic. The relationship between the two-way flow rate and the average number of passes initiated per mile in the simulated hour is given by

$$PPM = 0.00203Q_2^{1.79} \quad (3)$$

where

PPM = passes per mile initiated, and
Q_2 = two-way hourly flow rate.

This equation was obtained by a least squares fit of 16 data points over the range of hourly flow rates described earlier. The equation had a coefficient of determination (R^2) value of 0.92. Within the volume range studied over the 3-mi section, the number of passes per mile was found to be approximately the same with and without opposing traffic. Figure 4 shows the ROADSIM results along with the Wardrop (*4*) results.

Conflicts between vehicles desiring to initiate a passing maneuver and opposing vehicles were determined by comparing the number of passes initiated in each direction for the two-way flow and those initiated for one-way flow and hence no opposing traffic. The number of passes in each of the three 1-mi links of the roadway was compared between the two-way and the one-way flow. If the number of passes initiated on a 1-mi link was lower with opposing flow than for the same one-way volume with only one-way flow, then that number of delayed passes was counted for that 1-mi link because those passes were delayed into the next 1-mi link. If then, for example, in the next 1-mi link, the numbers of passes initiated for one-way and two-way flow were the same, an additional number of delayed passes would be counted equal to the same number in the first link.

Within this definition of delayed passes, the relationship between the two-way flow rate and the average number of delayed passes per mile in the hour was found to be

$$DPPM = 0.0000045Q_2^{2.57} \quad (4)$$

where DPPM is the number of delayed passes per mile. This equation was developed by a least squares fit to seven data points with nonzero number of delayed passes. The coefficient of determination was 0.975.

Delayed passes are not identical to potential conflicts as discussed under the Glennon and Wardrop formulations. With ROADSIM analysis, a pass can only be identified as being delayed if conflicting traffic postpones a desired pass from one section to a downstream section. A pass that is delayed but still occurs within the same 1-mi section is not detected in comparing unopposed and opposed simulation runs.

Table 2 presents a tabulation of Equations 3 and 4. Also presented in this table is the percent of the passes that are delayed.

By assuming a distribution of the average daily traffic volume throughout the day, it was possible to determine the number of passes initiated per mile per day and the average number of delayed passes per mile per day. An average day was as assumed previously. Table 3 presents the number of passes and delayed passes, and the ratio over the range of ADT values from 1,700 to 400 veh/day.

TABLE 2 RELATIONSHIP BETWEEN HOURLY FLOW RATE, PASSES, AND DELAYED PASSES

Flow Rate (veh/hr)	Passes (per mile per hour)	Delayed Passes (per mile per hour)	Delayed Passes per Pass (%)
250	39.8	6.55	16.4
225	33.0	4.99	15.2
200	26.7	3.69	13.8
175	21.0	2.62	12.4
150	16.0	1.76	11.0
125	11.5	1.10	9.6
100	7.7	0.62	8.0
75	4.6	0.29	6.4
50	2.2	0.10	4.7

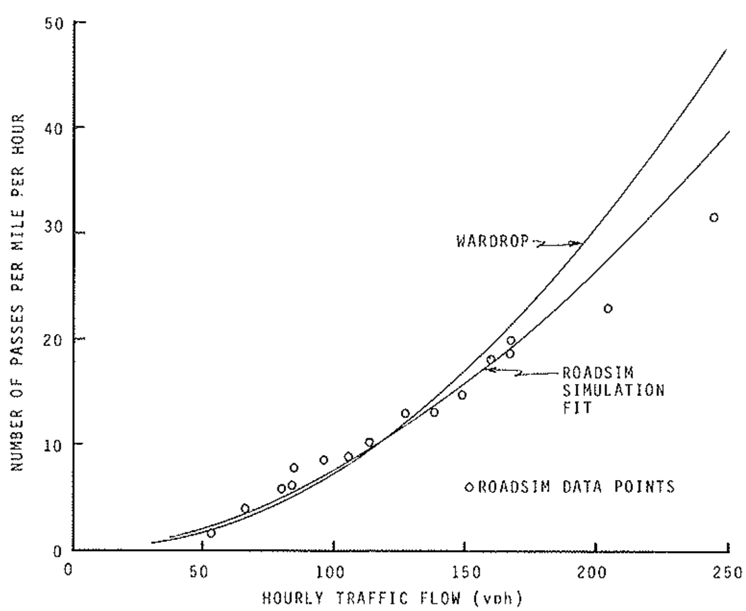

FIGURE 4 Number of passes versus two-way hourly volume.

