LEGIBILITY DISTANCES OF 9 TO 18 INCH CHARACTERS FOR LIGHT-EMITTING DIODE (LED) DYNAMIC MESSAGE SIGNS ON ARTERIAL ROADWAYS

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This report documents the results of a legibility study of 9-inch and 10.6-inch characters on dynamic message signs (DMS) for use on arterial roadways. The study, conducted at Dallas, TX, consisted of 60 Dallas residents (demographically balanced with respect to age and education) who drove a test vehicle as they approached DMSs with one of the above two character heights. Study administrators recorded the distance from the sign at which the participant could correctly read a three-character word. Data were recorded for three trials on each of the three character heights for each participant. Data were collected during daylight (sun overhead) and nighttime conditions. The 85th percentile legibility distances for each character height were used to estimate available viewing times under various approach speeds. These available viewing times dictate the units of information that can then be presented on a DMS of a particular character size. Based on the results of the analysis, researchers recommend that the City of Dallas continue to utilize 12-inch characters for DMS on their arterial roadways. Even then, the amount of information that is presented on the DMS should be limited to 3 units of information or less under nighttime viewing conditions. Agencies should consult other references, as documented within this report, regarding proper message design principles, appropriate abbreviations to use, etc. prior to designing and implementing an arterial street DMS system.

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LEGIBILITY DISTANCES OF SMALLER CHARACTER LIGHT-EMITTING DIODE (LED) DYNAMIC MESSAGE SIGNS FOR ARTERIAL ROADWAYS

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DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the City of Dallas. This report is not intended to constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Dr. Gerald L. Ullman, P.E. #66876.

ACKNOWLEDGEMENTS

This study was sponsored by the City of Dallas through an interagency agreement with the Texas Transportation Institute. Ms. Elizabeth Ramirez, P.E. of the City of Dallas served as the project director of the research. The authors would like to thank Ms. Ramirez and the rest of the staff of the Traffic Management Center at the City of Dallas who provided critical guidance and assistance during the conduct of this study. The authors would also like to thank Daktronics, Inc. and Precision Solar, Inc. for loaning DMS with smaller characters to the City of Dallas and TTI in order to conduct the study. The assistance of their staff in providing the signs and necessary technical support are likewise appreciated. Finally, the actual data collection activities at Fair Park in Dallas were supported by a number of staff with the TTI-Arlington office. Their contributions to the successful conclusion of this study are gratefully acknowledged.

TABLE OF CONTENTS

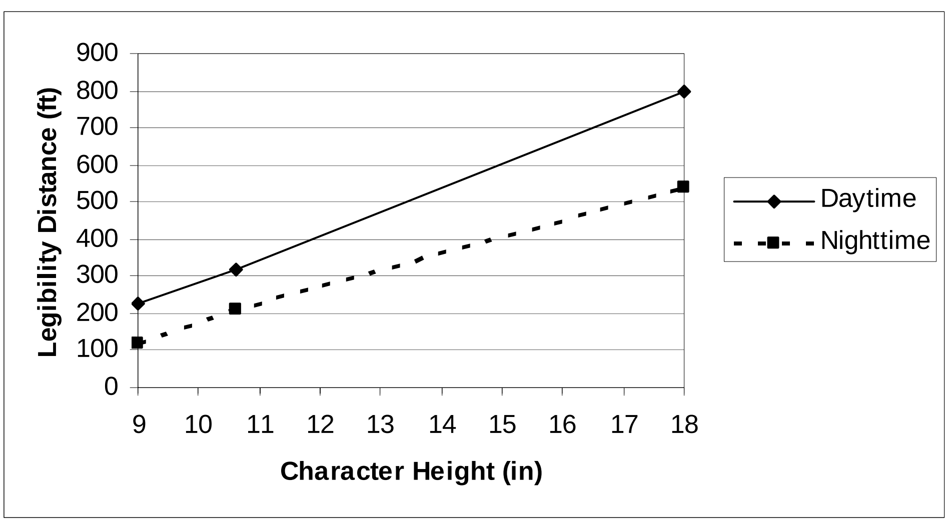
EXECUTIVE SUMMARY

Dynamic message signs (DMS) provide transportation agencies a direct communication link to the motoring public. The amount of time that a motorist has to read a DMS depends primarily on the size of the characters used to create the message. Generally, the larger the character, the farther away the message can be read by motorists, and so the longer the amount of time they have to read the sign. Whereas legibility distances for the current driving population have been developed for 18-inch DMS characters used on high-speed roadways, similar distributions have not been determined for smaller DMS characters that might be used on slower-speed (i.e., arterial) roadways. Therefore, the City of Dallas sponsored a study by the Texas Transportation Institute to accomplish the following:

1. Determine daytime and nighttime legibility distances of 9-inch and 10.6-inch light-emitting diode (LED) DMS characters based on subject drivers who are representative of the actual driving population in the City of Dallas.
2. Develop recommendations as to the proper character height to use for DMSs on arterial streets in Dallas.
3. Develop recommendations on how the typical messages to be used on the DMS might be reduced and thus require less reading time, legibility distance, and possibly smaller character heights.

TTI researchers conducted legibility studies using Dallas residents driving an instrumented vehicle at the Dallas Fair Park parking lot and adjacent roadways. The distances from the signs where participants correctly read three-character words on 9-inch and 10.6-inch character DMSs were recorded under both daytime and nighttime viewing conditions. All total, 60 Dallas residents participated in the study.

The legibility data from this study were combined with findings from a previous study of 18-inch DMS characters to develop a relationship between character height and 85th percentile legibility distance under both daytime and nighttime viewing conditions, as shown below.



Research has shown that motorists require two seconds of reading time for each unit of information on a DMS, and can only process a maximum of four units of information from a DMS message. This implies that drivers need 8 seconds of reading time to adequately read and process a four-unit message, 6 seconds to read a three-unit message, etc. (*1*) A unit of information is an answer to a basic question such as the problem on the roadway, the location of the problem, etc.

Researchers then converted these distances into the equivalent amount of time that a motorist would have available to read a message while approaching the DMS at various operating speeds, and converted these times into equivalent units of information that can effectively be displayed on a sign of that character size. The number of units of information that can be displayed on DMSs of different character sizes is shown below.

Maximum Units of Information That Can Be Effectively Displayed on the DMS

Character Height (in)	Average Roadway Approach Speed, Daytime Conditions				Average Roadway Approach Speed, Nighttime Conditions			
	30 mph	35 mph	40 mph	45 mph	30 mph	35 mph	40 mph	45 mph
9	3	2	2	2	1	1	1	1
10.6	4	3	3	2	2	2	2	2
12	5	4	4	3	3	3	3	2
18	5	5	5	5	5	5	5	4

Not recommended

Most messages that the City of Dallas desires to display contains at least three units of information even after reducing the typical messages using various human factors techniques. Therefore, the researchers recommend the following:

- The City of Dallas should continue to utilize DMS with 12-inch high characters on its arterial roadways. This size character allows the display of 4-unit messages during the day on roadways with average operating speeds up to 40 mph. However, the messages should be limited to only 3 units of information at night.
- The City of Dallas should not use 9-inch DMSs on arterial roadways. Even on roadways with average operating speeds as low as 30 mph, the legibility distance provided by 9-inch characters allows for no more than one unit of information to be displayed at night. This is insufficient for essentially all types of messages that the City of Dallas desires to display.
- The City of Dallas should also not use 10.6-inch character DMS on arterial roadways. Although this size character would provide adequate legibility and viewing time to accommodate 3- and 4-unit messages during daylight conditions on most roadways, only 2 units of information could effectively be displayed on a sign of that character size during nighttime conditions. Very few of the typical messages of interest to the City of Dallas can be effectively reduced to that size.

INTRODUCTION

STATEMENT OF THE PROBLEM

A dynamic message sign (DMS), also termed a changeable message sign (CMS), provides a transportation agency a direct communication link to the motoring public. Human factors studies conducted over the past 30 years have helped define the maximum amount of information that can be presented to motorists via a DMS, the information elements that are most important to motorists, the proper order of the information elements, the proper way to abbreviate certain words and phrases, and other important message design principles (*1*-*5*). Ultimately, messages designed according to these principles provide the most important information in the most effective format possible, as long as motorists are given adequate time to read and process the message.

The amount of time that a motorist has to read a DMS depends primarily on the size of the characters used to create the message. Generally, the larger the character, the farther away the message can be read by motorists, and so the longer the amount of time they have to read the sign. For freeway applications, previous DMS legibility studies have determined that 18-inch characters are necessary to provide drivers enough reading time while they are driving at freeway (55 mph or higher) speeds (*1*).

