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Bulb-Loss Effects on Message Readability of Motorist-Information Matrix Signs

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This study addresses the question of the amount of bulb loss that can be tolerated in an electronic motorist-information sign before the message becomes illegible, misunderstood, or misinterpreted. A representative group of traffic-descriptor and advisory words and route numerals were displayed on a real-time matrix sign. Selected percentages (10 to 50) of bulbs were failed in a random pattern, and slides were taken of the resulting displays. These slides were shown to subjects who were instructed to respond by writing the word if it was legible. From these data, specifications for 85th and 95th percentile correct comprehension were determined for both familiar and unfamiliar motorists.

The object of motorist-information systems, whether audio, visual, static, or dynamic, is to transfer meaningful messages to the motoring public. These messages usually pertain to various tasks associated with vehicular maneuvers and may include information on route guidance, traffic conditions, or hazard warning. In displaying information by electronic variable-matrix signs, the legibility of the words displayed is the critical first step in the message transfer. A designated portion of motorists must be able to effectively read the words shown. If the display fails in this capacity, then it is useless, and message transfer cannot be achieved.

In the operational setting of an electronic display, one or more matrix bulbs in the sign may be lost, but drivers still be required to read the sign before it is deemed necessary that the bulbs be replaced. Manufacturers of these signs recommend that bulb replacement is warranted from a public-credibility standpoint at a level of failure of approximately 10 percent. No published information is available relating bulb failure in electronic matrix signs to message readability. Specifically, in traffic engineering, the criteria for bulb-replacement specifications have followed the lead of the sign manufacturers. Credibility has been the primary control. This study is an evaluation of the experimental question, "How high is the percentage of bulbs that can be lost before a message is misunderstood or misinterpreted?" The emphasis is on the measurement of human comprehension of traffic-condition and advisement words or route numerals of various lengths as displayed on a variable-matrix sign with various degrees of bulb loss.

RESEARCH METHODOLOGY

General Approach

The research approach selected for evaluating the effects of bulb loss in electronic matrix signs on message legibility consisted of laboratory testing by using visual simulations. Slides (35-mm) of a full-scale, trailer-mounted matrix sign were used to increase the fidelity and realism of the laboratory study.

A trailer-mounted matrix sign obtained from an electronics firm in Texas was used in the laboratory studies. The sign was composed of a 7 by 60 array of 25-W bulbs, 0.46 m (1.5 ft) high by 3.7 m (12 ft) long. Any message or symbol not exceeding about 10 characters on a single line could be displayed. Normally, a character was 5 bulbs wide. The sign was programmed by punched paper tape. Characters were formed by one vertical column of bulbs at a time; i.e., each column of holes on the tape corresponds to a column on the sign. The punched tape, therefore, is a replica of the characters that are displayed on the sign.

The laboratory study needed to be as real-world as possible, but experimentation with a large number of human subjects required expediation also. The media-master laboratory on the Texas A&M University campus is an excellent facility for experiments of this nature. The laboratory has remotely controlled environmental testing and evaluation capabilities for approximately 20 subjects.

The slide presentations were projected onto an opaque wall screen by the rear-projection method. Taped voice instructions and the slides were synchronized by a multichannel control system located in the projection room. The laboratory's subject-response evaluation capabilities were not used because written responses were required.

The subjects tested were selected from among residents of Bryan and College Station, Texas. The demographic characteristics of the 226 subjects were stratified as to age, sex, education, and distance driven per year as shown in Table 1. The characteristics of the population pool were formulated carefully to be representative of the national driving public (1).

Experimental Design

The physical dimensions of the single-line lamp-matrix sign used imposed an upper limit on word length of 10 characters. Four-character words were chosen as the lower limit. Words of fewer characters are generally prepositions, conjunctions, and adjectives and were not considered, as the interest in this study was primarily with one and two-word combinations. Five different sets of highway situation or advisement words were chosen for each word length. The words chosen were to be representative of those currently used in practice on the electronic matrix signs employed for traffic control and advisement (2). Thus, the independent variable was length of word and varied from 4 to 10 characters. Five different route numerals were also chosen, for a total of 40 words and numerals [(5 x 7) + (5 = 40)]. These words and numerals were subsequently divided into two groups or sets of 20 each (Table 2).