TABLE 3 RELATIONSHIP BETWEEN ADT, PASSES, AND DELAYED PASSES

ADT (veh/day)	Passes	Delayed Passes	Delayed Passes per Pass (%)
	(per mile per day)		
1,700	165	18.7	11.4
1,400	116	11.3	9.8
1,200	88	7.6	8.6
1,000	64	4.8	7.5
800	43	2.7	6.3
600	26	1.3	5.0
400	12	0.4	3.7

LOS

The *Highway Capacity Manual* (*6*) describes the quality of flow associated with each LOS for two-lane highways. In the description of LOS A:

> The highest quality of traffic service occurs when motorists are able to drive at their desired speed. Without strict enforcement, this highest quality, representative of LOS A, would result in average speeds approaching 60 mph on two-lane highways. The passing frequency required to maintain these speeds has not reached a demanding level. Passing demand is well below passing capacity, and almost no platoons of three or more vehicles are observed. Drivers would be delayed no more than 30% of the time by slow moving vehicles. A maximum flow rate of 420 pcph, total in both directions, may be achieved under ideal conditions.

In LOS B, the passing demand becomes more important:

> LOS B characterizes the region of traffic flow wherein speeds of 55 mph or slightly higher are expected on level terrain. Passing demand needed to maintain desired speeds becomes significant and approximately equals passing capacity at the lower boundary of LOS B. . . .

From these descriptions it appears that no-passing pavement markings are desirable for LOS B operations, even if this LOS value is present only in the peak hour. On the other hand, LOS A operations may be acceptable without no-passing pavement markings. The relatively small number of drivers desiring to pass would have little difficulty finding appropriate passing opportunities.

The procedure of the *Highway Capacity Manual* has been adapted for the lower-volume two-lane highways considered in this study. The following assumptions were used:

- General terrain segment operating at LOS A;
- Traffic includes 6 percent trucks, no RVs, and no buses;
- 60/40 directional split;
- 12-ft lanes and 6-ft usable shoulder (with relatively low volumes, narrow lanes and restricted shoulders have minimal effects on flow);
- For level terrain, 20 percent no passing zones;
- For rolling terrain, 40 percent no passing zones; and
- For mountainous terrain, 60 percent no passing zones.

Table 4 presents the ADT values associated with providing LOS A in the peak hour. The K-factor is the proportion of ADT in the peak hour. Two-lane rural highways in Missouri are classified as presented in Table 5.

TABLE 4 MAXIMUM ADT VERSUS TERRAIN FOR LOS A IN PEAK HOUR ON TWO-LANE RURAL HIGHWAYS

K-Factor	Level Terrain	Rolling Terrain	Mountainous Terrain
0.10	2,979	1,561	741
0.11	2,708	1,419	673
0.12	2,482	1,301	617
0.13	2,291	1,201	570
0.14	2,128	1,115	529
0.15	1,986	1,041	494

In terms of the peak-hour LOS, Table 4, indicates that, for a peak hour equal to 15 percent of ADT, LOS A should not be expected on most arterials. LOS A would be expected on all local roads. For collectors, LOS A would be expected in level terrain but would not be expected in mountainous terrain. In rolling terrain, LOS A would be expected when the ADT is below about 1,041.

MISSOURI TWO-LANE HIGHWAY ACCIDENT CHARACTERISTICS

The accident rates in Missouri for 1988 were reported by R. Coplen (unpublished correspondence). Table 6 presents 1988 accidents by route marking designation on the state system. The route markings of primary interest in this study are state lettered. Table 7 presents accidents by type and Table 8 presents accidents by contributing circumstances. The contributing circumstances of primary interest to this study is improper passing. Improper passing contributed to 23 fatal accidents (3.0 percent), 571 injury accidents (2.5 percent), and 1,742 property damage accidents (3.3 percent).

