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Best Practices

BUS SIGNAGE FOR PERSONS WITH VISUAL IMPAIRMENTS: LIGHT-EMITTING DIODE (LED) SIGNS

January 2004

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This best-practices report provides key information regarding the use of Light-Emitting Diode (LED) sign technologies to present destination and route information on transit vehicles. It will assist managers and engineers in the acquisition and use of this technology to improve the dissemination of public transit information to persons with visual impairments. It includes information about system design and implementation, and offers lessons learned and recommended practices for successful deployments.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

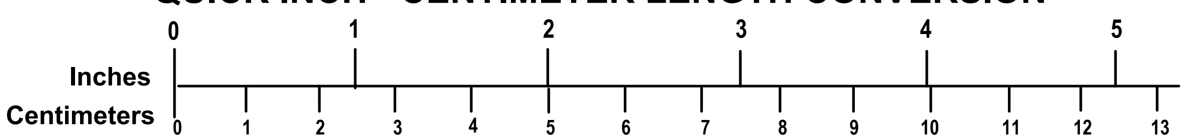
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

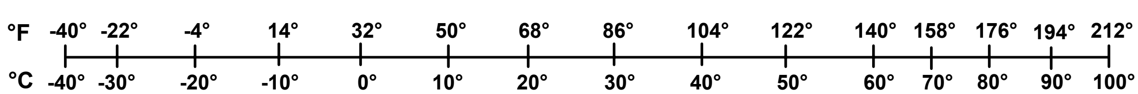
TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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EXECUTIVE SUMMARY

The user population for transportation systems is perhaps broader and more complex than the user population for any other system. Public transit systems are especially important to persons with visual impairments, since their reduced visual capabilities may make driving impossible. Unfortunately, a person with a visual impairment may have difficulties deciphering Light Emitting Diode (LED) destination signage provided both on and in transit vehicles. Not having access to this information can make the experience of public transportation difficult, and, in some instances, dangerous.

An increasing number of transit authorities are installing LED destination signage on their transit vehicles. Transit authority operators have discovered that the unique characteristics of LED displays, while meeting the requirements contained in § 38.39 for character size, illumination etc., may none the less be hard to read under day, night, and low-light conditions by persons with visual impairments. With this in mind, the FTA conducted an extensive research study to address the following questions:

- Do the ADA specifications for destination signs adequately address the needs of persons with visual impairments under various lighting conditions, when applied to LED displays?
- Are minimum character heights of 1 inch and 2 inches for side and front LED route and destination signs, respectively, sufficient for persons with visual impairments under various lighting conditions? If these sizes are not adequate, what character size is readable as well as appropriate for route and destination signs? For a given character size, what is the optimum distance of such a sign for readability?
- Are LED route and destination signs that display alternating text readable by persons with visual impairments under various lighting conditions?
- What color combinations provide the best levels of contrast under various lighting conditions?
- Are persons with visual impairments better able to read words of mixed uppercase and lowercase letters, or are all capitals preferable, under various lighting conditions?
- Does a wider character width improve readability for persons with visual impairments under various lighting conditions?

To answer the above questions, the study gathered accurate and unbiased data regarding LED sign characteristics that affect readability by persons with visual impairments; it included the following:

- Conduct a detailed literature search of commercial, government, and Internet databases to identify relevant past research efforts; perform a literature review and gap analysis to highlight inadequate or incomplete research areas; and provide recommendations as to which factors should be tested under laboratory conditions.

- Solicit questionnaire responses from selected transit authorities and transit users to address those factors not adequately addressed in the literature and receive first hand feedback from users and transit authority staff with sign acquisition responsibilities.
- Prepare and conduct human factors testing to address those factors not adequately addressed in the current literature.
- Publish recommendations in a FTA best-practices document.

The results of this effort provide additional recommended best practices for the presentation of information with LED signage. A summary best-practices table (Table 1) is presented below.

Table 1. Recommended Best Practices for LED Transit Vehicle Signs

Best Practices for LED Transit Vehicle Signs			
	Recommended Best Practices	**Current ADA Specifications**	**Discussion**
	**Letter Height**		
	Front sign not less than 8 inches	Not less than 2 inches	• Literature and research indicate larger letters on front signs (even as large as 10 inches or more) provide better viewing for persons with visual impairments. • This recommendation and actual letter size may be limited by the current sign technology and the space provided on the vehicle for sign placement. • Research is needed to determine whether, if space does not permit displaying a whole message in one line, greater legibility can be obtained with two-line message, scrolling or paging.
	Side sign not less than 5 inches	Not less than 1inch	• Literature and research indicate larger letters on side signs (even as large as 6 inches or more) provide better viewing for persons with visual impairments. • Viewing distance is limited by extreme visual angles associated with reading the side-signs.
	**Letter Width-to-Height Ratio**		
	5:7 to 1:1	3:5 to 1:1	• Existing research on this variable is fairly strong. • Research indicates that the more legible ratios are slightly larger than the minimum 3:5 width-to-height required by ADA Accessibility Guidelines (ADAAG) and that legibility tends to decrease as the ratio approaches the maximum 1:1 width-to-height permitted under ADAAG.

Best Practices for LED Transit Vehicle Signs

Recommended Best Practices	Current ADA Specifications	Discussion
Stroke Width-to-Height Ratio		
Not less than 1:5	1:5 to 1:10	• There is general (but not complete) agreement on values in and around this range for application to text readability.
Text Color		
Amber/Yellow	No current specification	• Literature and current research appear to indicate a general advantage for colors from the middle of the visual light spectrum (~ 570 – 590 nm wavelengths) across all environmental lighting conditions. • Some study results appear to indicate a shift to the longer wavelengths (e.g., green and blue) provides adequate legibility under lower lighting and night conditions. • All colors appear best when presented under positive contrast conditions (i.e., light letters on dark (black or dark blue) background). • White appears to provide decent visibility under daylight conditions but not under low light or night.
Luminance		
Night 30cd/m^2 Day >1,000cd/m^2	No current specification	• Existing research on this variable is fairly strong for individuals without vision impairments. • Additional research should be conducted to determine if these levels are sufficient for individuals with vision impairments. • European standards currently under development should be tracked to determine measurement methods/recommended levels.
Luminance Contrast Percentage		
$[(L_c - L_b)/L_b] \times 100 \geq 70\%$	No current specification	• Where: L_c = Luminance (brightness) of characters; L_b = Luminance (brightness) of background. • This formula produces “negative” contrast for signs and publications when the letters are dark against a light background, and “positive” contrast otherwise. • Existing research on this variable is strong for individuals without vision impairments. • Additional research should be conducted to determine if these levels are sufficient for individuals with vision impairments.