The individual word or numeral was presented statically on the electronic matrix sign with the various degrees of bulb failure simulated. Initial observations indicated that virtually no words or numerals were legible beyond a 50 percent bulb loss if they had not been shown previously at a lesser degree of bulb loss. For analysis purposes, all words or numerals were categorized as being exhibited to a driver in a familiar or an unfamiliar state. An unfamiliar word was defined as a word that had not been recognized and read at a lesser degree of bulb loss; a familiar word was the opposite. Five equal increments of bulb loss, ranging from 10 to 50 percent inclusive, were established.

As there is no real-world pattern to bulb loss, random bulb failure was simulated. A chart was plotted duplicating the actual 7 by 60 matrix on the sign, and by using column and row assignment within the matrix, bulb failures were generated from random-number tables until 42 positions (10 percent of 420 bulbs) had been selected. The corresponding bulbs were turned off by unscrewing. Each word or numeral was then displayed on the sign, and 16-mm slides were made. The same procedures were repeated for all percentages of bulb loss.

The slides of the highway situation or advisement words and the route numerals at the designated degrees of bulb failure were arranged randomly in two groups, A and B. Each group was then arranged into two series of presentations; one group in which the percentage of bulbs lost increased from 10 to 50 and the other in which the percentage of bulbs lost decreased from 50 to 10. Increasing bulb loss was assumed to represent the situation experienced by a familiar driver (a commuter or daily trip maker) when the word or numeral is first seen clearly legible and then gradually degraded over time until recognition is not possible. Decreasing bulb loss was designed to test unfamiliar drivers (tourists or infrequent trip makers) viewing the sign for the first time. Each series was measured separately to obtain the performance of both familiar and unfamiliar drivers. By averaging the ascending and descending series according to the psychophysical method of limits, it was also possible to offset errors of anticipation with errors of perserveration and obtain an average value that was best representative of driver recognition. The complete experimental design is summarized below.

Characteristic	Description
Independent variables	Characters per word and size of matrix (random), location of bulb failure (random), percentage of bulb failure in 10 percent increments
Criterion variables	Percentage of correct responses
Controlled conditions	Type of presentation (single word flash), presentation rate (3 s/word), response rate (10 s/word)
Statistical design	93 subjects, seven word lengths (4 to 10 characters/word) and one number length (4 characters—letters and numbers), 40 words/study, five levels of bulb failure per word (10 to 50 percent)

Experimental Administration

The subjects were tested in the media-master laboratory. All subjects were residents of Bryan or College Station and drawn from the population pool described in Table 1. The total number of subjects tested was 93; the groups viewing each order of slide presentation in both the familiar and unfamiliar states were approximately equal.

Each group of subjects was administered 100 words: 20 for each level of bulb loss. The words were given in a different random order at each bulb-loss level. From one to five subjects were tested at any given time. Taped voice instructions were played to the subjects, and an example slide was displayed onto the opaque wall screen by using the rear-projection method. Each word or numeral, with a given bulb loss, was projected on the screen for 3 s. (This time is a reasonable approximation of the visual exposure a driver would have on approaching a sign of standard legibility design at a normal operating speed.) The slide was then removed from the screen, and the subjects were given 10 s to completely and legibly write the word or numeral if such was discernible. This was ample time for a written response. Typical slides at various percentages of bulb loss are shown in Figures 1 to 10.

RESULTS

The criteria of correct response to bulb loss was that the subject must completely and exactly reproduce the word or numeral displayed; i.e., an incorrect response, or error, was recorded if the subject either omitted the word (numeral) completely or the reproduction was incorrect. The percentage-correct response for a given word length and percentage of bulb loss was calculated by using the formula, $[1 - (E/N)] \times 100$ percent, where E = total of errors (either omission or incorrect reproduction) and N = number of words presented at the designated bulb loss and word length.

Each group of words and numerals was analyzed for the ascending series and for the descending series series of percentages of bulbs lost. During the data reduction process, the two series were analyzed separately, representing the familiar and unfamiliar motorist conditions, and also evaluated in total. The percentages of bulbs lost versus the percentage-correct response versus the word lengths are summarized in Table 3.

Figures 11, 12, and 13 present plots of the percentage-correct responses versus the percentage of bulbs lost as a function of word length for the familiar, the unfamiliar, and the average motorist state respectively. The unfamiliar driver state represents the worst condition. The 85th and 95th percentile levels of correct response shown on these figures represent criteria commonly used in traffic-engineering practice as bases for design recommendations.

These data indicate the following:

Table 1. Demographic data of laboratory test subjects.

