Because the survey showed that, in general, the traffic-control management programs are less than adequate, cities need to institute effective programs to regulate street maintenance and construction activity.

Based on this research, if cities make the effort to implement traffic management programs for work zones, the quality of the traffic control through work zones should improve. The need now is to convince cities of the necessity for providing these programs. It is therefore recommended that a more comprehensive study be conducted of city traffic management programs in work zones to determine the needs and inadequacies of these programs and to recommend and test various proposals to improve the programs.

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Concrete Barriers at Transition Zones Adjacent to Two-Way Traffic Operation on Normally Divided Highways

LESLIE M.G. PANG AND JASON C. YU

One technique to control traffic around construction zones on four-lane divided highways is to close one of the roadways for construction work and provide two-way, two-lane operations on the opposite roadway. Because of the high frequency of head-on collisions under this type of traffic control, the Federal Highway Administration issued an emergency rule that, among other things, requires that concrete barriers be placed at the transition zones where four-lane operations change to two-lane and vice versa. The objective of this study was to verify whether barriers are justified at transition zones on the basis of accident experience. Data from 14 rural Interstate work sites showed that no head-on accidents occurred at the transitions but several occurred on the two-way, two-lane segments. This indicates that, at least on lesser-traveled highways, the probability of a head-on collision is low because of the minimal volume of oncoming traffic. Therefore, the barrier requirement is questionable on low-volume roadways. By using intuitive reasoning, the effects of project duration and approach speed on accident behavior in transition zones are also discussed.

Various management strategies have been implemented to control traffic through construction and maintenance work zones on rural, four-lane divided highways. One strategy is to close one roadway for the construction work and provide two-way, two-lane no-passing operations on the opposite roadway. Median crossovers at the transition zones are constructed between the roadways to divert traffic around the closed segment. Refer to Figure 1 for an illustration of the management strategy (1, p. 6B-10).

Under this type of traffic control, an alarming number of severe head-on accidents were found to have occurred (2). As a result, the Federal Highway Administration (FHWA) issued an emergency rule in 1979 that required the use of special traffic control devices along the two-way, two-lane segments and at the transition zones. The rule requires that (3, p. 53 739) "where two-way traffic must be maintained...opposing traffic (must) be separated either with concrete 'safety shape' barriers or with drums, cones, or vertical panels throughout the length of the two-way operation except for transition zones where concrete barriers are to be used in all cases."

This study was concerned with the latter portion of the emergency rule, which requires the use of concrete barriers at all transition zones. The transition zone is defined in this study as the roadway section at which traffic flow is converted from a four- to two-lane operation and vice versa. Because of its traffic flow configuration, transition zones were thought to be susceptible to head-on crashes. The installation of concrete barriers in the transition zone virtually eliminates the possibility of a head-on collision caused by a motorist straying across the centerline.

On the contrary, a number of highway engineers have pointed out the disadvantages with the barriers in response to the FHWA rule (4):

1. The presence of the concrete barriers is a traffic hazard in itself; also, there is an additional hazard during erection and removal of the barriers;
2. Barriers may not be practical in certain situations, such as low traffic volumes, low-speed roadways, or short-term projects;
3. The cost of material and labor for the concrete barrier will increase the project costs;
4. Crash cushions will be required at exposed barrier approach ends and add another fixed-object hazard to the driving environment as well as raise traffic control costs; and

5. A vehicular impact on the concrete barriers will be more severe than would be an impact with other delineation devices, such as drums, cones, and vertical panels.

ANALYSIS APPROACH

FHWA officials thought that concrete barriers are justified at transition zones based on the assumption that these zones are prone to head-on collisions when concrete barriers are not used. This study critically examined this assumption by reviewing the accident experience at transition zones without concrete barriers and determining the frequency of actual and potential head-on crashes at these zones. Potential head-on accidents are reported incidents where a vehicle or vehicles cross the centerline and enter the opposing traffic lane without colliding with the oncoming vehicles. It is hypothesized that if the incidence of head-ons are relatively low or nonexistent at the transition zones that do not have concrete barriers, the existing delineation devices (drums, cones, and vertical panels) are adequate, and concrete barriers are, therefore, unnecessary.