Best Practices for LED Transit Vehicle Signs

Recommended Best Practices	Current ADA Specifications	Discussion
Inter-character Spacing		
1.5 to 2.0 times stroke width	1/16 of uppercase letter height	• Research supports significantly wider spacing than that provided by the ADAAG.
Inter-word spacing		
75-100% letter height	No current specification	• Existing research on this variable is strong but available sign space, especially for longer destination/route messages, may be a limiting factor.
Inter-line spacing		
50 to 75% of letter height	No current specification	• Existing research on this variable is strong but available sign space will result in letters that are significantly smaller than the recommended 8 inches height. • Need additional research on whether messages should have multiple lines or scrolling if unable to fit on a single line.
Case		
Uppercase	No current specification	• Use all capital letters (uppercase) for stop designations, terminals, and other short labels. • Neither the literature review nor the current research present any evidence that lower case LED messages are legible to persons with visual impairments in any of the research conditions here.
Message Dynamics		
Static	No current specification	• Where possible, complete route/destination messages should be presented in static (i.e., not moving) format. • Additional research is necessary to determine relative advantages of streaming versus paging message dynamics for persons with visual impairments if route and destination messages are longer than can be presented in one sign.
Message Dynamic Display Time		
2.7 - 10 seconds	No current specification	• Research is not adequate to indicate the relative advantages and tradeoffs of display times for dynamic messages (e.g., streaming, paging).

Best Practices for LED Transit Vehicle Signs

Recommended Best Practices	Current ADA Specifications	Discussion
		• There appears to be a tradeoff of display time and reading distance for dynamic messages. That is, longer display time may not allow the entire message to be communicated in the distance a vehicle travels within the range of legibility for persons with visual impairments. Shorter display times may not allow for adequate exposure to determine the message.
Sign Placement on Vehicle		
Front	No current specification	• Sign should be placed above the windscreen or as low as practicable within the windscreen area (noting influence of glare on sign legibility), above the driver's field of view.
Side	No current specification	• Sign should be placed on side of vehicle, adjacent to the entrance that is closest to the front of the vehicle at a height of not less than 4 ft. to the lower edge of the display characters and not more than 8 ft. to the upper edge of the display characters measured from the ground.

Other Considerations

Glare and Fog Abatement

- Signs should be positioned at an angle to minimize unavoidable glare.
- Sign-covering material should be designed to minimize glare.
- Signs should not be placed directly behind windscreen if possible.
- Utilize a defogger, fresh air blower, or electric strip on the destination sign glass/covering surface to reduce fogging and improve readability.

Visual Clutter Abatement

- Competing alphanumeric information should not be displayed in proximity to bus route and destination signs where it may confuse passengers.
- Message content should be limited to route and destination information. Advertising and "Have a Nice Day" messages should be avoided as they may confuse passengers.

Cleanliness

- Route and destination signs should be kept clean from surface dirt and contaminants.

Maintenance

- Destination and route signs should be maintained according to the manufacturer's recommended preventive maintenance intervals and repair practices.

The best practices table displays the relevant recommendations as noted in the literature reviewed and research conducted during this project and should help transit agencies to choose and implement LED transit sign systems that will improve readability by persons with visual impairments. The content has been appended in part or in its entirety from the authors cited in this document. Since sign design itself will not adequately address the full needs of persons with visual impairments, it is important that the use of additional information technologies (e.g., auditory, tactile) to facilitate access to route and destination information be provided. In addition, less technology-driven solutions (e.g., improved driver training) may be considered to provide additional assistance and accessibility to all public transit users.

This effort represents a further refinement of the existing literature for the presentation of information on LED signage and expands the body of research knowledge in the transportation accessibility environment. In many cases, the existing documentation is difficult to identify and the issues too numerous to address in any single empirical study. The results of this effort capture the most current understanding and application of human factors principles to the use of LED signage for the presentation of route and destination information on public transit vehicles. However, future research is needed with LED signs in the following areas, under the environmental lighting and vehicle dynamic conditions described in this report:

- The influence of glare and background visual clutter on sign readability
- The readability tradeoffs associated with message-paging and message-streaming dynamics, including recommended display times
- The readability tradeoffs associated with two-line messages versus paging/streaming
- The limits of readability as a function of LED luminance and luminance contrast conditions

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ACRONYMS

ADA	Americans with Disabilities Act
ADAAG	ADA Accessibility Guidelines
AMLCD	Active Matrix Liquid Crystal Display
APTA	American Public Transit Association
DOT	Department of Transportation
DTIC	Defense Technical Information Center
FTA	Federal Transit Administration
HSIAC	Human Systems Information Analysis Center
ISTEA	Intermodal Surface Transportation Efficiency Act
LCD	Liquid-Crystal Display
LED	Light-Emitting Diode
NTIS	National Technical Information Service
PIDSS	Passenger Information Display Sign Systems
POCs	Point-of-Contact
SBPG	Standard Bus Procurement Guidelines
SME	Subject-Matter Expert
TCRP	Transit Cooperative Research Program
TNLCD	Twisted Nematic Liquid Crystal Display
TRIS	Transportation Research Information Service
VMS	Variable Message Signs

GLOSSARY

Auditory – pertaining to hearing, to the sense of hearing, or to the organs of hearing

Binocular – involving both eyes for viewing

Cataracts – an abnormality of the eye characterized by cloudiness of the lens

Colorblindness – inability to distinguish one or more chromatic colors, seeing only shades of gray, black, and white

Diabetic retinopathy – when diabetes damages the tiny blood vessels inside the retina, the light-sensitive tissue at the back of the eye

Dot pitch – specification for image sharpness on a display monitor

Glaucoma – a group of diseases that can damage the eye's optic nerve and result in vision loss and blindness