The accident rate on Missouri routes with letter designations is 285 accidents per 100 million miles traveled. Using this rate for the roads considered, the expected numbers of accidents per mile per year and accidents per mile per day are presented in Table 9. The accident cost per mile per day is based on Missouri accident patterns (R. Coplen, unpublished correspondence) and the work of Miller et al. (*8*). The assumed average cost per accident is $32,900. Fatal accidents were valued at $2,300,000, injury accidents at $22,000, and property damage accidents at $5,423. The value for fatal accidents was based on the concept of rational investment levels and "is consistent with universal Federal practice in benefit-cost analysis"(*8*). The value is approximately four times the "cost to society."

TABLE 5 FUNCTIONAL CLASSES OF RURAL HIGHWAYS IN MISSOURI (R. Coplen)

Functional Classification	ADT	Approximate Percentage of Miles
Arterials	Over 1,700	7.0[a]
Collectors	400–1,700	22.6
Local roads	Under 400	70.4

[a]Some arterials would have more than two lanes.

TABLE 6 ACCIDENTS BY ROUTE MARKING DESIGNATION (R. Coplen)

ROUTE MARKING DESIGNATION	FATAL ACCIDENTS	TOTAL FATALITIES	INJURY ACCIDENTS	TOTAL INJURIES	PROPERTY DAMAGE ACCIDENTS	TOTAL ACCIDENTS
Interstate	127	143	4,725	7,148	11,867	16,719
U.S. Numbered	187	222	5,258	8,646	12,934	18,379
State Numbered	232	269	7,484	12,035	16,978	24,694
State Lettered	184	209	4,169	6,492	7,164	11,517
Others	19	22	1,240	1,961	3,495	4,754
Totals	749	865	22,876	36,262	52,438	76,063

TABLE 7 ACCIDENTS BY TYPE (R. Coplen)

ACCIDENT TYPE	FATAL ACCIDENTS	TOTAL FATALITIES	INJURY ACCIDENTS	TOTAL INJURIES	PROPERTY DAMAGE ACCIDENTS	TOTAL ACCIDENTS
Accident occurred Off Roadway						
Overturned & Overturning	53	62	1,125	1,627	847	2,025
Pedestrian	0	0	1	1	0	1
Motor Vehicle in Traffic	1	2	39	66	53	93
Parked Motor Vehicle	2	2	80	108	148	230
Railroad Train	1	1	0	1	0	1
Bicyclist/Pedalcyclist	0	0	0	0	0	0
Animal (other than deer)	0	0	1	1	2	3
Deer	0	0	0	0	1	1
Fixed Object	277	302	5,018	6,938	6,284	11,579
Other Object	0	0	5	5	7	12
Other, Non-Collision	2	2	11	14	48	61
Other	35	38	775	1,101	919	1,729
Subtotals	371	409	7,055	9,862	8,309	15,735
Accident Occurred on Roadway						
Overturned & Overturning	2	2	199	266	142	343
Pedestrian	49	50	316	352	5	370
Motor Vehicle in Traffic	304	379	14,251	24,401	37,814	52,369
Parked Motor Vehicle	1	2	165	247	536	702
Railroad Train	2	3	11	21	15	28
Bicyclist/Dedalcyclist	1	1	115	117	17	133
Animal (Other than Deer)	0	0	76	91	531	607
Deer	0	0	99	114	2,962	3,061
Fixed Object	14	14	476	638	1,078	1,568
Other Object	0	0	49	56	667	716
Other, Non-Collision	5	5	64	97	362	431
Other	0	0	0	0	0	0
Subtotals	378	456	15,821	26,400	44,129	60,328
TOTALS	749	865	22,876	36,262	52,438	76,063

Accidents by weather condition are presented in Table 10; accidents by light condition are presented in Table 11. It is expected that recent paving will be obvious in daylight when the pavement is dry and many drivers may not expect pavement markings to be complete.