Whereas both research and field experience have proven that freeway DMS applications require the use of 18-inch characters on the signs, character height requirements for slower speed arterial street applications have received little or no research attention. Certainly, slower travel speeds on arterial streets imply that characters smaller than 18 inches high may provide adequate reading times of a DMS message. Unfortunately, the actual legibility distance of smaller DMS character heights have not been determined through objective research methods using actual drivers. Furthermore, evidence exists which suggests that the relationship between legibility distance and character height is not directly proportional. In other words, a 25 percent reduction in character height does not simply equate to a similar 25 percent reduction in legibility distance (*6*). Without actual legibility distance data, a risk exists of selecting a DMS character height that is too small to allow motorists to adequately read the messages that an agency desires to display on the sign, leading to potential safety and traffic flow problems on the roadway.

FUNDAMENTALS OF DMS OPERATIONS

Information “units” serve as the fundamental building blocks of DMS messages. Each unit of information can be thought of as an answer to a question the motorist would like to have answered in order to make a better driving decision. Examples of informational units in a DMS message are illustrated below:

• What is the problem?	ACCIDENT	1 unit
• Where is the problem?	AT ABRAMS	1 unit
• How many lanes are closed?	2 LANES CLOSED	1 unit

Research has shown that motorists require two seconds of reading time for each unit of information on a DMS, and can only process a maximum of four units of information from a DMS message while traveling at typical freeway speeds (five units is acceptable under low-speed operating conditions). This implies that drivers need 8 seconds of reading time to adequately read and process a four-unit message, 6 seconds to read a three-unit message, etc. (*1*).

Whereas the amount of information presented on a DMS defines the required reading time, the legibility distance of the characters on the sign and the travel speed of the approaching motorist define the amount of time that is actually available for reading the message. If the time available to read the sign is less than the amount of time required, operational and safety problems can occur. For example, motorists may slow significantly as they approach the sign in order to give themselves more time to read, which may create large speed differentials between them and any following vehicles. Motorists may also focus more attention on the DMS and less attention to other traffic control devices, traffic, and even the operation of their own vehicle. Even if the motorist does not commit any of these behaviors, it is likely that he or she will not obtain all of the information provided on the sign, leading to confusion as to the full meaning of the message and to incorrect or inefficient driving decisions.

Given that agencies have only limited control over vehicle speeds operating on a roadway, it is the design of the DMS that must be adjusted so as to provide legibility distances that equate to sufficient reading times at the prevailing traffic speeds. Figure 1 illustrates the relationship between approach speed of a vehicle and the legibility distance necessary to provide 8 seconds of viewing time (i.e., enough to read a four-unit message).

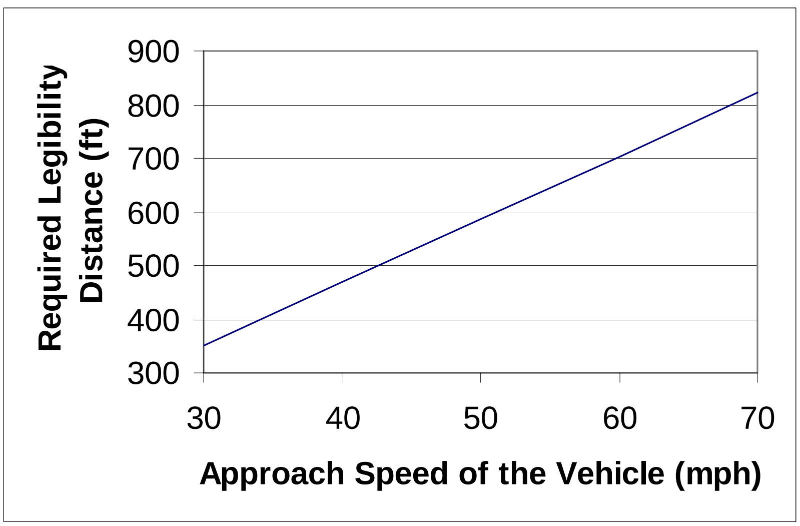


Figure 1. Legibility Distance Required to Provide 8 Seconds Reading Time for a Given Vehicle Approach Speed.

The values shown in Figure 1 represent best-case viewing conditions where the motorist can continue to view the message up until the point they pass the sign. Generally speaking, a DMS mounted directly over the travel lane comes closest to this best-case condition. If the DMS is mounted off to the side of the travel lanes, additional legibility distance is required to account for the fact that the message will become unreadable prior to actually reaching the sign location itself (as the sign appears to move farther and farther outside of the motorist's primary cone of vision). Figure 2 illustrates the additional legibility distances that are required as a function of the lateral distance that the DMS is located from the travel lane.

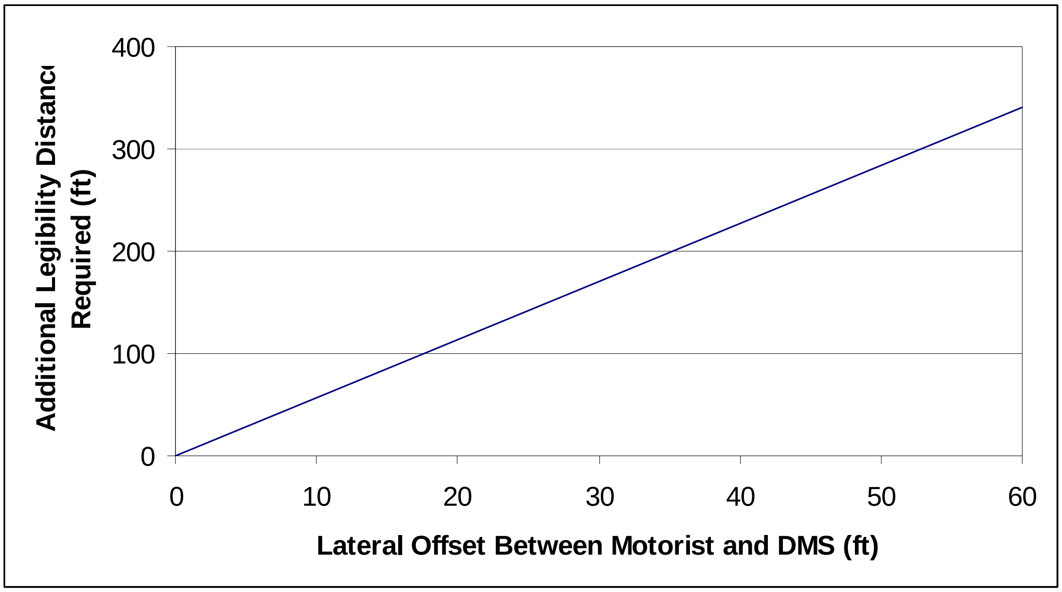


Figure 2. Additional Legibility Distance Required for Lateral DMS Offset.

Once the total legibility distance needed to provide adequate reading time for the DMS is known, the height of the characters needed on the sign to achieve such legibility distances can be determined. As part of this determination, individual differences in vision capabilities amongst drivers requires that a character size be selected which accommodates as much of the driving population as is practical. For example, Figure 3 illustrates the typical capabilities of motorists with regard to legibility distance of 18-inch DMS light-emitting diode (LED) characters under both daytime and nighttime conditions *(7)*. It is common in the highway industry to try and accommodate up to 85 percent of the driving population. In Figure 3, this corresponds to a daytime legibility distance of approximately 800 feet, and a nighttime legibility distance of about 600 feet.

Whereas these legibility distance distributions for the current driving population have been developed for 18-inch DMS characters, similar distributions have not been determined for smaller DMS characters. Limited laboratory data suggest that legibility distances of light-emitting DMSs are likely not directly proportional over all character heights *(6)*. Previously, it was not possible to estimate the available reading times provided by these smaller characters. Therefore, the legibility studies reported on in the remainder of this report were conducted to provide such data.