Characteristic	Percentage of Population	Characteristic	Percentage of Population
Sex		Junior high school grade	
Male	70.3	7	4.5
Female	29.7	8	7.2
Age, years		9	11.7
18 to 24	11.7	High school grade	
25 to 34	24.4	10	11.7
35 to 44	19.8	11	12.6
45 to 54	29.7	12	37.8
55 to 64	13.5	Years of college	
>64	2.7	1	19
Educational level		2	2.7
Elementary school grade		3	1.8
1	0	4	0
2	0.9	Kilometers driven per year	
3	0	0 to 16 100	42.6
4	0.9	16 100 to 32 200	42.6
5	3.6	>32 200	14.8
6	3.6		

Note: 1 km = 0.62 mile.

Table 2. Words used in bulb-loss study.

No. of Characters	Group A	Group B
4	Slow, toll, road	Lane, exit
5	Truck, route	Alert, wreck, merge
6	Bypass, access, reduce	Bridge, median
7	Blocked, traffic	Freeway, stalled, vehicle
8	Accident, entrance, pavement	Downtown, junction
9	Condition, alternate	Diversion, hazardous, collision
10	Congestion, expressway, visibility	Restricted, prohibited
Numerals	I-415, US-23	HWY-6, I-270, US-39

Figure 1. Four-character word at 10 percent bulb failure.

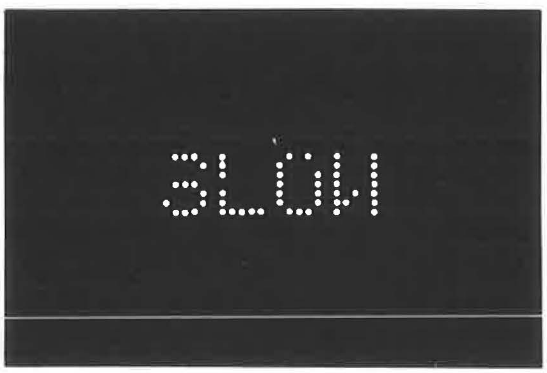


Figure 2. Four-character word at 50 percent bulb failure.

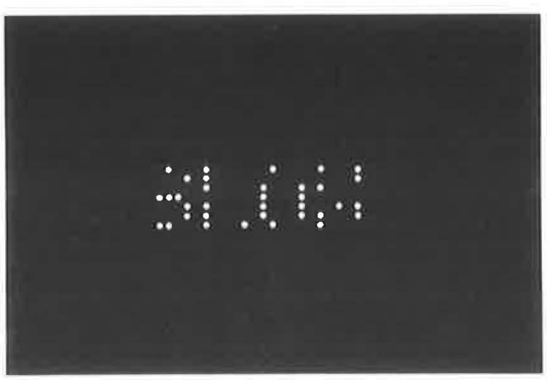


Figure 3. Six-character word at 10 percent bulb failure.

Figure 4. Six-character word at 50 percent bulb failure.

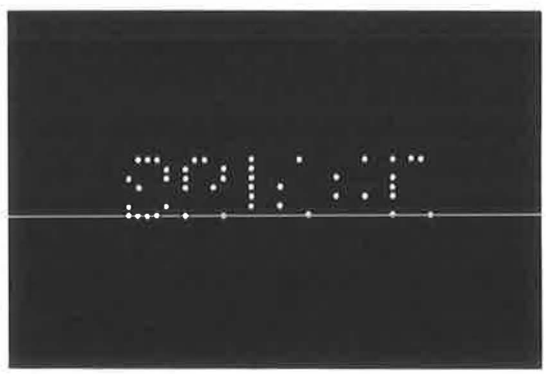
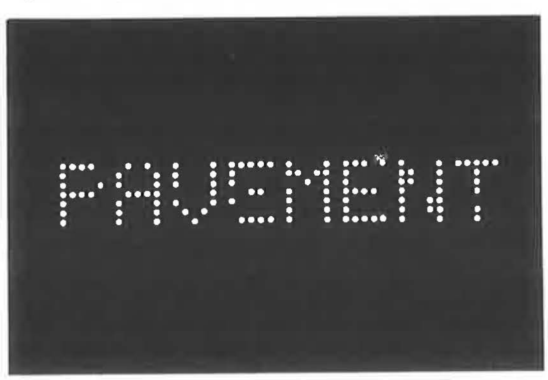


Figure 5. Eight-character word at 10 percent bulb failure.



