EVALUATION OF WORK ZONE DESIGN FEATURES TO AID OLDER DRIVERS

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ABSTRACT

Work zones are estimated to account for 22 percent of roadway crashes and more than 1000 fatalities annually. Moreover, older road users have been overrepresented in work zone crashes. In an effort to mitigate the increased risks associated with older drivers in work zones along with mitigating other hazards for older drivers, FHWA published the *Highway Design Handbook for Older Drivers and Pedestrians*. This paper presents the results of research conducted to evaluate the effectiveness of selected work zone design guidelines recommended in the FHWA Handbook. Central to this research was a field study along a rural segment of Interstate 91 in western Massachusetts. Several design features were evaluated including: 1) lane closure/lane transition practices; 2) portable changeable message signing practices; and 3) channelization practices and delineation of crossovers/alternate travel paths. In addition, a focus group was conducted to gauge opinion of the work zone configuration employed.

The major findings of the evaluation are as follows: 1) Older drivers' speeds approaching the work zone tend to be lower and have more variance then other drivers; 2) older drivers have a less uniform merging pattern, making more conservative early merges; 3) portable changeable message signs in advance of work zones are effective in reducing speeds among older drivers and other drivers; and 4) The combination of the arrow board and static signage appears to provide drivers with information needed to make safe merges. The results of the field study suggest that these design features are effective at changing driver expectancy that may lead to increased safety within the work zone.

INTRODUCTION

Researchers at the University of Massachusetts evaluated the impacts of deploying design features and recommendations first published in the *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians* and finalized in Federal Highway Administration's (FHWA) *Highway Design Handbook for Older Drivers and Pedestrians*. This paper presents the results of the research evaluating the effectiveness of selected work zone design guidelines and features recommended in the FHWA Handbook. Central to this research was a field study along a rural segment of Interstate 91 in western Massachusetts. Several design features were evaluated including: 1) lane closure/lane transition practices; 2) portable changeable message signing practices; and 3) channelization practices and delineation of crossovers/alternate travel paths. In addition, a focus group was conducted to gauge opinion of the work zone configuration employed.

An underlying aim of this paper is to examine the extent to which design features and recommendations in the FHWA Handbook influence driver expectancy and affect driver behavior among all drivers, and especially older drivers. The research presented in this paper attempts to address the following questions:

1. How do portable variable message signs (VMS) and static warning signs influence driver behavior in terms of speed selection and lane changing maneuvers in advance of a work zone and does this driver behavior differ by age group?
2. How do arrow boards, taper drums, and barriers influence driver behavior in terms of speed selection and lane changing maneuvers from the merge point through the work zone and does this driver behavior differ by age group?

BACKGROUND

The National Transportation Safety Board [*2*] stated that the *MUTCD* guidelines concerning signing and other work-zone safety features provide more than adequate warning for a *vigilant* driver but may be inadequate for an inattentive or otherwise impaired driver. It is within this context that functional deficits associated with normal aging may place older drivers at greater risk when negotiating work zones.The work zone environment provides a unique set of challenges for the older road user, many of which are based on violations of driver expectancy. Driver expectancy is a key factor affecting the safety and efficiency of all aspects of the driving task [*1*].

Work zone traffic control strategies change the expectancy of the driver to prepare them for the downstream work zone. "What the driver expects on a road is greatly influenced by the 'roadway environment.' Studies have shown that what a driver experiences on a road section—presence or absence of traffic control devices, road surface type, condition and width, narrow bridges or culverts, is what the driver expects to continue for the next one to two kilometers" [*3*]. Among the most prevalent reasons for crashes in work zone locations are driver inattention and failure to yield the right of way which are frequently associated with older drivers who are likely to have slower responses when faced with unexpected situations. This supports the notion that older drivers might be particularly challenged when faced with a work zone.

Highway Design Handbook for Older Drivers and Pedestrians

The *Guidelines and Recommendations to Accommodate Older Drivers and Pedestrians* [*4*] led to the *Highway Design Handbook for Older Drivers and Pedestrians* [5]. These documents included highway construction and maintenance zones because of their potential to violate driver expectancy attempting to mitigate the increased risk associated with work zones with the use of traffic control devices. The guidelines also state that driver expectancy is "a key factor affecting the safety and efficiency of all aspects of the driving task." The guidelines reference many studies that conclude construction zones produce a higher crash rate then the same area before the zones were implemented.