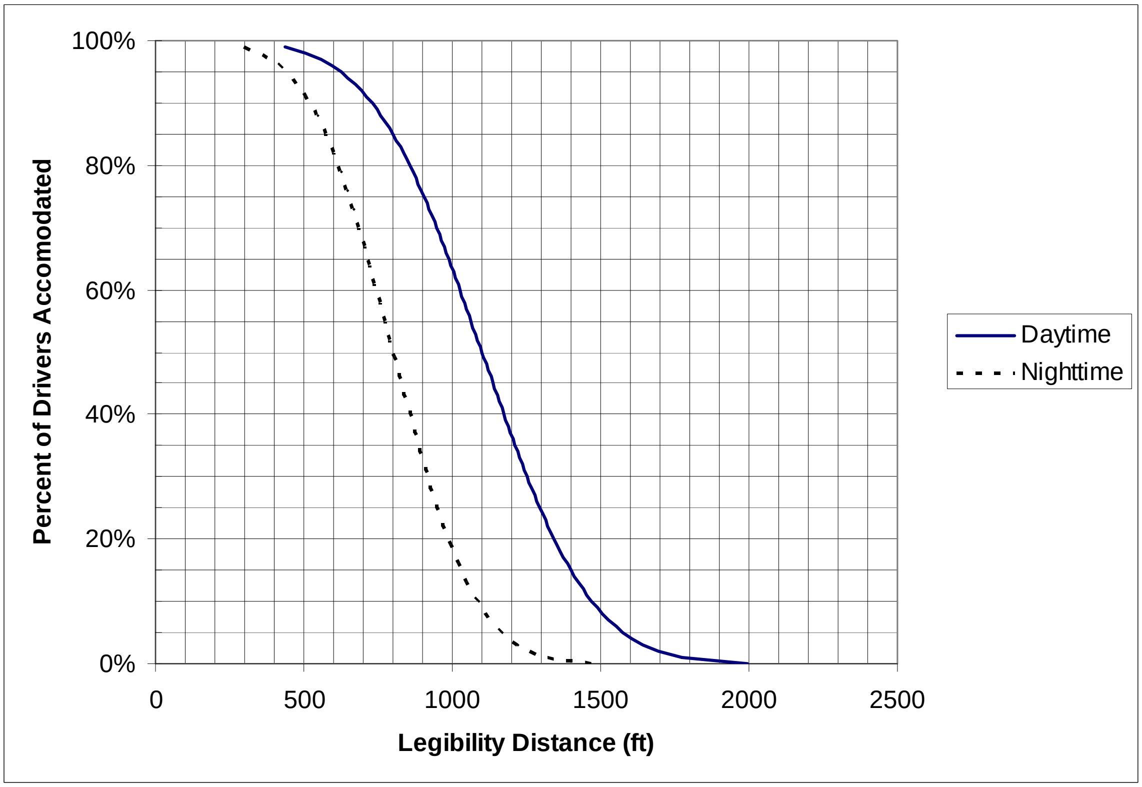


Figure 3. Distribution of Legibility Distances for 18-inch DMS LED Characters (*7*).

STUDY OBJECTIVES

The objectives of this study were as follows:

1. Determine daytime and nighttime legibility distances of 9-inch and 10.6-inch LED DMS characters based on subject drivers who are representative of the actual driving population in the City of Dallas;
2. Develop recommendations as to the proper character height to use for DMSs on arterial streets in Dallas; and
3. Develop recommendations on how the typical messages to be used on the DMS might be reduced and thus require less reading time, legibility distance, and possibly smaller character heights.

STUDY METHODOLOGY

OVERVIEW

A DMS legibility study was conducted at a parking lot of the Fair Park and on the adjacent arterial streets in Dallas, Texas during March 2004. Two portable DMSs borrowed from vendors were brought onto the parking lot at Fair Park that displayed words with character heights of 9 and 10.6 inches, respectively. Legibility distances for a 12-inch character sign were then extrapolated between these data and data from the previous legibility study of an 18-inch character LED DMS *(7)*.

A dynamic driving legibility study was conducted of each test DMS. The study was designed so that each study participant would approach and pass both signs three times, each time reading a different word, for a total of nine observations. At the conclusion of the three passes, the participant would make one final pass and drive towards either the 9-inch or the 10.6-inch character sign displaying a full four-unit text message. After passing the sign, the participant would be asked to recall certain pieces of information from the message. In that way, the level of driver comprehension and retention of that message on that particular sign could be estimated.

DESCRIPTIONS OF THE DMSs

Both the 9-inch and the 10.6-inch character DMS borrowed from vendors for use in this legibility study were specially manufactured to allow testing of both three-character words and a full sample DMS accident message typically utilized by the City of Dallas. The displays of both utilized a rectangular pixel consisting of four super-bright amber (reported wavelength approximately 590 nanometers) light-emitting diodes (LEDs), one on each corner. These pixels measured 0.9375 inches high by 1.125 inches wide. The spacing between pixels (center-to-center) was 1.33 inches for the 9-inch character sign, compared to 1.6 inches for the 10.6-inch character sign.

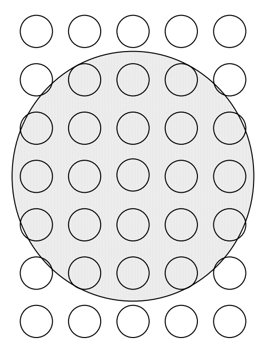
The physical dimensions of each sign and the stroke-width-to-character-height ratio calculated for each sign are summarized in Table 1. Previous DMS research of simulated characters on a computer screen suggested that legibility distances are fairly consistent and maximized when this ratio is approximately 0.1 to 0.18 *(6)*. As illustrated in Table 1, the ratios for the DMSs tested in this study fall within this acceptable range.

Table 1. DMS Dimensions

Character Height	Pixel Shape	Pixel Size	Pixel Spacing	Stroke-Width-to-Character-Height
9-inch	Rectangular	0.9375-in high, 1.125-in wide	1.33 inches	0.13
10.6-inch	Rectangular	0.9375-in high, 1.125-in wide	1.6 inches	0.11

To maintain comparability across signs, TTI researchers utilized a standard fixed font where each character was created out of a 5-by-7 pixel matrix. This type of font has been shown to also provide maximum legibility distances in most previous legibility studies (albeit that such studies were generally performed on larger character height signs) (*6*).

Prior to initiating the actual legibility studies, researchers measured the character luminance of both the 9-inch and 10.6-inch DMS using a Minolta luminance meter under both daytime and nighttime viewing conditions to insure that the signs fell within acceptable ranges. Researchers positioned themselves at a distance from each sign such that the measurement aperture (1 degree of arc) circumscribed the interior of a 5x7 character as shown in Figure 4. Luminance measurements were taken of the character with all pixels illuminated and all pixels off. Character contrast ratios were then calculated for daytime viewing conditions and compared to recommended values of between 5 and 50 (*6*). Nighttime character luminance values were likewise measured and compared to recommended values of between 30 and 150 candelas per square meter (cd/m^2) (*6*). As illustrated in Table 2, both the 9-inch and 10.6-inch DMS met daytime luminance requirements, but were slightly high on nighttime luminance levels. Researchers decided that these levels were acceptable for measurement purposes, as the values were still well below thresholds of discomfort or disabling glare (*6*).



5x7 Character Module

Figure 4. Luminance Meter Aperture Setting for Measuring Character Luminance.

Table 2. Character Luminance Levels and Contrast Ratios

Character Height	**Daytime Character Luminance** (cd/m^2)			**Nighttime Character Luminance** (cd/m^2)
	Pixels On	**Pixels Off**	**Contrast Ratio**	
9-inch	5750	188	30	439
10.6-inch	6330	471	12	237

DESCRIPTION OF THE TESTING FACILITY

The locations of the parking lot and sign locations to be tested in the legibility studies are illustrated in Figure 5. The 9-inch and 10.6-inch DMS were positioned laterally across from each other on the long parking lot that parallels the railroad tracks that bound the northern side of Fair Park. The signs were aimed in opposite directions so that a subject driver approaching from one direction could only see one sign display at a time (see Figure 5).

Figure 5. Dallas Fair Park and Vicinity Locations of DMS During Testing.

STUDY PROTOCOL

The legibility study was conducted with the study participant seated in the driver seat of a TTI vehicle instrumented to collect speed and distance information. The study administrator was positioned in the passenger seat to provide instructions, operate the data collection equipment, and record verbal responses from the subject.

The legibility study was conducted as a dynamic study with the study participant operating the test vehicle. The participant would begin the study at a designated point 2000 feet upstream of the DMS and accelerate to 40 mph approaching the DMS. The DMS sign displayed a three-letter word. Participants were asked to focus on the three-letter word displayed and to say the word aloud when they felt that they could correctly identify it. If the subject incorrectly identified the word, they were told to try again until they identified the word correctly. The study participants repeated this procedure for nine different test words.

Daytime studies were conducted from 9:00 am until 3:00 pm. The daytime studies were limited to these hours to minimize the amount of glare that was experienced by study participants due to the angle of the sun. Nighttime studies were conducted starting at 7:00 pm to ensure that it was completely dark prior to the first run of the legibility study.

Prior to beginning the legibility study, each participant met researchers at a staging location at which time researchers accomplished several tasks. Initially, researchers briefed the participant regarding the driving task they would be asked to perform and had them sign an informed consent form to acknowledge that all of their rights and responsibilities as a study participant had been explained to them. Second, each study participant was given two types of visual screening tests. The first was a standard static visual acuity (Snellen) screening, and the second was a contrast-sensitivity (Vistech) screening. These screenings provided comparison information for data reduction, and ensured that all participants had at least minimal levels of acceptable vision. No participant had to be disqualified from participation in the study based on the visual screenings.