Inter-character spacing – open space between characters on a display; carries no information, used to separate the characters

Luminance – the amount of light coming from the display surface; the light that ultimately reaches the user's eye

Macular degeneration – a disease that blurs the sharp, central vision needed for "straight-ahead" activities; affects the center of the retina, the "macula"; the part of the eye that allows you to see fine detail

Paging – character elements presented for a period of time and then disappearing all at once before the same or new elements are presented

Pixel – the basic unit of programmable color on an LED display

Retinitis pigmentosa – an inherited condition of the retina in which specific photoreceptor cells, called rods, degenerate

Snellen scale – eye chart imprinted with black letters or numbers in lines of decreasing size; used for testing visual acuity

Streaming – character elements moving smoothly and continuously across an LED display

Stroke width – the distance between the two edges of a character stroke, measured perpendicular to the stroke centerline

Stroke – a straight line or arc that is used as a segment of a graphic character

Tactile – of, pertaining to, or affecting the sense of touch

Visual acuity – sharpness of vision; the visual ability to resolve fine detail (usually measured by a Snellen chart)

Visual angle – the angle formed by two rays of light, or two straight lines drawn from the extreme points of an object to the center of the eye

INTRODUCTION

Section 222 of the ADA states, "It shall be considered discrimination for purposes of section 202 of this Act and section 504 of the Rehabilitation Act of 1973 (29 U.S.C 794) for a public entity which operates a fixed route system to purchase or lease a new bus, a new rapid rail vehicle, a new light rail vehicle, or any other new vehicle to be used on such system, if such bus, rail vehicle, or other vehicle is not readily accessible to and usable by individuals with disabilities, including individuals who use wheelchairs."

The Americans with Disabilities Act (ADA) was enacted on July 26, 1990. The ADA is designed to provide a clear and comprehensive national specification for the elimination of discrimination against individuals with disabilities in areas such as employment, public services, telecommunications, and transportation. The ADA defines disability as:

- Physical or mental impairment that substantially limits one or more of the major life activities of such individuals,
- A record of such an impairment, or
- Being regarded as having such impairment.

Since the passage of this law, transit agencies have undertaken significant initiatives to comply with legislation and improve access to public transportation for persons with disabilities.

Purpose

Public transit vehicles use signage on the outside of the vehicle to indicate important information, such as route number and final destination. Signs may be placed on the front, side, or rear of the transit vehicle. If route and destination information is not legible or readable to persons with visual impairments, then many other modifications to enhance accessibility will be ineffective.

This best-practices report provides key information regarding the use of Light-Emitting Diode (LED) sign technologies to present destination and route information on transit vehicles. It will assist managers and engineers in the acquisition and use of this technology to improve the dissemination of public transit information to persons with visual impairments. It includes information about system design and implementation, and offers lessons learned and recommended practices for successful deployments.

Organization

This report is presented in five sections with supporting bibliographic material.

- The INTRODUCTION briefly describes the project purpose, report organization, and research limitations.
- The BACKGROUND documents current ADA requirements and guidance for presenting messages on transit vehicle destination and route signs. This section also presents the FTA questions of interest that formed the basis for this effort.

- The RESEARCH APPROACH details the methods and procedures used during the course of this project to gather accurate and unbiased data regarding LED sign characteristics that affect readability.
- The RESULTS contains a summary of the relevant information gleaned from standards, guidelines, and best practices identified during the literature review and Subject-Matter Expert (SME) survey process. It also presents a summary of results from the human factors testing portion of this project.
- The CONCLUSIONS AND RECOMMENDATIONS completes the body of the report by synthesizing the results into best practices for the use of LED sign technology to present on-vehicle destination and route messages. This section also contains recommendations for research that will further refine the body of knowledge in the transportation accessibility environment.

Limitations

Many technologies for presenting transit-related information to travelers with visual impairments are discussed in the literature, including roller-curtain and flip-dot/split-flap signs as well as auditory and tactile displays. In addition, the use of these technologies is not limited to external vehicle displays, but extends to displays found in terminals or at stops and transit information centers. By direction of the FTA, this document focuses only on visual aspects of LED technologies designed to present external vehicle route and destination information for travelers with visual impairments. While documented in the vehicle-accessibility literature and recognized as necessary for the overall presentation of information to persons with visual impairments, elements such as auditory, tactile, Braille displays, and information regarding other sensory, cognitive, or mobility-related disabilities are not specifically addressed.

BACKGROUND

This project is part of the Federal Transit Administration (FTA) Strategic Plan, Strategic Goal #2: Mobility and Accessibility to ensure a transportation system that offers choices, and is accessible, integrated, and efficient, for all Americans. This effort continues research that was first documented in *FTA's Bus Signage Guidelines for Persons with Visual Impairments* (1998).

People who have visual impairments are particularly dependent on public transit since their visual status may render them ineligible for a driver's license. Many persons with visual impairments regard public transit as their "lifeline" to employment and the community. Impediments to transit signage readability are one of the obstacles limiting access to public transportation.

Current ADA Requirements and Guidance

The current regulations for external vehicle transit destination signage were developed by the Architectural and Transportation Barriers Compliance Board (Access Board) and first issued in the ADA Accessibility Guidelines (ADAAG), Section 4.30.2, in July 1991. After a period of public comment, these regulations were adopted by the U.S. Department of Transportation and were published in the *Federal Register*, Volume 55, Number 173, pp. 45757-45760, dated Friday, September 6, 1991.

Transit signage regulations are referenced in *Title 49, Code of Federal Regulations; Part 38 Americans With Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles; Subpart B-Buses, Vans and Systems; Section 38.39, Destination and Route Signs*. The text of the regulation citation is as follows (emphasis added):

> § 38.39 **Destination and route signs**.
> (a) Where destination or route information is displayed on the exterior of a vehicle, each vehicle shall have *illuminated signs on the front and boarding side of the vehicle*.
> (b) Characters on signs required by paragraph (a) of this section shall have a *width-to-height ratio between 3:5 and 1:1* and a *stroke width-to-height ratio between 1:5 and 1:10*, with a *minimum character height* (using an uppercase "X") *of 1 inch for signs on the boarding side* and a *minimum character height of 2 inches for front "head signs,"* with "wide" spacing (generally, the *space between letters shall be 1/16 the height* of uppercase letters), and *shall contrast with the background*, either dark-on-light or light-on-dark.