1. At all levels of bulb loss, the unfamiliar state resulted in poorer recognition than the familiar state. This was expected because the familiar subject had previously seen the words at lower loss levels and, hence, needed fewer parts of the words to recognize them at higher levels of bulb loss.

2. The length of the word had no systematic relationship to the percentage-correct response for the familiar state (Figure 11), but for the unfamiliar state, the longer words were somewhat more difficult to recognize than the shorter ones (Figure 12).

At first the relationship between word length and performances seemed to be inconsistent with other studies of word recognition that indicate that words having a larger number of characters can be read at a higher

Figure 6. Eight-character word at 50 percent bulb failure.

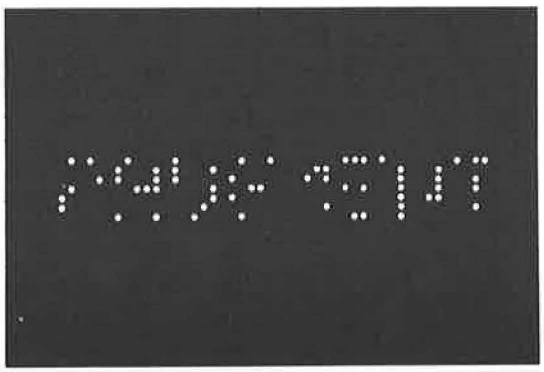


Figure 7. Ten-character word at 10 percent bulb failure.

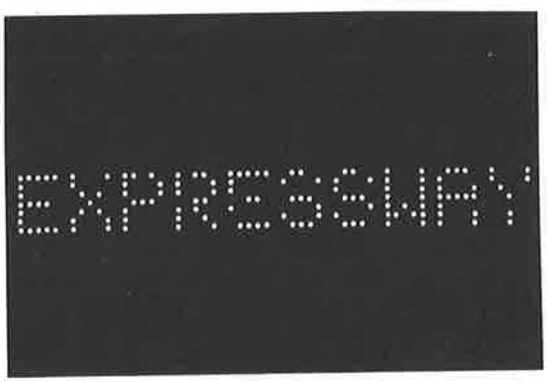


Figure 8. Ten-character word at 50 percent bulb failure.

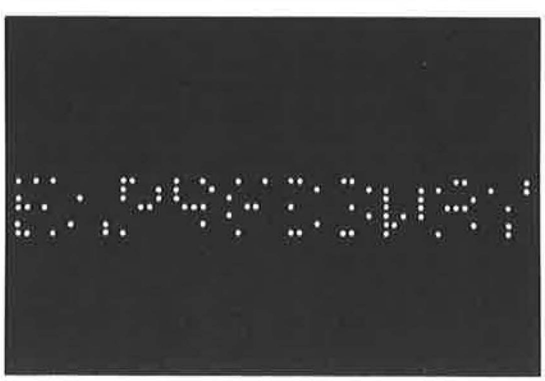


Figure 9. Route numeral at 10 percent bulb failure.

Figure 10. Route numeral at 50 percent bulb failure.

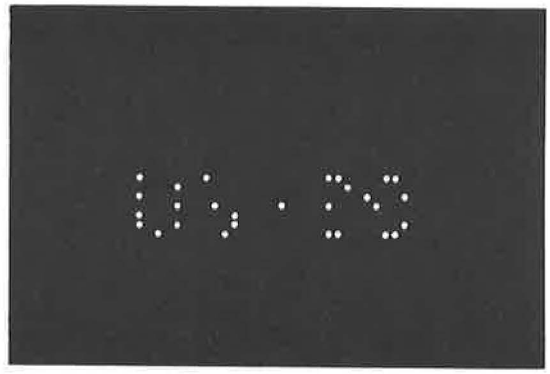


Table 3. Percentage of bulb loss versus percentage of correct responses versus word length.