Construction work zone accident data were provided by the accident records divisions of the Nebraska Department of Roads and the Iowa Department of Transportation. Accident experience at a total of 14 work zones located at 16 projects that used two-way two-lane traffic control on normally divided highways was examined. All of the projects were located on various rural segments of Interstate 80 throughout Nebraska and Iowa. Table 1 presents descriptions of the projects and the project work zones examined in this study. The project period included the years 1977-1979.

Figure 1. Two-way, two-lane traffic operation on highways that are normally divided.

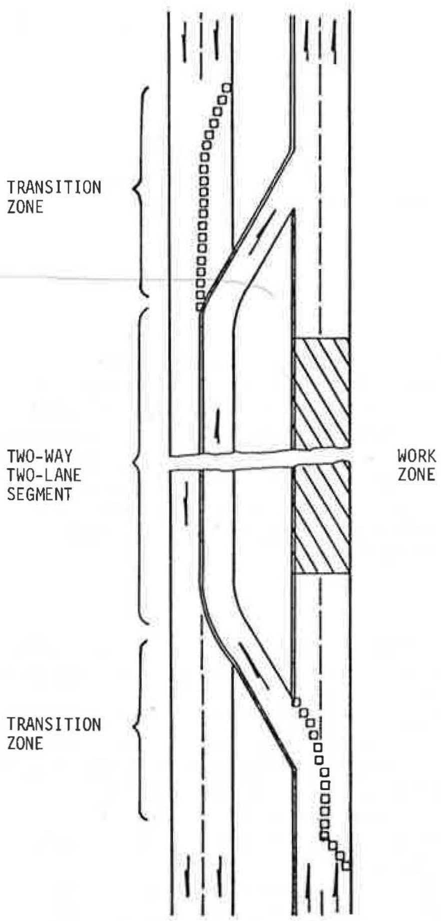


Table 1. Project background.

Project No.	Type of Construction	Work Site Length (miles)	Duration (days)	Average Daily Traffic
1	Bridge repair	0.7	127	8 500
2	Pavement repair	7.3	115	10 600
3	Pavement repair	5.3	116	9 400
4	Bridge repair	0.8	123	10 300
5	Bridge repair	0.6	112	10 400
6[a], 7[a], 8[a]	Bridge repair	1.3	79	13 000
9	Bridge repair	1.6	87	12 500
10	Pavement repair	3.9	124	11 600
11	Pavement repair	4.8	118	8 500
12	Pavement repair	3.7	109	9 400
13	Pavement repair	4.6	48	11 000
14	Bridge repair	1.9	120	15 300
15	Pavement repair	7.0	116	12 600
16	Pavement repair	6.0	69	11 400

Note: All projects were located on I-80 in rural areas of Nebraska and Iowa.
[a]Because of the close proximity of these projects, all were contained in a single work zone.

DISCUSSION OF FINDINGS

Table 2 gives the summary of accident statistics at all project locations. The accident data are based on an estimated total of 16 048 700 times a vehicle entered one of the 32 transition zones reviewed. The results also represent a cumulative total of 1463 project days. As given in Table 2, a total of 44 accidents were reported at the rural I-80 work sites studied. Thirty-four out of the 44 total accidents occurred within the transition zone, but none of them were head-on collisions. Four head-on accidents occurred on the two-way, two-lane segments away from the transitions.

The absence of head-on collisions at the reviewed transition zones raises questions on the necessity for concrete barriers at those locations. However, examination of the nature of the accidents in the transition zones showed that more than half of them (56 percent) had the potential of becoming head-on collisions. The collision diagram of accidents in a transition zone is illustrated in Figure 2. The reason why the potential incidents did not result in an actual head-on accident was because no immediate traffic was in the opposing lane when the errant vehicle crossed the centerline. Therefore, at least on relatively low-volume highways, delineation devices appear to be adequate at transition zones, assuming that they are placed properly.

The direct relationship between head-on accident rate and traffic volume is supported by a regression analysis by Pang (5). In his study, he found a high correlation between the accident rate in a transition zone and the annual average daily traffic (AADT) for a range between 8500 and 13 000 vehicles/day. At a correlation coefficient of 0.75, the linear relationship between the two variables was determined to be

$$Y = -789.75 + 89.45 X_1 \quad (1)$$

where Y is the transition zone accident rate per 100 million entering vehicles and X_1 is AADT in 1000 vehicles/day.