The Access Board also issued a Technical Assistance Manual in October 1992, *Buses, Vans, and Systems* that recommended that signage characters contrast with the background by 70 percent.

Questions of Interest to the FTA

An increasing number of transit authorities are installing LED destination signage on their transit vehicles. LEDs have unique characteristics that differ from static or electromagnetic signage, however, and if not correctly designed and engineered, may be hard to read under various lighting conditions by persons with visual impairments. LED technology has the capability to meet or exceed current ADAAG requirements for message presentation. However, if message characteristics simply comply with ADAAG requirements, they may still not be readable by persons with visual impairments. The FTA, to ensure the best use of LED technology, funded this research effort to address the following questions:

- Do the ADA specifications for destination signs adequately address the needs of persons with visual impairments under various lighting conditions, when applied to LED displays?
- Are minimum character heights of 1 inch and 2 inches for side and front LED route and destination signs respectively, sufficient for persons with visual impairments under various lighting conditions? If these sizes are not adequate, what character size is readable as well as appropriate for vehicle placement? For a given character size, what is the optimum distance of such a sign for readability?
- Are LED route and destination signs that provide multiple messages with alternating text readable by persons with visual impairments under various lighting conditions?
- What color combinations provide the best levels of contrast under various lighting conditions?
- Are persons with visual impairments better able to read words of mixed upper and lowercase letters, or are all capitals preferable, under various lighting conditions?
- Does a wider character width improve readability for persons with visual impairments under various lighting conditions?

The goal of this document is to summarize the findings of this and previous research, and to present the findings in the form of recommended best practices for the presentation of information on LED vehicle signage that is inclusive of the needs of persons with visual impairments.

RESEARCH APPROACH

The FTA developed a plan to gather accurate and unbiased data regarding electronic sign characteristics that affect readability. The developed plan recommended design and implementation best practices for LED signs on transit vehicles for persons with visual impairments. This plan included the following:

- Conduct a detailed literature search of commercial, government, and Internet databases to identify relevant past research efforts; perform a literature review and gap analysis to highlight inadequate or incomplete research areas; and provide recommendations as to which factors should be tested under laboratory conditions.
- Solicit questionnaire responses from selected transit authorities and transit users to address those factors not adequately addressed in the literature and receive first-hand feedback from users and transit authority staff with sign acquisition responsibilities.
- Prepare and conduct human factors testing to address those factors not adequately addressed in the current literature.
- Publish recommendations in an FTA best-practices document.

The first three elements are discussed in additional detail below. This report represents the published best-practices document.

Literature Search, Literature Review, and Gap Analysis

A comprehensive search of both government and commercial literature databases was conducted to identify relevant information. An Internet search was also conducted to identify and retrieve current industry practices, major issues, innovations, standards, guidelines, and human factors research in transit vehicle signage not published in the traditional open literature sources. The material was reviewed to identify the most pertinent results, and selected documents were identified and acquired to use as source material for a gap analysis.

Subject-Matter Expert (SME) Search

A search was also conducted to identify key organizations and SMEs that (1) train, assist, or support persons with visual impairments with orientation and mobility related skills; and (2) design, manufacture or procure transit vehicle signage. The following sections describe the specific methods of identification and contact.

Orientation, Mobility, Aging, and Disability Organizations

The literature database search and in-house knowledge of service providers were starting points for identifying organizations that could assist with the project. Agencies and advocacy groups working directly with persons with visual impairments were included, as were research and health service organizations. These agencies provide not only a clinical perspective to the issues surrounding visual impairments but also insight into how advocacy and assistance programs incorporate the use of buses and trains to help their clients.

Examination of organization websites produced potential contacts and links to other related organizations. Initial contact was established either by telephone or email. A short description of the project was given to each person contacted and their potential role described. Roles include providing expert knowledge, reviewing results, producing data and materials in the project, and helping to coordinate the inclusion of other relevant contributors. Those who agreed to provide assistance were asked if they could provide contact information for additional SMEs.

Transit Sign Vehicle Manufacturers

Transit vehicle sign manufacturers were identified and contacted to obtain information concerning sign specifications or requirements that differed from the existing ADA specifications.

Once the FTA approved the literature search strategy, the list of identified documents, and the SME contacts, a gap analysis technical report, *Bus Signage Guidelines for Persons with Visual Impairments: Electronic Signs* (FTA-VA-26-7026-02.1), was developed to summarize available guidelines, specifications, lessons learned, recommendations, and research findings pertaining to vehicle transit signage design to accommodate persons with visual impairments.

Questionnaire Responses From Transit Authorities and Transit Users

A follow-up needs analysis was conducted to capture input from transit agencies, transit system users, and advocacy groups for persons with visual impairments. Two structured questionnaires were prepared and administered to capture factors that were not adequately addressed in the open-source literature. These surveys provided first-hand feedback from (1) transit agency personnel responsible for the specification and acquisition of transit destination signage, and (2) persons with visual impairments whose best corrected visual acuities ranged from 20/70 to 20/400. The result of this effort allowed for prioritization of subsequent human factors research to address the most important user needs in a cost-effective manner.

Transit Authority Survey

Completed transit authority surveys were received from the Miami Valley Regional Transit Authority, Dayton, Ohio; Los Angeles County Metropolitan Transportation Authority; San Francisco Municipal Railway; Lee County Transit, Ft. Meyers, Florida; the New Jersey Transit Corporation; Maryland Transit Administration; and the Massachusetts Bay Transportation Authority. An analysis of the surveys revealed the need for consistent, quantitative acquisition specifications to be developed and documented in an effort to procure signage that accommodates persons with visual impairments.

Transit User Survey

Identification of individuals to complete the transit user surveys was achieved through direct contact with transit authority advocacy groups, orientation and mobility professionals, national support organizations (e.g., Easter Seals PROJECT ACTION), and knowledge of organizations and advocates for persons with visual impairments.