Characters per Word	Bulb-Loss Percentage	Motorist Condition Familiar	Unfamiliar	Avg
4	10	99	96	96
	20	98	91	94
	30	97	79	88
	40	91	51	69
	50	80	29	54
5	10	100	97	99
	20	99	92	96
	30	98	77	87
	40	92	37	61
	50	79	10	42
6	10	98	94	96
	20	98	78	88
	30	96	57	76
	40	91	29	59
	50	79	13	46
7	10	100	94	97
	20	99	89	94
	30	98	82	90
	40	93	63	76
	50	83	28	47
8	10	98	93	95
	20	96	80	84
	30	93	65	78
	40	86	38	62
	50	78	9	44
9	10	97	88	91
	20	96	70	84
	30	95	50	74
	40	88	26	54
	50	82	7	40
10	10	99	92	95
	20	98	78	88
	30	95	59	77
	40	85	34	55
	50	78	12	49
Numerals	10	100	94	97
	20	97	90	93
	30	96	70	82
	40	84	40	60
	50	59	8	35

percentage of degradation than can words having fewer characters. For example, affirmative is more easily recognized than yes. The better recognition of shorter words here may be due to their higher frequency of occurrence in the traffic vocabulary.

The percentages of bulb loss associated with the 85th and 95th percentile criterion performance levels are summarized in Table 4.

Many different viewpoints can be taken in arriving at conclusions in this study. For the freeway commuter or the familiar driver, bulb losses of approximately 45 and 30 percent respectively, corresponding to the 85th and 95th percentile design levels, are tolerable before deterioration reaches a point where legibility is a problem. Of course, poor appearance and possible loss of credibility may justify bulb replacement before this level of loss develops.

Figure 11. Bulb loss versus correct response as a function of word length in a familiar motorist state.

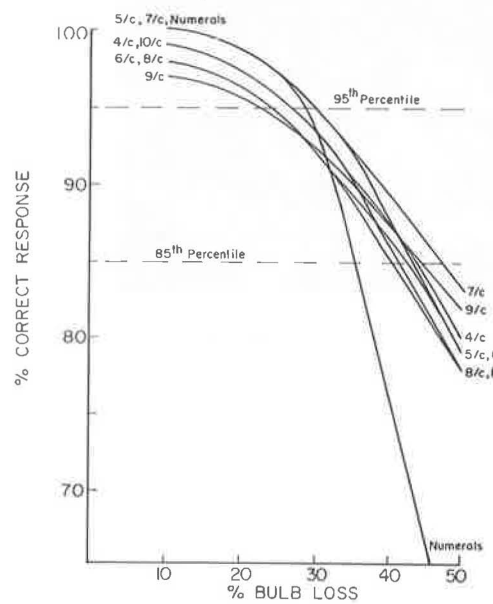
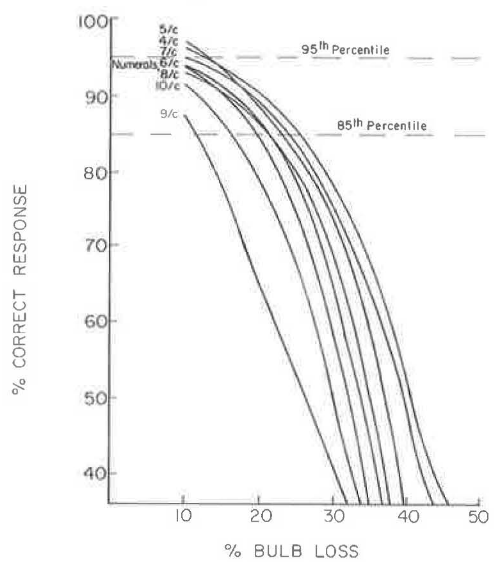


Figure 12. Bulb loss versus correct response as a function of word length in an unfamiliar motorist state.



However, for the unfamiliar motorist, the tolerable bulb-failure percentages are approximately 20 and 10 percent for the 85th and 95th percentile design levels. These loss percentages are consistent with the appearance criterion and the manufacturer's suggested bulb-replacement specification of 10 percent loss. The dependence of the unfamiliar driver on dynamic signing information is also an argument in favor of the 10 percent criteria. The tolerable bulb-loss percentages for the average-motorist state [approximately 30 percent (the 85th percentile) and 15 percent (the 95th percentile)] maybe more representative of the normal stratification of familiar and unfamiliar motorists in the driving public. However, at the 85th percentile design levels, the appearance is questionable; thus, bulb loss should not exceed 10 percent if both sign readability and credibility are to be maintained.

Most dynamic motorist-information systems display messages involving two-word combinations on one line, and this must also be taken into consideration. A message may consist of two words of different lengths for which different percentages of bulb loss are tolerable. The poorest performance measured by recognition of a word of a specified character length is the critical factor in the message transfer. For example, as shown in Table 4, for the familiar state, route numeral performance, from a standpoint of bulb failure versus legibility, was 36 percent at the 85th percentile design level, and nine-character words performed at 23 percent for

Figure 13. Bulb loss versus correct response as a function of word length in an average motorist state.