SUBJECT DEMOGRAPHICS

Study subjects were recruited from the Dallas area. A total of 60 subjects were recruited, 30 participating in the daytime portion of the legibility study and 30 participating in the nighttime portion. All subjects were required to have current Texas driver's licenses in order to qualify as a participant in the legibility study, and nighttime participants were required to have no night driving restrictions on their license.

The study participants were selected according to a demographic sample of the driving population of Texas with regard to gender, age, and education level. The statistics utilized for age and gender were obtained from the United States Department of Transportation – Federal Highway Administration Statistics for 2001. The education level statistics are based on the Texas information from the United States Census Bureau for the year 2000. Gender statistics indicated that there is an even split of male versus female drivers. Table 3 contains the percentages for the education level and age category demographic splits along with the corresponding number of participants recruited within each category for the daytime and nighttime studies.

Although this current study was not designed to specifically isolate the effects of age upon legibility distance of smaller character DMS, previous studies have shown that drivers aged 65 years or more have legibility distances that are at least 25 percent lower than drivers 45 years or younger (*6, 7*). Consequently, regions that serve a significantly higher proportion of drivers in the 65+ age category may require larger character DMS on their arterial roadways in order to adequately serve the needs of that particular segment of the driving population.

Table 3. Study Participant Demographics for Each Viewing Condition (Daytime and Nighttime)

Age Category	Education Level				Total
	High School Diploma or Less (50%)		Some College or More (50%)		
	M	F	M	F	
18-39 (47%)	3	4	4	3	14
40-54 (29%)	2	2	3	2	9
55+ (24%)	2	2	1	2	7
Total	7	8	8	7	30

EXPERIMENTAL DESIGNS

Subjects were shown three-letter words during their participation in the legibility study. There were two sets of three-letter words developed, one for the daytime study and one for the nighttime study. The same words were viewed by all of the subjects in either the daytime or nighttime legibility studies. Within each group, the words were presented in random order to counter any learning effects that may have been present and to account for possible differences in recognition times between the words and the character heights. Tables defining the specifics of the experimental designs for the daytime and nighttime studies are presented in Appendix A.

A final run was conducted for each participant to view a typical message that could be displayed on arterial DMSs in the Dallas area. The format of the messages is typical for that currently used by the City of Dallas. This portion of the study was conducted to determine a driver's ability to comprehend the necessary pieces of information using the different character height DMSs. The message used for this portion of the study is provided in Figure 6. The display time per phase was two seconds, which allowed a person viewing the message for 8 seconds total (the preferred reading time for a four-unit message) to be able to read the message twice through.

ALTERNATING DMS MESSAGE
(displayed for 2.0 seconds each phase)

IH 635 EAST	IH 635 EAST
AT ABRAMS	AT ABRAMS
ACCIDENT	2 LANES CLOSED
1st Phase	2nd Phase

Figure 6. DMS Message Tested at End of Participant Trial

Each participant saw the message on either the 9-inch or the 10.6-inch DMS. An equal number of participants viewed the message on the 9-inch and 10.6-inch signs for each the daytime and the nighttime conditions. Participants drove by the DMS and then were asked the following questions regarding the message by the study administrator:

1. What is the traffic problem?
2. Where is the traffic problem located?
3. How many lanes are closed?
4. Did you feel you had enough time to read the sign?

Questions were randomized to help avoid any biases in the responses due to question order.

STUDY RESULTS

LEGIBILITY DISTANCES

Daytime Viewing Conditions

The cumulative distribution of legibility distances measured for each of the two signs evaluated in the study are summarized in Figure 7. As can be seen in Figure 7, the 10.6-inch character DMS yielded a median legibility distance that was about 100 feet greater than that of the 9-inch character DMS.

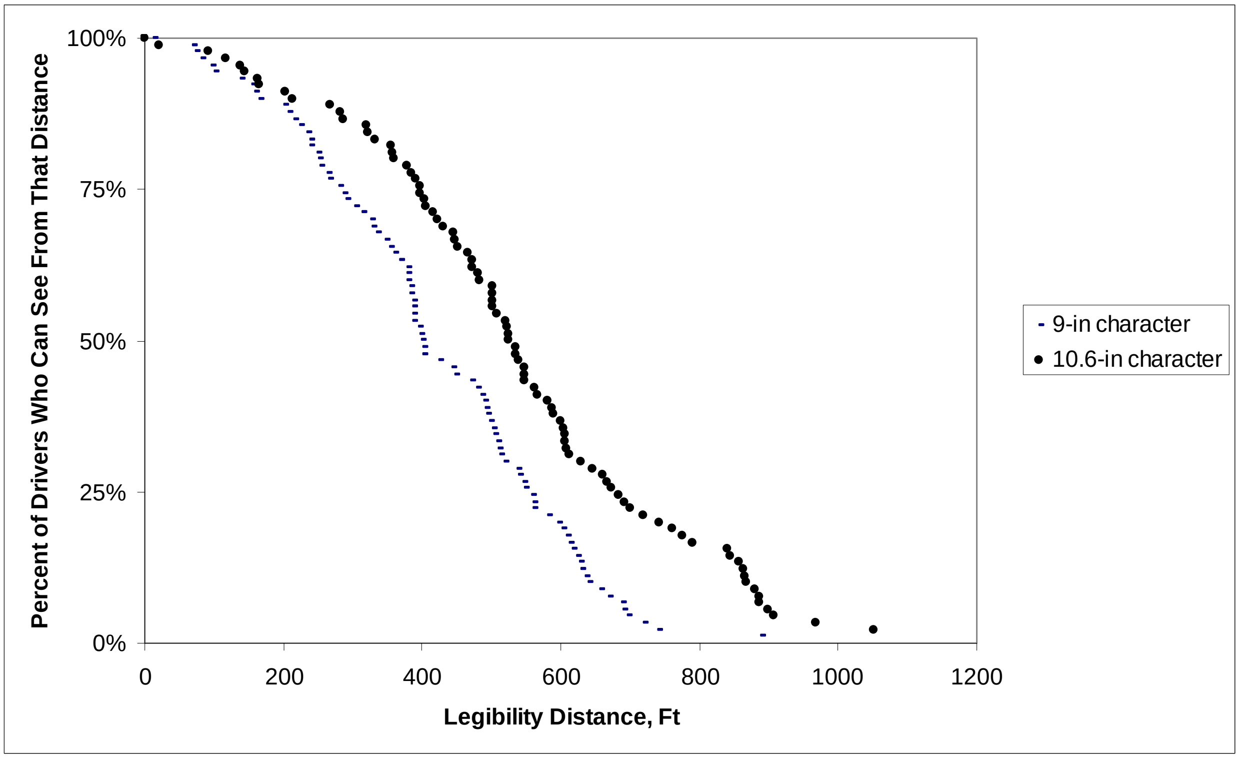


Figure 7. Cumulative Distribution of Daytime Legibility Distances Measured with Dallas Study Participants.

Next, researchers combined these data from the 9-inch and 10.6-inch character sign evaluations with data collected in a previous study to measure legibility of 18-inch LED DMS characters *(7)*. These cumulative legibility distributions are presented in Figure 8. Also shown in Figure 8 are comparisons of these data to calculated normal distributions (based on the average and standard deviation of each sample collected). As can be seen in the figure, data from all three character heights map fairly well to a normal cumulative distribution. Descriptive statistics (median, mean, standard deviation, and 85th percentile) for each of these distributions are tabularized in Appendix B. Also shown in Appendix B are similar descriptive statistics for each word used in the study, by sign and viewing condition. As expected, legibility distances did vary substantially depending on the word chosen, but this effect was kept identical across signs through the experimental design process.

As noted previously, accommodation of at least 85 percent of drivers is the design goal commonly established in the highway industry. Consequently, Figure 9 presents the 85th percentile daytime legibility distance as a function of character height. A clear linear relationship exists between the data from the 9-inch, 10.6-inch, and 18-inch characters. Consequently, it appears quite reasonable to extrapolate from this graph for all possible character heights between 9 and 18 inches, including that for a 12-inch character.