The recommendations were written "to enhance the performance of diminished-capacity drivers as they approach and travel through construction/work zones, keyed to five specific design elements:

A. lane closure/lane transition practices
B. portable changeable (variable) message signing practices
C. channelization practices (path guidance)
D. delineation of crossovers/alternate travel paths
E. temporary pavement markings." [4,5]

The guidelines stress repeated and simple notice of the upcoming work zone. The work zone studied had advanced warning signage starting three miles from the work zone giving drivers the repeated and simple warning of the condition ahead, the location, and the required driver response.

Driver attention errors may be caused by impairments as well as distractions that are commonplace in the driving task. In the research leading to the formation of the guidelines, the most frequent contributing factor to crashes were driver attention errors and failure to yield right-of-way [*6*]. Failure to yield right-of-way may be caused by aggressive driver behavior or by failure to comprehend and react to a complex situation. "Research on selective attention has

documented that older adults respond much more slowly to stimuli that are unexpected [*7*], suggesting that older adults could be particularly disadvantaged by changes in roadway geometry and operations such as those found in construction zones" [*4, 5*]. The preferred choice is to have drivers make decisions in a situation where there is not the necessity to make a split second decision by providing enough advanced warning so that drivers will feel compelled to make an early merge or be prepared to make a merge when the channelizing devices make such a maneuver necessary. The differences in reaction time that were seen in the observation of traffic entering the work zone "are described by *complex reaction times* that are longer than reaction times in simple situations with expected cues. In Mihal and Barrett's analysis [*8*] relating simple, choice, and complex reaction time to crash involvement, only an increase in complex reaction time was associated with crashes. The relationship with driver age was most striking: the correlation between complex reaction time and crash involvement increased from r= 0.27 for the total analysis sample (all ages) to r = 0.52 when only older adults were included" [*4, 5*].

One explanation for some older drivers not heeding the many repeated and simple warnings of the work zone ahead could be the diminished visual capabilities of some older drivers. If the driver had limited vision due to cataracts or poor peripheral vision, it can be almost impossible for that driver to heed even repeated warning. In the cases of these drivers, the guidelines give more opportunities for the driver to heed the warnings; however, there is a chance that the driver may not receive the warning until the time that the work zone is approaching.

CASE STUDY: GREENFIELD, MASSACHUSETTS

Survey data collected by the American Association of Retired Persons (AARP) regarding driving concerns indicated that a significant percentage of respondents reported problems with accurately judging distances in construction zones [*9*]. These drivers reported additional problems in negotiating work zones including, but not limited to: congestion/traffic, lack of adequate warning, narrow lanes, lane closures and lane shifts, and difficulty staying in their lane.

The research effort evaluated the following design features:

A. Lane Closure/Lane Transition Practices
   1. Add consistent use of a flashing arrow panel at the taper for each lane closure.
   2. Use of a changeable message sign announcing lane closure.

B. Variable (Changeable) Message Sign Practices
   1. Consistent use of variable message signs as a traffic control method.

C. Channelization Practices
   1. Traffic cones will be 900mm high, with two bands of retroreflective materials totaling at least 300-mm wide for nighttime operations.
   2. Drums will be 450 mm x 900 mm with high brightness sheeting for the orange and white retroreflective stripes.

D. Delineation of Crossovers/Alternate Travel Paths
   1. Positive barriers will be used in transition zones and positive separation between opposing two-lane traffic throughout a crossover will be established.
   2. Channelizing devices in throughout transition areas will be spaced at one half the construction zone speed limit.

The data collected for this project addressed the following questions:

1. How do portable variable message signs (VMS) and static warning signs influence driver behavior in terms of speed selection and lane changing maneuvers in advance of a work zone and does this driver behavior differ by age group?
2. How do arrow boards, taper drums, and barriers influence driver behavior in terms of speed selection and lane changing maneuvers from the merge point through the work zone and does this driver behavior differ by age group?