Gap analysis and survey results identified those sign characteristics that are important to both the transit authorities and the transit user for the clear presentation of vehicle destination information. These efforts narrowed the list of possible variables for investigation and addressed the most troublesome of design and display conditions facing persons with visual impairments as they navigate the public transit system. As such, the human factors research approach was designed to address identified variables under lighting (i.e., daytime, low light, night) and vehicle dynamic (i.e. front sign moving, side-sign moving) conditions stipulated by the FTA.

Human Factors Testing

As a result of the literature and questionnaire data collected and analyzed during the early phases of this task, the FTA determined it was necessary to conduct human factors testing to capture empirical data for the readability of messages presented on existing LED transit-vehicle destination signs. An experimental approach was developed to conduct hypothesis testing of the issues outlined below:

- Do the ADA specifications for destination signs adequately address the needs of persons with visual impairments under various lighting conditions, when applied to LED displays? For a given sign configuration, what is the optimum distance for readability?
- Are LED destination signs that provide multiple messages with alternating text readable by persons with visual impairments under various lighting conditions?
- What color combinations provide the best levels of contrast under various lighting conditions?

This effort represents a further refinement of the existing literature for the presentation of information on LED signage and expands the body of research knowledge in the transportation accessibility environment.

RESULTS

The following sections briefly identify the needs of persons with visual impairments and summarize the major design issues identified from the literature review and human factors testing, including technology descriptions, standards, guidelines, and best practices for current signage methods and electronic signage technologies designed to better communicate with persons with visual impairments.

Visual Impairment Defined

Visual impairment represents a continuum, from those with very poor visual acuity or limited visual field[1] to those who can see light but no shapes, to those who have no perception of light at all. According to Garvey (2002), the U.S. Census Bureau (1997) reported that 3.7% of U.S. citizens (7.7 million people) over 15 years of age "had difficulty seeing words/letters"; this increases to 12.1% for individuals 65 years of age and older. Based on National Center for Health Statistics data it has been estimated that in the United States there are "6.6 million people unable to read printed signs at normal viewing distances." Diseases causing severe visual impairments (glaucoma, cataracts, macular degeneration, and diabetic retinopathy) are common among the aging population as well. With current demographic trends toward a larger proportion of older adults, the incidence of visual impairments will certainly increase. For general discussion, however, it is useful to think of this population as representing two broad groups, those with *low vision* and those who are *legally blind*.

Low vision, for the purpose of this report, includes problems *after correction* that people may describe as dimness of vision, haziness, film over the eye, foggy vision, extreme near- or far-sightedness, distortion of vision, spots before the eyes, color distortions, visual field defects, tunnel vision, no peripheral vision, abnormal sensitivity to light or glare, and night blindness. It does not include acuity below 20/200 or visual fields of less than 20 degrees.

Persons are identified as *legally blind* when their visual acuity (sharpness of vision) is 20/200 (Snellen scale) or worse, in the better eye, *after correction*, or when their field of vision is less than 20 degrees in the best eye after correction. Those who are legally blind may still retain some perception of shape and contrast or of light versus dark, (the ability to locate a light source), they may be totally blind (having no awareness of environmental light), they may be able to read large print, or read signs at close distances.

Destination Sign Technology

Two technologies, printed roller-curtain signs and electromagnetic flip-dot/split-flap signs, have traditionally dominated the transit destination sign market. Each technology offers distinct advantages and disadvantages that are discussed in some detail in a 1998 FTA Report,

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[1] For purposes of this best practices document, diminished visual acuity is defined as having a best-corrected acuity in the range of 20/70 to 20/400 on the Snellen scale. The Snellen scale tests distance visual acuity (distance vision) and is only one of the tests done to assess eyesight. A chart is usually made up of capital letters, numbers, symbols or pictures, which are larger at the top and smaller at the bottom of the chart. This measure of distance vision compares one's distance visual acuity to that of a normal patient. Most eye care professionals are careful to describe 20/20 as normal, not perfect. Visual fields, contrast sensitivity, glare, halos, and other measures of visual function are not assessed with Snellen acuity.

Bus Signage Guidelines for Persons with Visual Impairments (FTA-MD-26-0001-98-1). The sections below briefly summarize the material contained in that report. A summary of the newer hybrid and LED technologies and their respective advantages and disadvantages is also provided[2].

Roller-Curtain Print Signs

Figure 1. Roller-curtain print sign

The traditional roller-curtain print signs have been used successfully for many years in a wide variety of transit applications. This technology offers substantially lower acquisition costs, and utilizes a wide variety of colors and graphics to present transit information. However, this technology is limited in the number of destinations that can be accommodated within the diameter of the roll that fits inside the overhead compartment in most transit vehicles. In addition, much effort, and potentially cost, can be spent in updating the signs with new routes or destinations. This process involves "splicing" in new text or replacing the entire curtain roll.

Electromagnetic Flip-dot/Split-flap Signs

This sign technology consists of matrices of dots or split-flaps with an electromagnet behind each dot that reverses polarity on a signal from a driver-controlled central processor. A change in polarity causes the dot to flip over or the split-flap to open, thereby exposing either the painted (typically reflective yellow, though other colors are available) or the black side. A more extensive treatment of flip-dot/split-flap sign design guidelines is provided in *Bus Signage Guidelines for Persons with Visual Impairments* (FTA-MD-26-0001-98-1, 1998).

Figure 2. Flip-dot sign

Hybrid Signs

Recent advances in flip-dot/split-flap signs include the introduction of LED or fiber optic illumination of the individual painted surfaces. This technique provides additional "brightness" for both night and bright sunlight viewing; however, the use of moving parts (i.e., the disks and flaps that are electro-mechanically flipped) can present associated maintenance concerns and costs.

Light-Emitting Diode (LED) Signs

Technological advances have generated an emerging interest in electronic information systems utilizing LED signs to present external vehicle transit destination information. This sign technology presents its own set of advantages and disadvantages, and while mentioned briefly in the 1998 FTA guideline document, it is the primary focus of this document.

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[2] Material in this section is drawn or quoted primarily from the Transit Cooperative Research Program ((TCRP), Transportation Research Board, 1996) Report 12, *Guidelines for Transit Facility Signing and Graphics* and a 1998 Federal Highway Administration report (DTFH61-96-R-00061, Task E Working Paper), *Optimizing Changeable Message Sign Design and Use*.