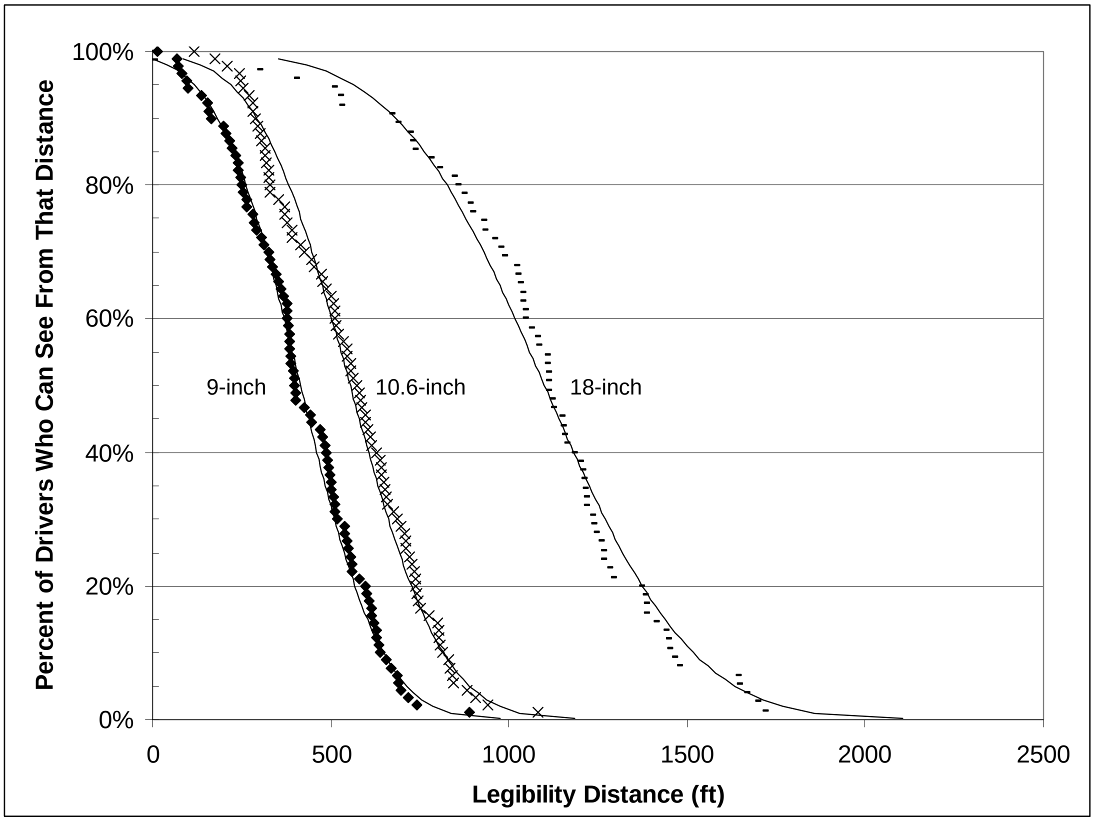


Figure 8. Daytime Legibility Distances for 9, 10.6, and 18-Inch LED DMS Characters.

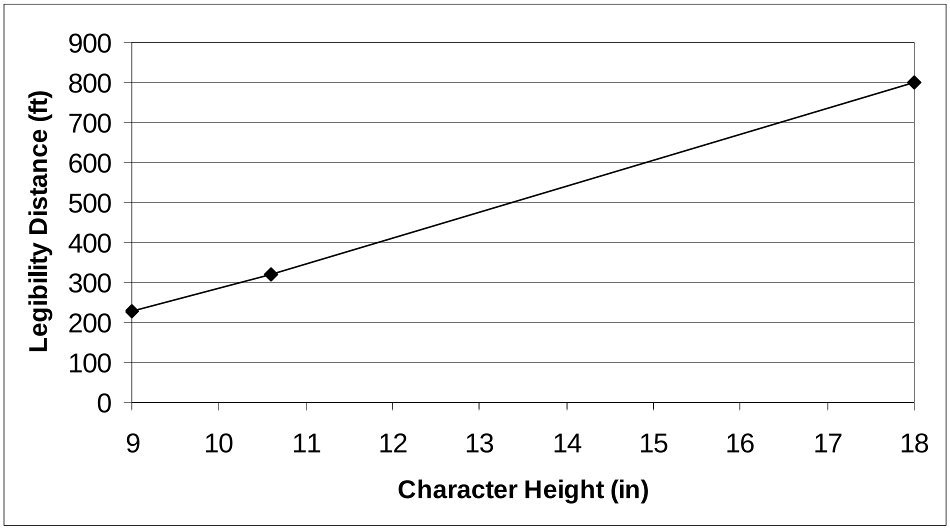


Figure 9. 85th Percentile Daytime Legibility Distance Versus LED DMS Character Height.

Although a strong linear relationship does exist between character height and 85th percentile legibility distance, the relationship is not directly proportional (i.e., a 50 percent reduction in character height does not equate to a 50 percent reduction in legibility distance). This fact is further illustrated in Figure 10, where the legibility distance is divided by character height to compute the corresponding legibility index (feet of legibility per inch of character height). Whereas the 85th percentile legibility index for the 18-inch character was found to be nearly 45 feet per inch of character height, the 85th percentile legibility index of the 9-inch character was calculated to be only 25 feet per inch of character height, 45 percent lower than the legibility index of the 18-inch character. The legibility index of the 10.6-inch character was approximately 30 feet per inch of character height, a value 33 percent lower than for the 18-inch character.

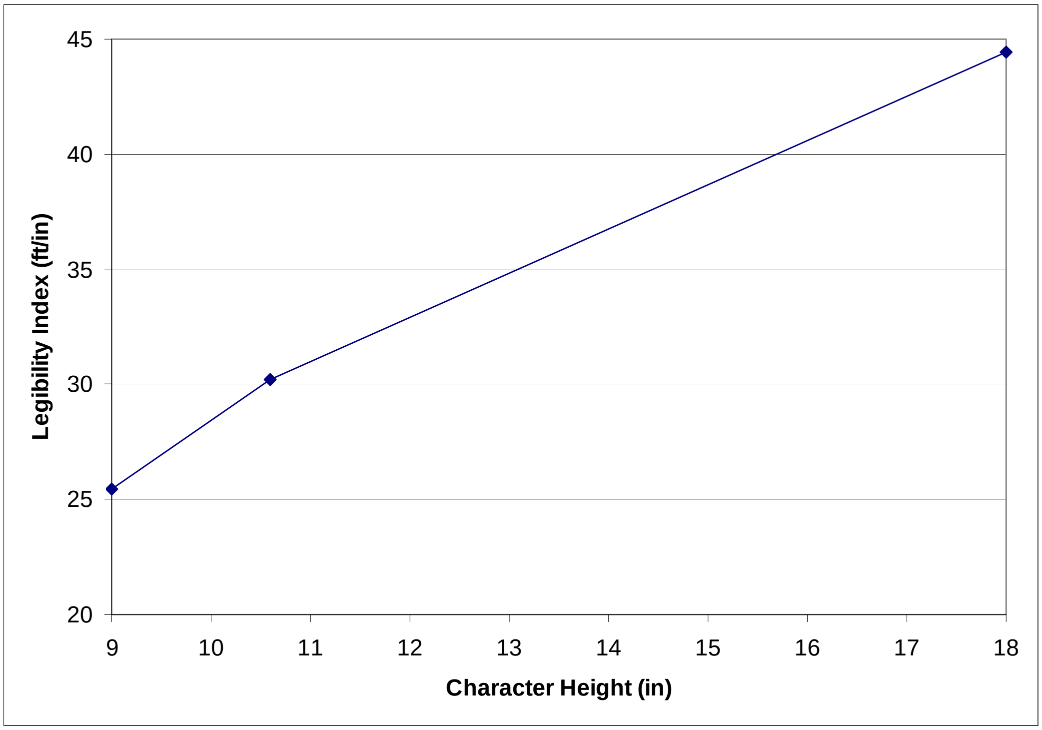


Figure 10. 85th Percentile Daytime Legibility Indices Versus LED DMS Character Heights.

Nighttime Viewing Conditions

As with the data from the daytime viewing conditions, researchers used only the data from the 9-inch and 10.6-inch character sign evaluations from the nighttime viewing conditions. The cumulative legibility distributions for those character heights are presented in Figure 11, along with the data from the previous legibility study of 18-inch characters. The continuous lines once again represent a normal distribution cumulative curve fit to each of the datasets. Descriptive statistics (median, mean, standard deviation, and 85th percentile) for each of these distributions are tabularized in Appendix B.