The data collection and analysis presented below provides answers to these questions.

Data Collection Procedures

Data was collected in a location where there was a full lane closure on a long-term bridge replacement project along Interstate 91 in Greenfield, Massachusetts. Speed data was collected using LIDAR speed detection and pneumatic road tubes with automated data collection units. Video was recorded with high resolution cameras to approximate the age of the drivers traversing the work zone and to observe the maneuvers of the drivers. Older drivers were considered to be 60 years or older. Speed and video data were collected over a four-month period to observe the effects of the work zone features implemented and to assess the traffic patterns, vehicular movements, and driver behavior in the work zone area. The data collection plan included locations for each data collection period at which volume and speed data were collected.

The data collection locations, shown in Figure 1 selected with the evaluation of speed data in mind, have provided a large amount of data for evaluation purposes. In total, the data collected consists of: 78 Hours of video capturing vehicle movements, 708,505 individual vehicle speeds collected by the pneumatic tubes and automated data collection units, 2,000 vehicle speeds characterized by driver age in samples of 100 and 200 collected by LIDAR speed detection instruments. The data was collected at the following seven specific locations:

- Location 1 – 3 miles upstream of the activity area.
- Location 2 – 2 miles upstream of the work zone and after the location of the VMS.
- Location 3 – 1.5 miles north of the activity area.
- Location 4 – 1 mile from the work zone
- Location 5 - ¼ mile from the work zone.
- Location 6 - inside the taper.
- Location 7 - inside the activity area.

ANALYSIS AND RESULTS

Tables 1 and 2 summarize the major findings based on questions 1 and 2. These finding are based on statistical tests that provide insights on the changes in driver behavior. All tests were conducted at a 95% confidence level.

Figure 1: Aerial Photograph Showing Work Zone Strategy and Data Collection Locations.

Table 1. Summary of Results for Research Question # 1

Feature	Findings
VMS	• Speed was analyzed with 182 hourly samples. • The average speed drop was approximately 8.5 miles per hour after the VMS. • All 182 samples showed a significant difference in speed. • Older drivers' speeds were significantly different from other drivers. (Table 3) • The speed variances were shown not to be significantly different between the pooled samples (Table 4)
Static Signage	• Speed was analyzed with 159 hourly samples. • The speed change was negligible before and after the static signage. • All 159 samples showed no significant difference in speed. • The variances of the speeds were shown to be significantly different in the first set of samples but not the second set of samples. • Older drivers' speeds were significantly different from other drivers.

Table 2. Summary of Results For Research Question #2

Test	Findings
Arrow Board & Transition Taper	• Speed was analyzed with 159 hourly samples. • The average speed change was approximately 7.5 miles per hour in the first sample set and 6.1 miles per hour in the second sample set. • All 159 samples showed significant difference between the before and after the entrance of the taper. • Speed was analyzed by location from a sample of older drivers. Two samples were examined. • A speed of older drivers was shown to not be significantly different before and after the taper is in sight. • Older drivers speed selection was shown to be significantly different then other drivers. • The variances of the speeds were shown to be significantly different in all sets of samples.
Positive Protection	• Speed was analyzed with 182 hourly samples. • The average speed drop was approximately 3 miles per hour in the work zone as compared to in the taper. • Many samples showed a significant difference between the before and after the entrance of the activity area. • Some samples showed an increase of speed in the activity area. Those samples all occurred in the late night hours (12 AM to 4 AM). • Older drivers speed selection was shown to be significantly different then other drivers. • The variances of the speeds were shown not to be significantly different between the pooled samples.

The results show that the measures that were recommended by the Highway *Design Handbook for Older Drivers and Pedestrians* appear to have a positive effect on driver behavior

for all drivers as well as older drivers. The only test that was shown not to be significantly different was concerning the use of the static signage which was not a recommendation of the FHWA Design Handbook but is a standard part of temporary traffic control plans.

- 8.5% of sampled vehicles merged into the open lane before the taper was in sight.
- 17% of sampled vehicles maneuvered into the open lane from 1 mile to one half mile away from the taper.
- 30% of sampled vehicles maneuvered into the open lane between one half mile and one-quarter mile away from the taper.
- 44.5% of vehicles merged into the open lane within one quarter of a mile away from the merge point.