An LED is a semiconductor device. A small current is passed through the semiconductor material that causes electrons in the material to be temporarily excited (raised in energy) such that they move to a higher level energy state than their normal position. When the electrons return to their normal energy state, photons (specific quantities of light energy) are emitted. The type of semiconductor material in the LED determines the color of the light emitted.

Advantages of LED displays, compared to other transit system display technologies include the following:

- Advancements in LED technology include the development of brighter devices that emit a broad range of colors across the entire visible spectrum
- Can display text in a wide range of character heights (including ADA compliant)
- Lower cost due to extended life span (~ 100,000 hours of continuous operation) and low power consumption
- Solid-state design resists vibration (making LEDs suitable for on-vehicle use)
- Flat configuration suitable for use in limited space situations
- Animation capability (thus more suitable for advertising)

Disadvantages of LED displays, compared to other transit system display technologies include the following:

- May be more subject to glare than other types of displays
- Brightness and color consistency may be affected by ambient temperature
- The electronics are heat sensitive; therefore the ventilation fans required to maintain a consistent temperature may eliminate realized power savings
- Readability may be distorted when viewed at extreme angles

In addition to the above disadvantages, LED displays may require larger character size to be legible from the same distance as other technologies. Nevertheless, LED displays are most suitable for on-vehicle or vehicle-stop displays where space limitations, vibration, and the desire for good visibility under most lighting conditions exist. Implemented correctly, systems that use this technology may provide a significant benefit to all passengers and specifically for persons with visual impairments.

Standards, Guidelines, and Research

The same basic design principles apply to LED destination signs as for all information systems for public transport—clarity, legibility, readability, relevance, and accessibility. The following sections contain excerpts from relevant research and guideline documents identified during the literature search portion of this project. Not every standard or research document covers all aspects of designing LED signs for persons with visual impairments. Information not directly related to transit vehicle signage, but still relevant to text readability for persons with visual impairments, is included when appropriate. Finally, not all documents identified contained quantitative guidelines or standards that could be implemented directly in the engineering or design process. In many cases the information is presented in qualitative terms (e.g., display should be bright) or as best practices for the implementation of LED signage systems to accommodate persons with visual impairments.

***American Public Transit Association (APTA) Guidelines* (1997)**

The *Standard Bus Procurement Guidelines* (SBPG) issued by APTA are a model for solicitation of offers and contracts for the supply of transit buses. They are intended to be a starting point for a transit agency assembling a solicitation of offers and to assist in a cost-effective procurement. SBPG *Part 5: Technical Specifications* defines requirements for a heavy-duty transit bus which, by the selection of specifically identified alternative configurations, may be used for both suburban express service and general service on urban arterial streets. It is intended for the widest possible spectrum of passengers, including children, adults, older adults, and persons with disabilities. The destination sign design guidelines offered within *Part 5* of the SBPG document are as follows (emphasis added):

- An automatic electronic destination sign system shall be *furnished on the front*, *on the right side near the front door*, and *on the rear of the vehicle*. Display areas of destination signs *shall be clearly visible in direct sunlight and/or at night*. The sign system shall provide optimum visibility of the message display units for passengers and *shall meet applicable ADA requirements defined in 49 CFR, Part 38.39*.
- The *front destination sign* shall have no less than 1,689 octagonal dot pixels, 16 rows by 105 columns, with a *message display area of not less than 9.8 inches high by not less than 63 inches wide*.
- The *side destination sign* shall have no less than 672 octagonal dot pixels, having at least 8 rows and 84 columns with a *message display area of not less than 3.15 inches high by not less than 30 inches wide*.
- The *rear route number sign* display area shall have no less than 448 octagonal dot pixels, having at least 8 rows and 28 columns with a *message display area of not less than 6.1 inches high by not less than 11 inches wide*.
- Sign displays shall have alternating message capability with programmable blanking time between message lines as may be required. *Variable blanking times shall be* programmable *between 0.5 to 25 seconds in duration*.

***Best Practice Manual for the Publication and Display of Public Transport Information* (2000)**

The Aging and Disability Department, in association with the Royal Blind Society of New South Wales, produced this manual in recognition that many older adults and persons with disabilities have difficulty with information about the public transport system. The stated aim of the manual is to assist the operators of public transport services to develop clear and understandable information that meets the diverse needs of their passengers.

Route numbers. These should be displayed on the front, side, and rear of vehicles. Often the layout of terminals or the placement of bus stops means that passengers may approach the vehicle from the rear. Numbers at the side where boarding occurs make it easy for passengers to confirm that they are boarding the correct service. Failure to do this may result in unnecessary confusion and delay.

The size and legibility of route numbers are particularly important on vehicles for the following reasons.

- Some people may have difficulty reading information that is moving.
- It is necessary to be able to identify a route number from a considerable distance to hail the vehicle in time for it to stop safely.
- It may be necessary to identify a route number in a crowded street or interchange or where multiple buses are grouped together in line.

In Canada it is recommended that *route numbers outside the front and rear of buses be a minimum of 200 mm (7.9 in.) high* (Hunter-Zaworski & Watts, 1994).

Destination boards. Regular transit users may need only the route number to identify the service they want whereas other passengers will require more detailed information. The destination boards displayed at the front of the bus generally provide this.

As a rule of thumb, the final destination should be shown with major points along the route indicated. This is particularly important if there is no obvious route or if the service deviates from what seems to be a direct route. Scrolling destination signs are an option, but *the scroll rate should be slow enough to allow people the time to read and comprehend the information*.

As with other text, *high contrast with the background is necessary. Yellow characters on a black background are a good choice* (Marner, 1991).

Transportation Research Board, Transit Cooperative Research Program (TCRP)

The TCRP, proposed by the U.S. Department of Transportation (DOT), authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), and established under FTA sponsorship in July 1992, serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet the demands of upgrading transit systems, expanding service areas, increasing service frequency, and improving transit system efficiency.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems and support, and complement other ongoing transit research and training programs. The next sections provide excerpts from two TCRP reports containing relevant transit signage guidelines and recommendations.