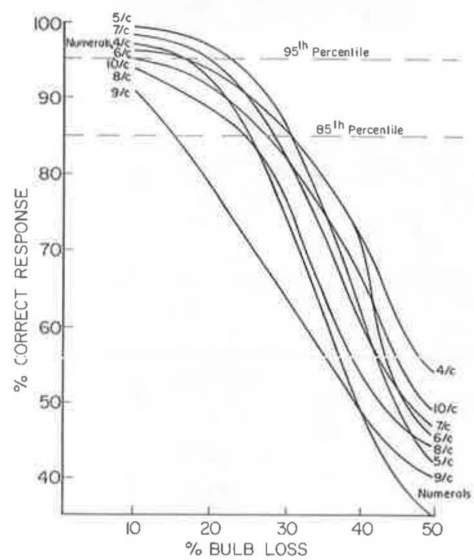


Table 4. Percentage of bulb loss associated with 85th and 95th percentile criterion performances as function of word length.

No. of Characters	Bulb-Loss Percentage: Familiar 85th	Familiar 95th	Unfamiliar 85th	Unfamiliar 95th	Avg 85th	Avg 95th
4	45	28	23	11	31	17
5	44	31	21	12	32	21
6	43	25	20	8	31	17
7	49	31	21	10	30	20
8	41	25	20	6[a]	25	6[a]
9	46	23[a]	10[a]	8	16[a]	7
10	42	28	15	7	28	10
Numerals	36[a]	31	18	8	26	17
Avg	44	28	18	8	28	14

[a]Maximum bulb loss tolerable for criterion performance regardless of length.

the 95th percentile design level. The corresponding lowest bulb-loss percentages were 10 and 6 percent by nine and eight-character words respectively for the unfamiliar state and 16 and 6 percent also by nine and eight-character words respectively for the average state. These performances should be considered in bulb replacement for multiword messages.

Route numerals pose special problems of concern with degradation and legibility. For an average state, unsatisfactory performance is exhibited for the 85th percentile correct-response level beyond a bulb loss of approximately 20 percent and for the 95th percentile level beyond a bulb loss of approximately 10 percent. This indicates that the tolerable bulb-loss criteria for both legibility and appearance of route numerals are closely related. Special bulb specifications should be considered when using messages with route numerals. Numbers are harder to recognize than words because there is no sequential redundancy, i.e., knowing one number does not help a driver to anticipate the next, but the verbal language does permit filling in missing or distorted letters.

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions and recommendations concerning the effects of bulb loss on the legibility of words, route numerals, and the messages displayed on electronic variable-matrix signs are suggested by the results of this study. Some are as follows:

1. For 85 or 95 percent of traffic-related words to be correctly read, the percentage of bulb failures must not be greater than that shown below.

Motorist State	Correct-Response Criteria 95	85
Unfamiliar	8	18
Average	14	28
Familiar	28	44

2. Bulb-replacement criteria for a specified level of legibility performance vary with the motorist state.
3. At the 85th percentile performance criterion, for both familiar and unfamiliar-motorist states, bulb replacement will probably be controlled by appearance (e.g., 10 percent bulb loss) rather than by legibility. The matrix sign may be legible at a level of bulb loss at which the overall appearance is unacceptable.
4. Only in the unfamiliar state and at the 95th percentile does the bulb-replacement criterion approach that designated by sign manufacturers (approximately 10 percent).
5. Messages with route numbers are read with difficulty at bulb failures beyond approximately 15 percent. Special considerations are advised for route numeral bulb replacement specifications.

In summary, it is emphasized that the manufacturer's specifications for bulb replacement should be adhered to beyond a 10 percent failure rate. There is also a need to further evaluate the results of this study and how they relate to real-world situations. On-site testing and a study of the legibility performance of three-character words and multiword combinations are justified.

ACKNOWLEDGMENT

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Abridgment

Survey of Motorist Route-Selection Criteria

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Other research and surveys have focused on the types of traffic descriptors motorists prefer (1, 2, 3) and the specific techniques for displaying such information in real-time.

It is also necessary to ask the motorist directly certain questions about his or her typical driving habits—the routes taken and the reasons for selecting these routes when he or she is familiar with other routes. The daily commuter makes a route-choice decision in traveling to and from work, and the intercity traveler makes