Table 3. Test of Differences in Mean Speed Before and After Design Features

T-test Results						
Design Feature	Speed			Samples	$T_{calculated}$	Significant[a]
	Before	After	Difference			
VMS	76.1	67.7	8.4	364	68.857	Yes
Static Signs	68.1	68.3	-0.2	112	-0.527	No
Static Signs	67.4	67.4	0	206	-0.057	No
Taper in Sight	66	61.5	4.5	286	20.9	Yes
Taper	68.3	60.9	7.4	112	9.24	Yes
Taper	67.4	61.3	6.1	206	25.082	Yes
Activity area	61.1	58.1	3	364	8.057	Yes
Test	Other	Older	Difference	# of Vehicles	$T_{calculated}$	Significant[a]
Age (At VMS)	66.7	60.3	6.4	100	5.21	Yes
Age (At Static Signs)	66.4	62.9	3.5	100	3.22	Yes
Age (At Static Signs)	65.2	62.9	2.3	112	1.663	No
Age (At Taper)	64.6	58.3	6.3	200	7.67	Yes
Age (At Activity area)	60.0	52.4	7.6	200	13.19	Yes

[a] Statistical significance was examined using the "t" test to compare average sample mean values of speeds

Table 4. Test of Differences in Variance in Speed Before and After Design Features

F-test Results						
Design Feature	Before	After	Difference	Samples	$F_{calculated}$	Significant[b]
VMS	1.364	1.425	-0.061	364	0.958	No
Static Signs	1.326	1.889	-0.563	112	0.702	No
Static Signs	1.244	1.846	-0.602	206	0.674	Yes
Taper in Sight	1.61	5	-3.39	286	0.323	Yes
Taper	1.89	33.61	-31.72	112	0.056	Yes
Taper	1.84	4.32	-2.48	206	0.427	Yes
Activity area	13.108	12.617	0.491	364	1.039	No
Test	Other	Older	Difference	# of Vehicles	$F_{calculated}$	Significant[b]
Age (At VMS)	21.7	26.7	-5	100	0.8136	No
Age (At Static Signs)	21.1	19.1	2	100	1.105	No
Age (At Static Signs)	19.1	34.2	-15.1	112	1.786	Yes
Age (At Taper)	32.1	17.08	15.02	200	1.88	Yes
Age (At Activity area)	9.29	22.8	-13.51	200	.4068	Yes

[b] Statistical significance was examined using the "F" test to compare values of speed deviation

FOCUS GROUPS

In order to gain perspective on how road users perceive the I-91 work zone, a focus group session was conducted. The focus group session consisted of 10 individuals who had driven through the work zone within the previous month. Participants represent a reasonable cross-section of the population and range in age from 28 to 76.

When asked if they encountered any problems when approaching a work zone, all ten participants responded YES. Driver 3 acknowledged that many drivers were very inconsiderate when merging into the work zone. Driver 1 added that many people seem to "not believe the signs" and wait until the last minute to merge into the work zone. This forces other drivers to be pushed into the median, as was the case with Driver 7. Driver 3 also mentioned that, when drivers in the open lanes fail to accommodate merging drivers, merging drivers end up driving in the shoulder of the road. When asked to comment on strategies that they believe would help the situation within the work zone, the participants gave a variety of suggestions. Many of the suggestions involved driver anticipation of the work zone including limiting VMS messages to one panel, broadcasting traffic delays on the radio, fixed arrow boards placed high enough to be seen, and ensuring that people know alternate routes. Driver 7 suggested that work be completed at night when driver volumes were low.

Several drivers also observed how individuals on the road deal with the current work zone conditions. Many drivers noticed a marked increase in speed of drivers hoping to get through the work zone as quickly as possible. Others just avoid the work zone altogether, especially during the weekend peaks. Other drivers perceive the drums as useful because they did not tip over as easily as the cones. Driver 3 noted that the presence of police cruisers causes him to slow down and he has noticed this effect on other drivers. Driver 10 added that she believes rumble strips will help slow individuals down when entering the work zone.