Guidelines for Transit Facility Signing and Graphics—TCRP Report 12 **(1996).** This report was designed to assist transit operators in the use of appropriate signs and symbols for their facilities. These guidelines describe the use of signs and symbols that provide for the safe and efficient movement of passengers to and through transit facilities. These guidelines also assist transit operators in providing passenger information systems that encourage the use of transit by new users, infrequent riders, and individuals with disabilities.

While not specific to destination signage, a section of the report, devoted to electronic visual information displays, describes the characteristics of LED displays (size, dot pitch, character formation, and display luminance) that affect performance as follows (emphasis added):

- **Size**–The diameter (or width if the display is a matrix of square LED elements) of one LED is referred to as the "dot size" of the display. *The prevalent dot size for transit system displays is currently 5 mm (0.197 in.)*.
- **Dot Pitch**–*The dot pitch, or distance between dot centers, which is currently prevalent in transit system displays is 6 mm* (.236 in.). Greater spacing between dots produces a reduction in readability. This is due to the loss of a cumulative effect whereby adjacent LEDs act together to form an image, rather than as individual dots.
- **Character Formation**–To form a character, *a minimum dot matrix of 7 x 9 is preferred*. *Characters must be double stroke* (made up of two adjacent rows of dots).
- **Display Luminance**–The display *must be capable of enough brightness to be visible in the intended environment*. If lighting conditions are variable, this will make the display too bright for the lower illumination levels. Therefore, *dimming controls or sensors should be used for displays with varied ambient conditions*. Current indoor, semi-outdoor, and ultra-bright versions of LED blocks for different illumination levels are available. Their ratings are given in Table 2.

Table 2. LED Ratings for Different Illumination Levels

Use*	Color	Display Luminance (cd/m^2)
Indoor (V&P)	Red-green-amber	100
Outdoor (V)	Red-green-amber	500
Outdoor (P)	Gradient control red (ultra bright)	1000

*V=Vehicles P=Platforms

***Passenger Information Services: A Guidebook for Transit Systems—TCRP Report 45* (1999).** The objective of this report is to produce a clear and practical guidebook to assist transit professionals in making transit information more accessible and user friendly for transit systems of varying complexity. The guidelines include a compilation of principles and design format details that are part of all passenger information aids. This research did not develop a high technology, paperless approach to passenger information; rather, it focused on traditional media for presentation of information, such as schedules, maps, and signage. Therefore, this section first offers recommendations specific to traditional bus header/identifications signs. It then presents general recommendations and guidelines to help make transit information systems easier to read and understand.

- A *bus header/identification sign is mounted on the bus front* (at least, rear and sides, if possible) in static or electronic form, to identify the route number and name (if any) and, if applicable, the direction in which the bus is traveling. The sign should be visible to passengers waiting at the bus stop.
- Route number *must be legible to persons with low vision* (20/200), in daylight conditions, *at 30 feet* (*i.e., six-inch high characters and/or symbols, preferably larger*).
- *Placement* should be *high on the bus body, above the window lin*e.
- Display may be by changeable message sign. Back illumination or flood illumination should be provided for night operations.

For general application to transit industry information systems, the following suggestions apply:

- *Use all capital letters* (uppercase) *for stop designations*, terminals, and other short labels.
- Use uppercase and lowercase letters for long legends and instructions.

Given that viewing distances for signs will vary according to where they are placed in relation to the intended reader, this guidebook specifies most sign character sizes in terms of visual angle. This is expressed either in degrees of visual angle or in radians. The visual angle is the angle that the letter or other object makes up in the visual field of the reader. A person with "normal" vision (20/20) will just be able to make out letters that are 1/12 degrees (0.00145 radian) of arc. ADA requirements call for the major route designators and other essential information to be visible from 30 feet away by individuals with low vision. This translates into a requirement for approximately 1-degree letters (0.017 radian). Sample 1-degree and ¼-degree (15 min) character sizes are shown in Table 3.

Table 3. Sample 1-Degree and ¼-Degree Character Sizes for Given Viewing Distance

Viewing Distance	One-Degree Character Height	15-Minute Character Height	Viewing Distance	One-Degree Character Height	15-Minute Character Height
3 feet	0.6 inches	0.2 inches	30 feet	6.1 inches	1.5 inches
6	1.2	0.3	40	8.2	2.0
9	1.8	0.5	50	10.2	2.6
12 feet	2.4 inches	0.6 inches	60 feet	12.2 inches	3.0 inches
15	3.0	0.8	70	14.3	3.6
18	3.7	0.9	80	16.3	4.1
21 feet	4.3 inches	1.0 inches	90 feet	18.4 inches	4.6 inches
24	4.9	1.2	100	20.4	5.1
27	5.5	1.4			

For signs and printed materials that are not black-on-white (especially for bus stop signs, which may be a unique color for visibility against other street signs), a contrast formula can help determine how well text or other elements will stand out against a background. The defining formula is provided as follows:

Contrast (%) = $L_c - L_b/L_b$

Where:
L_c = Luminance (brightness) of characters
L_b = Luminance (brightness) of background

"Luminance" is measured in ft-lamberts or in candela/meter^2

NOTE: If the reflectances (in percent) of the characters and the sign background are known, these values can be substituted for the L_c and L_b in the equation above to find the contrast. Black type has a reflectance of 10%, and white paint has a reflectance of 90%. Substituting in the equation above, the contrast would be

Contrast = ((10-90)/90) x 100 = -88.9%

This formula produces “negative” contrast for signs and publications when the letters are dark against a light background, and “positive” contrast otherwise. Contrast for all signs, schedules, and publications should be at least 70 percent.

The Public Service Vehicle Accessibility Regulations 2000

This United Kingdom requirements document is intended to provide guidance for those in the manufacturing and operating industries. *The Public Service Vehicles Accessibility Regulations 2000* prescribes the *minimum* acceptable criteria to meet the needs of persons with disabilities. The guidance explains the intention of the regulatory requirements and provides advice on *best practices* that should be followed, recognizing that there may be circumstances in which design or operational constraints apply.