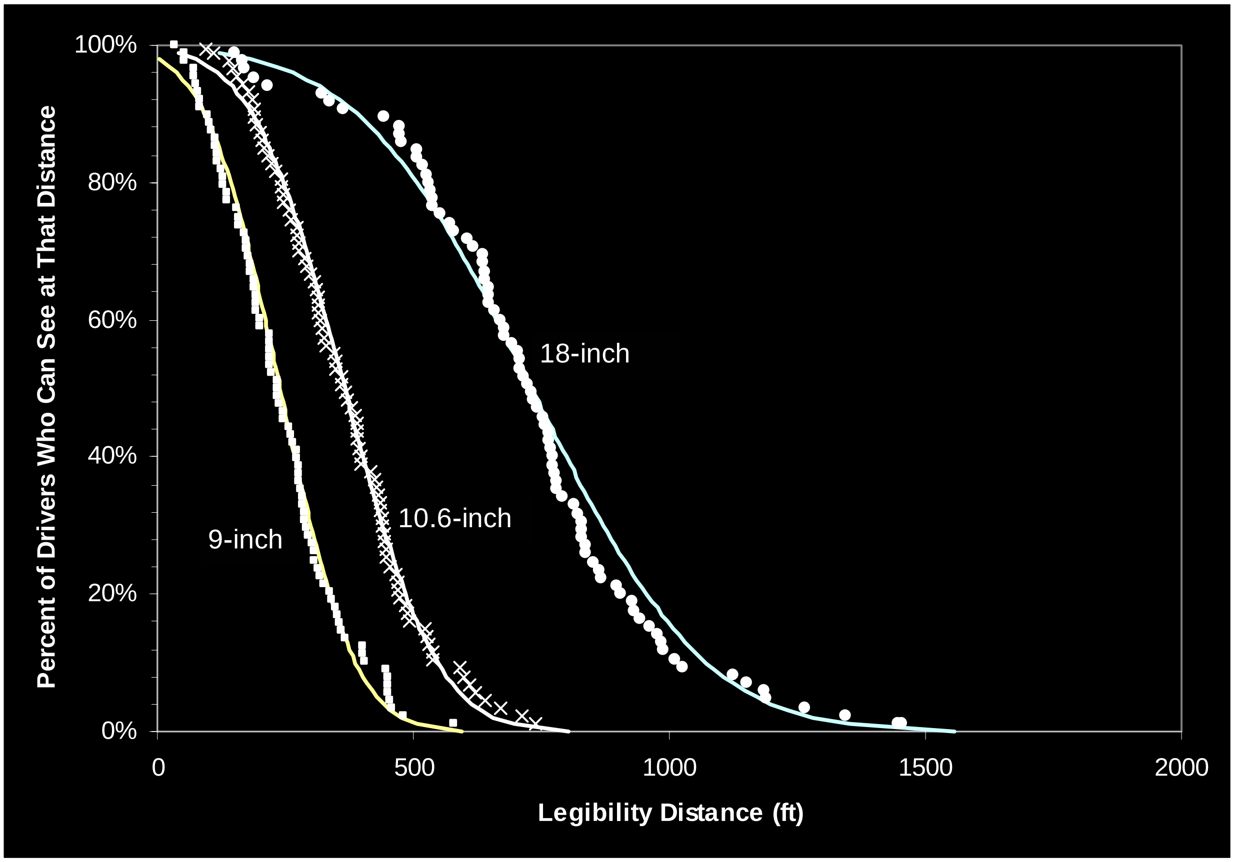


Figure 11. Nighttime Legibility Distance for 9, 10.6, and 18-Inch LED DMS Character Heights.

Figure 12 presents the 85th percentile nighttime legibility distance as a function of character height. A linear relationship once again exists between the data from the 9-inch, 10.6-inch, and 18-inch characters. Meanwhile, Figure 13 presents these data in terms of legibility indices (feet of legibility distance per inch of character height). In the nighttime viewing condition, the relationship between legibility index and character height was found to be nonlinear. For 9-inch characters, researchers found the 85th percentile legibility index to be only about 13 feet per inch of letter height. The value was slightly better (approximately 20 feet per inch of letter height) for the 10.6-inch characters, whereas 18-inch characters are capable of producing 33 feet of legibility distance per inch of letter height. In other words, the 9-inch and 10.6-inch legibility indices represent only 39 and 61 percent of the 18-inch character legibility index, respectively.

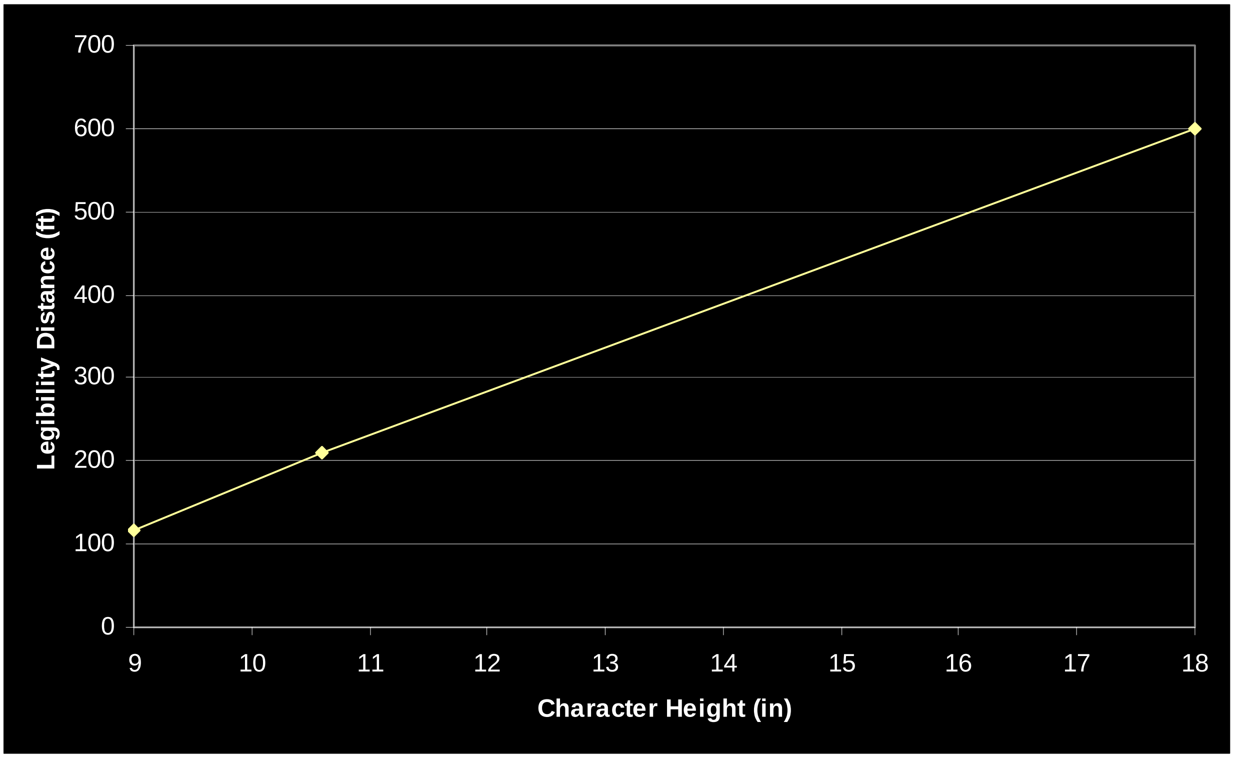


Figure 12. 85th Percentile Nighttime Legibility Distance Versus LED DMS Character Height.

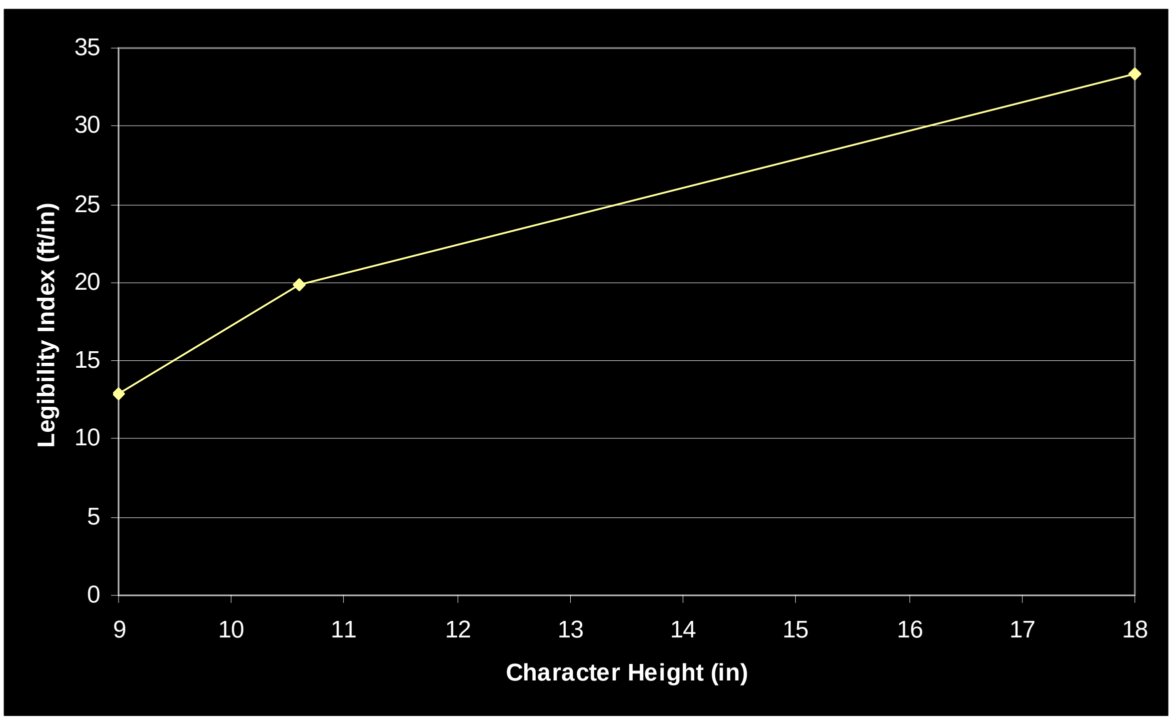


Figure 13. 85th Percentile Nighttime Legibility Indices Versus LED DMS Character Heights.