All of the drivers in the focus group agreed that the jersey barriers marking the work zone are "scary." Driver 4 added that the barriers lead to rubber necking. Driver 3 added that narrow passing zones are also "scary." The following questions were posed to the participants at the conclusion of the focus group session. The results of the questionnaire are presented in Figure 2.

Question 1: When approaching a work zone, do you encounter any challenges or problems?
Response: Yes or No
Question 2: To what extent do you find a variable message sign helpful?
Response: 1) Not Helpful 2) Somewhat Helpful and 3) Very helpful
Question 3: To what extent do you find the orange construction signs helpful?
Response: 1) Not Helpful 2) Somewhat Helpful and 3) Very helpful
Question 4: To what extent do you find the orange drums helpful?
Response: 1) Not Helpful 2) Somewhat Helpful and 3) Very helpful
Question 5: To what extent do you find the flashing arrow helpful?
Response: 1) Not Helpful 2) Somewhat Helpful and 3) Very helpful
Question 6: To what extent do you find the jersey barriers helpful?
Response: 1) Not Helpful 2) Somewhat Helpful and 3) Very helpful

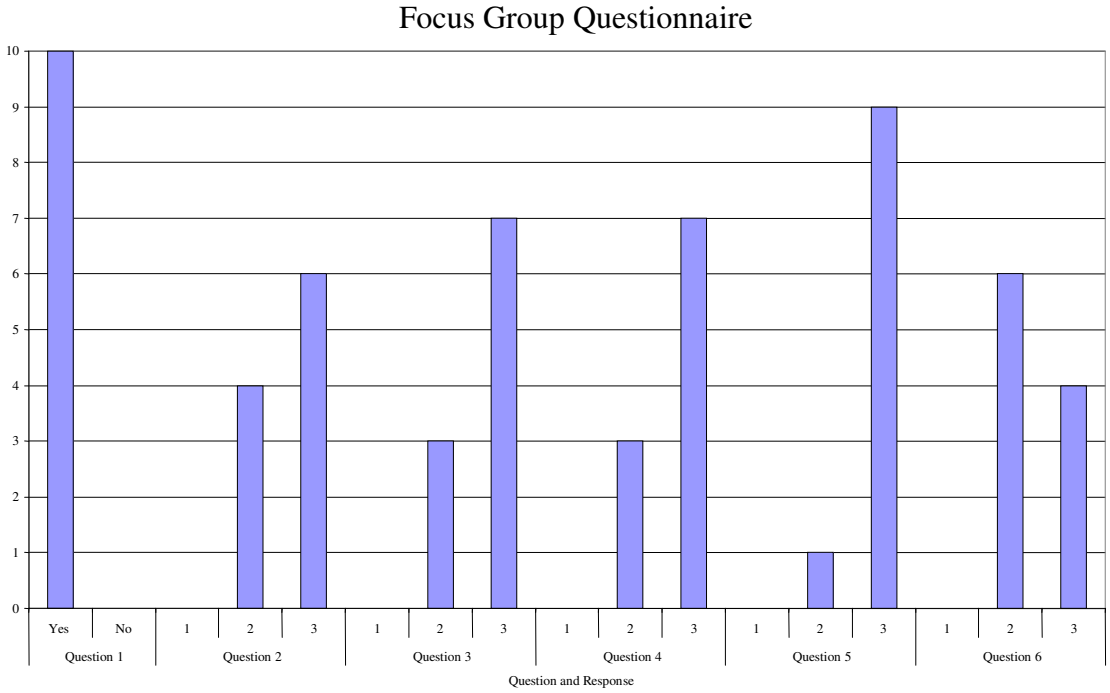

Figure 2: Focus Group Questionnaire Responses

Responses to question 1 show that drivers feel there are increased challenges when entering work zones. With this established, interest shifted to determine which safety measures were helpful to drivers navigating the work zone. Questions 2-5 show that drivers perceive that the measures implemented are working well. Participating drivers considered the orange drums the most helpful. As stated during the discussions, the drivers felt that the drums were not only indicative of the work zone but also had less of a tendency to tip over than the orange traffic cones. Driver 6 also commented that the variable message signs, while considered helpful, often

moved too slowly for drivers to be able to read the entire message. Question 6 suggests that drivers agree that the jersey barriers are helpful in navigating the work zone. Three of the ten participants rated the jersey barriers as very good. Drivers 6 and 8 commented that jersey barriers were sometimes a tight fit especially when traffic pushed them towards the barriers. Again, it should be noted that in the general discussion, the consensus among the group was that jersey barriers were "scary."