ANALYSIS OF POTENTIAL BENEFITS AND COSTS

Marking no-passing zones during resurfacing projects would probably require temporary pavement markings. Permanent markings would then be placed at the completion of the project. The cost of applying preformed removable solid yellow marking tape was approximately $112 per 100 ft in 1989 (*9*). The removal cost was $16 per 100 ft. Temporary pavement striping cost $21.25 per 100 ft of 4 in. solid yellow. For two 4-in. solid lines, the cost would be $1,122 per mile of no-passing zone.

A resurfacing project lasting 14 days was taken as an upper limit of project length. Assume a road with an ADT of 2,000 veh/day, a repaving project lasting 14 days, and that no-passing zones were marked at the end of the project. On average, a given no-passing zone would be unmarked for about 7 days. If no-passing markings could reduce the expected number of all accidents in the no-passing zone by one-half, the value of those savings would be one-half of $188/mi-day times 7 days, or $658 per mile of no-passing zone. Because the cost of the temporary pavement marking would be about $1,122 per mile of no-passing zone, the benefit-cost ratio would be about 0.6. Missouri accident statistics indicate that improper passing is involved in only about 3 percent of accidents. This would seem to imply that the benefit-cost ratio is, at best, only 0.12. It appears obvious that marking no-passing markings during resurfacing projects cannot be justified by benefit-cost analysis unless the ADT is much greater than 2,000 veh/day or benefits other than accident reduction are considered.

TABLE 8 ACCIDENTS BY CONTRIBUTING CIRCUMSTANCES (R. Coplen)

	DRIVERS INVOLVED IN			
CONTRIBUTING CIRCUMSTANCES	FATAL ACCIDENTS	INJURY ACCIDENTS	PROPERTY DAMAGE ACCIDENTS	TOTAL ACCIDENTS
Speed, Exceeded Limit	110	853	910	1,873
Speed, Too Fast for Conditions	164	4,591	7,433	12,188
Failure to Yield Right-of-Way	73	4,380	9,867	14,320
Improper Passing	23	571	1,742	2,336
Violation, Electrical Signal	19	302	460	781
Violation, Stop Sign	7	570	909	1,486
Wrong Side (Not Pasing)	172	1,446	1,491	3,109
Following Too Closely	12	2,723	6,886	9,621
Directional Signal, Failed to or Wrong	1	91	312	404
Improper Backing	1	50	639	690
Improper Turn	14	616	2,036	2,666
Wrong Way on One Way	11	49	91	151
Improper Start, From Park	0	46	219	265
Improper Parking	3	148	247	398
Vehicle Defects	20	836	2,051	2,907
Drinking	136	1,697	1,249	3,082
Drugs	6	72	63	141
Other Violation	0	0	0	0
Inattention	269	11,295	23,774	35,338
None	413	17,472	43,406	61,291
Totals	1,454	47,808	103,785	153,047
For Drivers (Number =)	1,149	41,053	95,168	137,370
In Accidents (Number =)	749	22,876	52,438	76,063

TABLE 9 ACCIDENT RATES AND COSTS

ADT	Accidents per Mile per Year	Accidents per Mile per Day	Accident Cost per Mile per Day
400	0.42	0.00114	$ 38
800	0.83	0.00228	75
1,200	1.25	0.00342	113
1,600	1.66	0.00456	150
2,000	2.08	0.00570	188

ADDITIONAL CONSIDERATIONS

Driver Expectations

Drivers expect different driving characteristics from different types of roads. The principal function of rural local roads is to provide access to adjacent land. Travel distances are short and mobility is not a primary concern. Arterials are expected to provide for high speeds and high volumes. Many of the trips are long and there should be little interference for the through movements. On rural collectors, both land access and mobility are important. Trip lengths are longer than those on local roads but shorter than those on arterials. Speeds are generally higher than on local roads but lower than on arterials (*10*). Drivers expect higher mobility on arterials than on collectors and higher mobility on collectors than on local roads.