COMPREHENSION OF SAMPLE MESSAGE

After viewing all of the three-character words according to the study protocol, study participants made one last approach to either the 9-inch or the 10.6-inch character DMS while it displayed the sample accident message shown in Figure 6. Once past the sign, participants were queried to determine whether they correctly comprehended and retained the information contained in the message. The percent of correct comprehension and recall by unit of information and character size is shown in Table 4.

Table 4. Comprehension and Information Recall Results

Viewing Condition and Information Unit	Percent Correct Responses	
	9-inch Character	10.6-inch Character
Daytime:		
What was the Problem?	87%	87%
Where was the Location?	73%	80%
How Many Lanes Closed?	80%	93%
Correct responses to all three questions	53%	73%
Did You Have Enough Time to Read the Sign?	60% yes	93% yes
Nighttime:		
What was the Problem?	47%	47%
Where was the Location?	60%	60%
How Many Lanes Closed?	87%	80%
Correct responses to all three questions	33%	40%
Did You Have Enough Time to Read the Sign?	33% yes	53% yes

During the daytime viewing condition, both character heights failed to achieve an 85 percent correct response on all three information questions. Slightly over one-half of the study participants correctly recalled all three informational units of interest, compared to nearly three-fourths of the participants viewing the 10.6-inch character. At night, the percentage of correct responses dropped significantly for both character heights. In fact, fewer than one-half of the participants could correctly recall the three units of information that were included in the accident message. Consistent with these comprehension and recall results, the percentage of participants who felt they had enough time to read the message was considerably lower at night as compared to daytime viewing conditions.

IMPACT OF LEGIBILITY DISTANCES UPON DMS VIEWING TIMES

As noted in the introduction, both legibility distances and the speed of the approaching motorist dictate the amount of time that is ultimately available for that motorist to read the DMS message. Therefore, the legibility distances identified for the 9-inch, 10.6-inch, and (by extrapolation) 12-inch character signs represent slightly different viewing times depending on the approach speed of traffic on a given roadway segment. Tables 5 and 6 identify the seconds of viewing time afforded by each character height at speeds of 30 through 45 mph under both daytime and nighttime viewing conditions. As the tables illustrate, the approach speed of the vehicle does affect the amount of viewing time a given character height can provide. Table 6 also illustrates that, under nighttime viewing conditions, the smaller character heights evaluated in this study provide rather limited viewing times to approaching motorists. The 9-inch character height, for example, would provide the 85th percentile driver with less than three seconds of viewing time at 30 mph, and less than two seconds of viewing time at 45 mph.

Table 5. 85th Percentile Viewing Times (Seconds) to DMS, Daylight Viewing Conditions

Character Height (in)	Average Roadway Approach Speed			
	30 mph	35 mph	40 mph	45 mph
9	5.2	4.5	3.9	3.5
10.6	7.3	6.2	5.5	4.8
12[a]	9.4	8.0	7.0	6.2
18	18.2	15.6	13.6	12.1

[a] Extrapolated from other character height data

Not recommended (shaded cells: 9 in at 35, 40, 45 mph; 10.6 in at 45 mph)

Table 6. 85th Percentile Viewing Times (Seconds) to DMS, Nighttime Viewing Conditions

Character Height (in)	Average Roadway Approach Speed			
	30 mph	35 mph	40 mph	45 mph
9	2.6	2.3	2.0	1.8
10.6	4.8	4.1	3.6	3.2
12[a]	6.4	5.5	4.8	4.3
18	13.6	11.7	10.2	9.1

[a] Extrapolated from other character height data

Not recommended

Using the well-accepted standard that each unit of information presented on a DMS requires two seconds of viewing time to be read and correctly comprehended, Tables 7 and 8 convert available viewing time into the maximum number of information units that can be presented using the various character heights at the different approach speeds. Previous research has shown that motorists can process and retain no more than five units of information, regardless of the amount of viewing time available (*5*). Consequently, that value has been used as the upper limit in the tables.

Table 7. Maximum Units of Information That Can Be Displayed on the DMS, Daytime Viewing Conditions

Character Height (in)	Average Roadway Approach Speed			
	30 mph	35 mph	40 mph	45 mph
9	3	2	2	2
10.6	4	3	3	2
12[a]	5	4	4	3
18	5	5	5	5

[a] Extrapolated from other character height data
■ Not recommended

Table 8. Maximum Units of Information That Can Be Displayed on the DMS, Nighttime Viewing Conditions

Character Height (in)	Average Roadway Approach Speed			
	30 mph	35 mph	40 mph	45 mph
9	1	1	1	1
10.6	2	2	2	2
12[a]	3	3	2	2
18	5	5	5	4

[a] Extrapolated from other character height data
■ Not recommended

REDUCING THE NUMBER OF UNITS IN COMMON DMS MESSAGES

The values in Tables 7 and 8 specify the maximum number of units of information that can be read by at least 85 percent of drivers traveling at that particular speed. For most of the sign sizes and operating speeds, particularly under nighttime viewing conditions, the amount of information that can be read is limited to values below the five units of information that humans can effectively comprehend and retain while driving *(5)*. If a message intended for display exceeds the corresponding value in Table 7 or 8 for the particular character height/operating speed condition, it must be shortened. This shortening should be accomplished by eliminating the lowest priority information.

TTI researchers performed a human factors critique of the current sample messages that the City of Dallas desires to display on DMS to identify ways of shortening the messages. The results of that critique are presented in Table 9. The modified messages are, for the most part, as minimal as possible. That is, further reductions in the units of information in the message would result in unintelligible messages that would provide no useful information to the driver.

Table 9. Reducing the Number of Units of Information in Sample DMS Messages

Display Condition	Original Message		Reduced Message	
	Text	Units of Information	Text	Units of Information
Accident on Freeway (Sign on Nearby Arterial)	IH 635 EAST AT ABRAMS ACCIDENT ⇳ IH 635 EAST AT ABRAMS 2 LANES CLOSED	4 Units	2 LANES CLOSED ON IH 635 EAST AT ABRAMS	3 Units
Accident on Freeway (Sign on Nearby Arterial)	IH 35 SOUTH ILLINOIS TO LOOP 12 CONSTRUCTION ⇳ IH 35 SOUTH 2 LANES CLOSED 9 PM TO 5 AM	5 Units	2 LANES CLOSED ON IH 35 SOUTH AT ILLINOIS	3 Units
General Adverse Weather Condition Warning in Region	FLASH FLOOD WARNING DALLAS AREA ⇳ DO NOT CROSS FLOODED STREETS	5 Units	FLASH FLOOD WARNING TUNE TO RADIO	2 Units

Table 9. Cont'd

Display Condition	Original Message		Reduced Message	
	Text	Units of Information	Text	Units of Information
Specific Roadway-Related Weather Warning	FLOOD CLOSURE NORTHWEST HWY TRAMMEL TO BUCKNER ⇳ FIND ALTERNATE ROUTE	4 Units	NORTHWEST HWY CLOSED TRAMMEL TO BUCKNER or NW HWY CLOSED TRAMMEL TO BUCKNER FIND ALTERNATE ROUTE	2 Units 3 Units
Amber Alert	AMBER ALERT KIDNAPPED CHILD TUNE TO RADIO/TV	3 Units	KIDNAPPED CHILD TUNE TO RADIO/TV	2 Units

For 4-unit messages that are split between two phases, the display time for each phase should be in proportion to the amount of information presented on that phase. In other words, if the message is split into two units of information on each phase, the display time for each phase should be equal. If the information is split three units on one phase and one unit on the other, the display time of the first phase should be three times that of the second phase. Also, the total cycle time of the message (the sum total of the two phases) can be either 4 seconds, if the City of Dallas prefers to cycle through the message twice during the motorists' available reading time, or 8 seconds if the City of Dallas prefers to cycle through the message only once during the available reading time. Studies conducted by TTI indicate that either approach results in acceptable motorist comprehension and information retention rates (*4*).