The focus group provided insight on the behaviors and concerns of drivers navigating the work zone. Driver behaviors observed in the video and speed data analysis reinforced by the focus group include:

- Aggressive Driver Behavior that Some Drivers Described as "Inconsiderate"
- The Driver Preference to the Drums and the Arrow Board
- The Overall Effectiveness of the Work Zone Strategy

CONCLUSIONS AND RECOMMENDATIONS

The evaluation of the effectiveness of work zone design features based upon the change in driver behavior is important because such evaluations may lead to a refinement of design guidelines and further recommendations to enhance the performance of diminished-capacity drivers as they approach and travel through work zones.

As part of the field evaluation, the following design features were assessed: 1) lane closure/lane transition practices; 2) portable variable message signing practices; and 3) channelization practices and delineation of crossovers/alternate travel paths. The major findings of the field evaluation are summarized below.

Evaluation of Lane Closure/Transition Practices

Lane closure/transition practices consisted of the use of a flashing arrow board, portable changeable (variable) message signs, and redundant static signs to help drivers navigate the work zone. The following conclusions were found in regards to these practices:

- The portable variable message sign appears to be an effective tool in drivers reducing speeds for drivers of all ages.
- The combination of the arrow board and static signage appears to provide most drivers the information needed to make a smooth merge.
- Some older drivers did not heed any of the warnings and made risky merges.
- The redundancy provided drivers with the necessary knowledge of the road conditions ahead to adjust their speeds at appropriate times.
- There is some question to the comprehension of the "dogleg" graphical merge sign.

Evaluation of Portable Variable Message Signing Practices

- Due to the location of the sign, two miles ahead of the work zone, it was difficult to measure lack of comprehension of the sign.
- Speeds dropped considerably after the VMS suggesting that there was high comprehension of the sign.
- The VMS had a message that appeared to be comprehendible and effective.
- Older drivers appear to adjust their speeds lower then other drivers.

Evaluation of Channelization Practices (Path Guidance)

- The drum channelization was effective at path guidance for drivers.
- Not once did a driver hit a drum in observation of the work zone.
- The positive guidance and enhanced retroreflectivity appeared to be effective at helping drivers navigate the taper.
- The deceased spacing appeared to give drivers a visual aid in navigating the horizontal curve in the taper.

Lessons Learned

The results of the field study suggest that the design features discussed above are effective in changing driver expectancy that may in turn lead to positive decision making by drivers and uniform driver behavior which tend to increase safety for all drivers on the roadway and especially for older drivers. For example, the observations made based on the field study support the notion that drivers changed their behavior as they encountered the different design features. The VMS had a significant effect on the driver speed selection. Drivers reduced their speed when encountering the VMS and continued their lower speed through the activity area. Drivers also maneuvered safely through the activity area due to the signage and the flashing arrow board, which was shown to be effective because of the successful navigation of drivers through the activity area. In the almost 80 hours of video collected at the site no drivers were seen hitting the taper drums.

While the research team recognizes that only limited crash data was available, the crash data appear to show no major change in the total number of crashes after the implementation of the work zone. It was also learned that observations from the focus group session supported the conclusions in the field study pertaining to the level of driver comprehension with the design features employed in the work zone. Based on these lessons, it is recommended that these design features be considered for incorporation into the work zone design guidelines employed in Massachusetts.

To assist in the quest for further knowledge and a better understanding of driver behavior in work zones it is recommended that advanced traffic analysis tools be developed with the specific characteristics of work zone design features and impacts in mind. Microsimulation and visualization techniques would help engineers design work zones more efficiently. An initial step in developing a microsimulation model of traffic conditions in work zones should focus on the development of an algorithm that deviates from conventional car following theory and driver behavior analysis and provides a new theory and structure for simulating expected driver behavior changes due to work zone features and other characteristics.

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