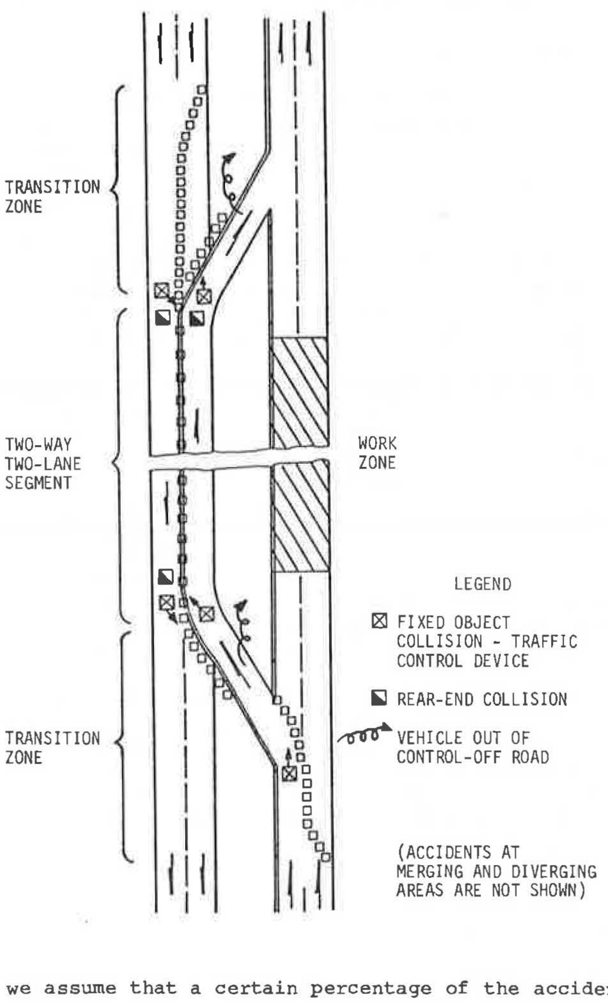
This indicates that, as AADT increases, the accident rate at transition zones also increases. If

Table 2. Accident summary.

	Entire Project Length			Transition Zones Only		
Project No.	Total No. of Accidents	No. of Head-On Accidents	Total Accident Rate[a]	Total No. of Accidents	No. of Head-On Accidents	Transition Zone Accident Rate[b]
1	0	0	0	0	0	0
2	3	0	67.31	3	0	247.04
3	4	1	68.99	2	0	183.52
4	0	0	0	0	0	0
5	1	0	141.42	1	0	86.27
6[c], 7[c], 8[c]	2	0	150.96	2	0	194.74
9	7	2	397.81	5	0	460.32
10	6	0	102.81	6	0	400.96
11	7	0	140.44	5	0	481.51
12	1	0	26.36	0	0	0
13	2	0	82.35	2	0	378.79
14	5	0	143.80	3	0	163.93
15	3	0	29.32	3	0	205.25
16	3	1	63.56	2	0	254.26
Total	44	4	101.08[d]	34	0	218.33[d]

[a]Accidents per 100 million vehicle miles.
[b]Accidents per 100 million entering vehicles.
[c]Because of the close proximity of these projects, all were contained in a single work zone.
[d]Mean.

Figure 2. Collision diagram of accidents in transition zone.



we assume that a certain percentage of the accidents in a transition zone involve head-on collisions, a high correlation would be expected to also exist between traffic volume and head-on accident rate. That is, as AADT increases, the head-on accident rate at the transition zone also increases.

Besides traffic volumes, two other variables also appear to affect the head-on accident behavior at transitions--project duration and approach speeds.

Project duration is the time interval during which traffic flows through the transition zones of the project work site. A strong correlation was found between the accident rate in a transition zone and project duration (6, p. 83). With a correlation coefficient of 0.80, the linear relation between the two variables is as follows:

$$Y = 818.26 - 6.42\,X_2 \tag{2}$$

where Y is the accident rate in the transition zone per 100 million entering vehicles and X_2 is the project duration in days.

The above equation indicates that, as project duration increases, the accident rate at the transitions decreases. Therefore, for projects of short duration, a higher accident rate is expected in the transition zone. Graham arrived at the same conclusion regarding accident rates in construction zones in general (6, p. 83).