RECOMMENDATIONS

This study was conducted to determine the legibility distances of smaller-character DMS for use on arterial roadways. A dynamic legibility study of 9-inch, 10.6-inch and 12-inch high DMS characters was performed at the Dallas Fair Park and surrounding arterials utilizing City of Dallas residents. The legibility distance determined for each character height was converted into an equivalent amount of time a motorist traveling at a particular speed has to view and read a message on a DMS of that character size. Using the accepted standard requirement of two seconds of viewing time per unit of information presented on the DMS, researchers then computed how many units of information could be presented on the DMS of each character height on roadways with one of several approach speeds (shown in Tables 7 and 8).

Given that most messages that the City of Dallas would desire to display will contain at least three units of information (even after reducing the typical messages using various human factors techniques), TTI researchers provide the following recommendations.

- Researchers recommend that 9-inch character DMS not be used on arterial roadways in Dallas. Even on roadways with vehicles operating as low as 30 mph, the legibility distance provided by 9-inch characters allows for no more than one unit of information to be displayed at night. This is insufficient for essentially all types of messages that the City of Dallas desires to display.

- Researchers also recommend that 10.6-inch character DMS not be used on Dallas arterial roadways. Although this size character would provide adequate legibility and viewing time to accommodate 3- and 4-unit messages during daylight conditions, only 2 units of information could be effectively displayed on a sign of that character size during nighttime conditions. Very few of the typical messages of interest to the City of Dallas can be effectively reduced to that size.

- Researchers recommend that the City of Dallas continue to utilize DMS with 12-inch high characters on its arterial roadways. This size character allows the display of 4-unit messages during the day on roadways with operating speeds up to 40 mph. However, researchers recommend that messages be limited to only 3 units of information at night.

The data also suggest that a 12-inch character may be insufficient on roadways where the average speed at night is 45 mph or higher, as only 2 units of information can be effectively displayed in that situation. Based on the data shown in Figure 12, character heights near 18 inches would be needed to allow 4-unit messages to be displayed at night on these types of facilities, or 15 inches if messages were limited to 3 units or less at night.

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APPENDIX A:

EXPERIMENTAL DESIGNS

Table A-1. Daytime Experimental Design

Subject No	sign 1 rep 1	sign 2 rep 1	sign 3 rep 1	sign 1 rep 2	sign 2 rep 2	sign 3 rep 2	sign 1 rep 3	sign 2 rep 3	sign 3 rep 3	Full Message Sign # (1 & 2 only)
1	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	2
2	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	1
3	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	2
4	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	1
5	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	BAT	2
6	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	BAT	CAB	1
7	SKY	SEE	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	2
8	SEE	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	1
9	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	2
10	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	1
11	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	2
12	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	1
13	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	2
14	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	BAT	1
15	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	BAT	CAB	2
16	SKY	SEE	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	1
17	SEE	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	2
18	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	1
19	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	2
20	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	1
21	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	2
22	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	1
23	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	BAT	2
24	ZOO	SKY	SEE	TOP	MOW	BOW	SAW	BAT	CAB	1
25	SKY	SEE	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	2
26	SEE	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	1
27	TOP	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	2
28	MOW	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	1
29	BOW	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	2
30	SAW	BAT	CAB	ZOO	SKY	SEE	TOP	MOW	BOW	1

Note: sign 3 was eventually dropped from the study

Table A-2. Nighttime Experimental Design

Subject No	sign 1 rep 1	sign 2 rep 1	sign 3 rep 1	sign 1 rep 2	Sign 2 rep 2	sign 3 rep 2	sign 1 rep 3	sign 2 rep 3	sign 3 rep 3	Full Message Sign # (1 & 2 only)
1	VAN	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	1
2	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	2
3	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	DAM	1
4	BOX	ACE	KID	TEA	FAR	TIP	VAN	DAM	BIG	2
5	ACE	KID	TEA	FAR	TIP	VAN	DAM	BIG	BOX	1
6	KID	TEA	FAR	TIP	VAN	DAM	BIG	BOX	ACE	2
7	TEA	FAR	TIP	VAN	DAM	BIG	BOX	ACE	KID	1
8	FAR	TIP	VAN	DAM	BIG	BOX	ACE	KID	TEA	2
9	TIP	VAN	DAM	BIG	BOX	ACE	KID	TEA	FAR	1
10	VAN	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	2
11	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	1
12	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	DAM	2
13	BOX	ACE	KID	TEA	FAR	TIP	VAN	DAM	BIG	1
14	ACE	KID	TEA	FAR	TIP	VAN	DAM	BIG	BOX	2
15	KID	TEA	FAR	TIP	VAN	DAM	BIG	BOX	ACE	1
16	TEA	FAR	TIP	VAN	DAM	BIG	BOX	ACE	KID	2
17	FAR	TIP	VAN	DAM	BIG	BOX	ACE	KID	TEA	1
18	TIP	VAN	DAM	BIG	BOX	ACE	KID	TEA	FAR	2
19	VAN	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	1
20	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	2
21	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	DAM	1
22	BOX	ACE	KID	TEA	FAR	TIP	VAN	DAM	BIG	2
23	ACE	KID	TEA	FAR	TIP	VAN	DAM	BIG	BOX	1
24	KID	TEA	FAR	TIP	VAN	DAM	BIG	BOX	ACE	2
25	TEA	FAR	TIP	VAN	DAM	BIG	BOX	ACE	KID	1
26	FAR	TIP	VAN	DAM	BIG	BOX	ACE	KID	TEA	2
27	TIP	VAN	DAM	BIG	BOX	ACE	KID	TEA	FAR	1
28	VAN	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	2
29	DAM	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	1
30	BIG	BOX	ACE	KID	TEA	FAR	TIP	VAN	DAM	2

Note: sign 3 was eventually dropped from the study

APPENDIX B:

LEGIBILITY STUDY DESCRIPTIVE STATISTICS

9-Inch Character Sign

Legibility Distance By Viewing Condition

Statistic	Daytime Viewing Condition (ft)	Nighttime Viewing Condition (ft)
Median	399	233
Mean	415.3	238.1
Standard Deviation	181.4	118.1
85th %-tile	228	114

Legibility Distance By Word

Daytime Legibility Distance (ft)					Nighttime Legibility Distance (ft)				
Word	Median	Mean	Std. Dev.	85th %-tile	Word	Median	Mean	Std. Dev.	85th %-tile
BAT	357	382.4	166.1	189	ACE	282	243.9	122.1	93
BOW	366	373.0	163.8	153	BIG	234	215.1	114.6	45
CAB	382	351.1	118.5	185	BOX	220	233.4	99.7	91
MOW	315	333.4	271.2	41	DAM	188	238.3	81.8	157
SAW	343	327.4	119.7	162	FAR	271	259.7	117.3	98
SEE	556	519.1	149.9	274	KID	181	188.3	83.1	80
SKY	387	393.0	211.6	78	TEA	240	269.1	137.3	81
TOP	553	514.1	125.5	332	TIP	263	288.5	168.8	99
ZOO	585	543.8	143.5	320	VAN	235	228.1	108.8	111

10.6-Inch Character Sign

Legibility Distance By Viewing Condition

Statistic	Daytime Viewing Condition (ft)	Nighttime Viewing Condition (ft)
Median	525	355
Mean	543.7	358.9
Standard Deviation	236.4	145.7
85^{th} %-tile	324	203

Legibility Distance By Word

Daytime Legibility Distance (ft)					Nighttime Legibility Distance (ft)				
Word	Median	Mean	Std. Dev.	85^{th} %-tile	Word	Median	Mean	Std. Dev.	85^{th} %-tile
BAT	607	586.9	194.5	310	ACE	348	319.4	94.4	184
BOW	473	495.9	104.8	354	BIG	319	336.3	121.0	193
CAB	525	543.8	166.8	359	BOX	404	348.6	156.4	136
MOW	378	382.4	213.3	79	DAM	269	285.4	109.6	149
SAW	376	367.3	176.6	105	FAR	348	313.4	110.6	152
SEE	560	621.8	237.9	306	KID	470	435.6	174.4	245
SKY	606	606.8	192.7	361	TEA	402	417.2	148.0	248
TOP	641	713.7	342.9	314	TIP	450	455.1	171.5	230
ZOO	513	558.8	279.3	189	VAN	341	319.1	151.1	97