Driver Information

Most resurfacing projects are conducted during the spring, summer, and fall, so most peak volumes will occur in daylight hours. The number of passes is roughly proportional to the square of hourly volume and the number of potential conflicts is roughly proportional to the cube of volume. Recent resurfacing and new 4-ft dashes will be obvious to most drivers during daylight hours. Therefore most drivers in the critical

TABLE 10 ACCIDENTS BY WEATHER CONDITIONS (R. Coplen)

WEATHER CONDITION	FATAL ACCIDENTS	INJURY ACCIDENTS	PROPERTY DAMAGE ACCIDENTS	TOTAL ACCIDENTS
Clear	509	14,573	30,329	45,411
Cloudy	166	4,933	10,402	15,501
Rain	42	2,225	4,689	6,956
Snow	11	421	1,180	1,612
Sleet	4	82	182	268
Freezing	5	238	508	751
Fog/Mist	12	260	558	830
Other	0	0	0	0
Not Stated	0	144	4,590	4,734
Totals	749	22,876	52,438	76,063

TABLE 11 ACCIDENTS BY LIGHT CONDITIONS (R. Coplen)

LIGHT CONDITION	FATAL ACCIDENTS	TOTAL FATALITIES	INJURY ACCIDENTS	TOTAL INJURIES	PROPERTY DAMAGE ACCIDENTS	TOTAL ACCIDENTS
Daylight	381	437	15,023	23,977	37,151	52,555
Dark w/Streetlights on	59	64	2,890	4,599	6,082	9,031
Dark w/Streetlights Off	1	1	146	211	329	476
Dark - No Streetlights	307	362	4,770	7,396	8,675	13,752
Not Stated	1	1	47	79	201	249
Totals	749	865	22,876	36,262	52,438	76,063

time periods will be aware of the recent resurfacing. In addition, the majority of drivers on local and collector roads are nearby residents who will use the road many times during the course of the resurfacing project. Therefore, many drivers may not expect permanent pavement markings to be present.

CONCLUSIONS AND RECOMMENDATIONS

The primary considerations leading to the recommendations on marking no-passing zones during pavement resurfacing operations are as follows:

1. No-passing zones are most important to drivers with a high expectation of mobility. Drivers on arterial roadways expect provisions that enhance their perceived mobility.
2. For roads in level terrain with relatively few sight distance limitations, the number of passes and potential conflicts do not present a significant safety hazard if the ADT is below 1,700 veh/day.
3. For a road in rolling terrain, sight distance limitations and the reduced speeds of some vehicles increase the hazard caused by passes and potential conflicts.
4. In mountainous terrain, with heavy vehicles operating at crawl speeds and relatively few sections of road with adequate passing sight distance, the hazard caused by the desire to pass and potential passing conflicts becomes significant at relatively low volumes.
5. The monetary value of reduced accidents that might result from marking no-passing zones does not justify the additional cost of no-passing zones on collector roads. However, drivers on collectors that have few sections with inadequate passing sight distance probably expect some positive guidance to support their decisions to pass or not to pass.

The recommendations are presented in Table 12.

If these recommendations are followed, traffic on roads with temporarily unmarked no-passing zones will operate at a high quality of flow. In the peak hour, few platoons of three or more vehicles will develop and the number of passes and potential passing conflicts will be reasonably low. Platooning, passes, and potential conflicts will be much lower in nonpeak hours.

The state rural system in Missouri is 70.4 percent local and 22.6 percent collector. Most state systems include fewer miles of low-volume roads. Decisions on pavement markings for rural local and collector roads in most states are more likely to be made at the county level.

TABLE 12 RECOMMENDATIONS ON MARKING NO-PASSING ZONES DURING RESURFACING PROJECTS

Rural Road Classification	Recommendation
Arterial (ADT > 1,700)	Mark during project
Collector (1,700 > ADT > 400)	Mountainous terrain: mark during project Rolling terrain: mark during project when ADT exceeds 1,000 veh/day Level terrain: mark at end of project
Local (ADT < 400)	Mark at end of project

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Missouri Highway and Transportation Department in the conduct of this work.

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The conclusions and recommendations presented herein are solely those of the authors.

Publication of this paper sponsored by Committee on Traffic Safety in Maintenance and Construction Operations.