Again, assuming that a certain percentage of accidents in transition zones involve head-on collisions, it is anticipated that for projects of short duration, the head-on accident rate is higher than that for longer-term projects. An interpretation why projects of short duration have higher accident rates is that most accidents occur in the early days of the project. At that time, motorists do not expect the construction work or its special traffic controls and, as a result, are prone to accidents. As the project progresses, this unexpectancy, particularly of local motorists, decreases and the accident frequency is expected to decline. In determining the overall accident rate, long-term projects would have to average the high- and low-accident periods, whereas short-term projects just have the early high-accident period.

Since the accident rate in the transition zone increases with the shorter project duration, one plausible conclusion is that concrete barriers may be needed for short-term projects. But these installations may not be cost effective when considering the actual reduction in the number of accidents during such a short period. On the other hand, long-term projects are expected to have a greater number of accidents due to a longer period of exposure. Thus, installation of concrete barriers would be more economically justified for long-term projects than for short-term ones, assuming that they are needed at all. Remember that the accident experience from the sites in this study failed to support the necessity of barrier installation for low-volume roadways.

In regard to approach speeds, it can be expected that, as speed to the transition increases, the chances of a head-on collision would also increase. This is because at higher speeds vehicles would have a greater tendency to stray out of their lanes, particularly at curves such as those present at transition zones. This is implied in recent roadway delineation research (7). By using this reasoning, concrete barriers appear to be justified at transition zones where approach speeds are high. It is difficult to see a need for barriers at zones that have low approach speeds since the head-on accident frequency is expected to be low under those circumstances.

CONCLUSIONS

This paper was prepared with the aim of collecting, tabulating, and analyzing accident data from construction and maintenance zones to determine the validity of the requirements for concrete barriers at transition zones as part of a FHWA emergency rule.

The results of this study and the findings based on past research indicate that concrete barriers do not appear to be justified at those transition zones located on relatively low-volume roadways. The accident data showed that the occurrence of head-on collisions at transition zones was nonexistent at the rural sites reviewed. When errant vehicles did stray into the opposing traffic lanes within these zones, oncoming vehicle volumes were low so that no collisions occurred.

Intuitively, it appears that concrete barriers may be needed at the transitions during the early days of the project, due to the relatively low driver expectancy of the new traffic patterns. However, attention must be given to costs, particularly on short-term projects. Barriers also appear justified at transition zones where approach speeds are high because of the increased probability of a vehicle straying out of its lane due to the geometrics of the transition.

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Abridgment

Alternative Sign Sequences for Work Zones on Rural Highways

RICHARD W. LYLES

Two experiments were done on a two-lane rural road (US-2) in central Maine to evaluate the effectiveness of alternate signing sequences for providing warning to motorists of construction and maintenance activities that require a lane closure on the road ahead. The signs tested included a standard Manual on Uniform Traffic Control Device (MUTCD) warning sequence, the same sequence on both sides of the road augmented with continuously flashing beacons, and a sequence of symbol signs. Data were collected covertly on random motorists by using a combination of inductance loops imbedded in the roadway and piezoelectric cable sensors on the road surface. Analysis of the data showed that (a) the most effective sign sequence was the MUTCD sequence augmented with flashing beacons, (b) the symbol sign sequence appeared to be at least as effective as the standard sequence, and (c) in no instance did the sign sequence appear to cause confusion or potentially dangerous abrupt motorist reaction.

Over the past several years interest has increased in the safety aspects of construction and maintenance activities undertaken when traffic is maintained. Specifically, How can the safety of both passing motorists and the workers be assured while traffic is maintained? Relative to the traffic, the key issues are to alert the approaching motorists to the activity to be encountered ahead and to reduce their speeds in advance so that they can stop safely if the need arises nearer, or in, the work area.

Previous research in this area has ranged from information needs (1), through evaluations of barriers and barricades (2,3), to questions of liability (4,5). Several state-of-the-art reviews are also available (e.g., King and others 6). The Federal Highway Administration's (FHWA) recent programs have been reviewed by Warren and Robertson (7). Within this context, two experiments were undertaken in 1977 to examine several alternative sign sequences for work areas in rural, two-lane situations.

EXPERIMENT IMPLEMENTATION

The original designs for the experiments, (6) were