A regulated public service vehicle shall be fitted with a route-number display and a destination display in the following positions:

- On the front of the vehicle, as close as practicable to the part of the windscreen that is within the driver’s field of vision; and
- On the near-side of the vehicle adjacent to the entrance which is closest to the front of the vehicle at a height of not less than 1.2 meters (3.9 ft.) to the lower edge of the display characters and not more than 2.5 meters (8.2 ft.) to the upper edge of the display characters measured from the ground and, if fitted with a kneeling system, with the vehicle in the normal condition for vehicle travel.
- The front display may be fitted above the windscreen or, as low as practicable within the windscreen area, but above the driver’s field of view. It must not be placed in any position that may obscure the driver’s field of view.
- A regulated public service vehicle shall be fitted with a route-number display on the rear of the vehicle.

Any *route-number display* shall be capable of displaying the following:

- Characters not less than 200 mm (7.9 in.) in height on the front and rear of the vehicle and not less than 70 mm (2.8 in.) in height on the side of the vehicle
- Characters that contrast with the display background
- Characters that are provided with a means of illumination
- Not less than three characters

Any *destination display* shall be capable of displaying the following:

- Characters not less than 125 mm (4.9 in.) in height when fitted to the front of a vehicle and not less than 70 mm (2.8 in.) in height when fitted to the side of a vehicle
- Characters that contrast with the display background
- Characters that are provided with a means of illumination
- Not less than fifteen characters
- White or bright yellow lettering on a black background is most clearly visible

- LED/LCD or other electronically generated characters should only be used if they can offer the same clarity, both night and day, as a conventional roller-blind display
- Destination information shall not be written in capital letters only. The use of both upper and lowercase text helps ensure that words that are not completely clear and legible to persons with a degree of vision impairment or learning disability, are still identifiable through shape recognition of the word

***Transit Vehicle Signage for Blind or Visually Impaired Persons* (1996)**

The research note, *Transit Vehicle Signage for Persons Who Are Blind or Visually Impaired*, by Joffee (September—October 1995 issue) describes, in part, the results of human-factors research that was completed under a subcontract to the American Foundation for the Blind (Bentzen, Easton, Nolin, & Mitchell, 1994). The results of this FTA-funded research were used to develop the recommendations found in the 1998 FTA document, *Bus Signage Guidelines for Persons with Visual Impairments* (FTA-MD-26-0001-98-1). This is the only empirical research, as can be determined, with persons with a range of visual acuities that uses any type of electronic signage in a dynamic situation similar to the topic of this project (e.g. a vehicle or sign moving toward a stationary reader). Admittedly, the research did not use LED signs; however the matrix nature of flip-dot and LED signs has important similarities. Both are likely to require greater character height for the same legibility distances.

***Specifications for Transit Vehicle Next-Stop Messages* (1996)**

Bentzen and Easton (1996) project was undertaken to determine optimum characteristics to promote legibility of internal vehicle LED next-stop message signs by persons with varying visual acuities, including both individuals having no visual impairments and those who are legally blind. Characteristics of LED next-stop message signs considered relevant to this report were color, letter characteristics, inter-character spacing, streaming versus paging[3], and change rate.

The project obtained both objective data on legibility of messages displayed to 84 participants riding buses, and subjective data on legibility of messages displayed to three focus groups seated in a room. The following items summarize the relevant results of that research effort:

- **Color**–One-word green messages were significantly more legible than red messages at the fast streaming rate and there was a strong preference for green next-stop message signs. Participants in both post-experimental focus groups suggested that advertising messages and next-stop messages should be different in color.
- **Letter characteristics**–Both objective measures of legibility and subjective judgments indicate that the 5:7 character width-to-height ratio is more legible than the 6:7 character width-to-height ratio. The results of this research indicate that there are very real differences in legibility of LED letters having different proportions. The more legible 5:7 ratio is slightly wider than the minimum 3:5 width-to-height permitted by ADAAG; the less legible 6:7 ratio is somewhat

[3] Streaming text is characterized by the lettering appearing to "travel" across the display area from left-to-right or right-to-left. Paging text appears to fill the display area, is static for a period of time, and then is replaced with entirely new text material.

narrower than the maximum 1:1 width-to-height permitted by ADAAG. This suggests that, at least for dynamic in-vehicle LED signs to be read at distances of 3-33 feet, letters having width-to-height ratios equal to or wider than 6:7 should not be permitted.

- **Inter-character spacing**–The pre-experimental focus group of persons with visual impairments found messages having inter-character spacing of two stroke widths (that is, 2:7) to be subjectively easier to read than messages having inter-character spacing of just one stroke width (1:7). This is consistent with the findings of research on flip-dot signs. This is a much wider inter-character width than currently suggested by ADAAG. The results of this research indicate that for in-vehicle changeable message LED signs to be read at distances of 3-33 feet, an inter-character spacing of 1:16 (as suggested by ADAAG) would definitely not result in optimal legibility for persons having visual impairments.
- **Streaming versus paging**–Static signs are more legible than streaming signs. The objective measure of legibility for streaming versus paging signs showed highly significant differences favoring streaming signs over paging signs. One of the two post-experimental focus groups, however, tended to prefer paging signs.
- **Change rate**–There was an objective effect of rate on legibility that interacted with placement. The best legibility for two-word messages was achieved for messages that changed at the slower rate (2.74 seconds per frame dwell time).

Relevant recommendations from this report are as follows:

- LED next-stop message signs should use a character that is 5x7 (character proportion 5:7), having all capital characters with a one-pixel-wide stroke width (1:7).
- LED next-stop messages should have an inter-character distance of two stroke widths (2:7).
- Where message length is short enough to fit within the length of an LED sign, the message should be static (that is, it should not stream or page).
- Where message length is too long to fit within the length of an LED sign, the message should stream with a dwell time of 2.74 seconds.
- Paging motion should not be used for next-stop messages.
- Advertising messages and next-stop messages should be different in color.

***Synthesis on the Legibility of Variable Message Signing (VMS) for Readers With Vision Loss* (2002)**

The goal of Garvey's research was to gather information on the legibility of VMS for persons with visual impairments with the intent of identifying the features of current and prospective VMS technology that can be improved to better serve the needs of this user group.

The research conducted for this report identified the existence of certain design criteria that, if met, will be capable of significantly improving the legibility of VMS for a large percentage of individuals with vision impairments. A summary (Table 4) of recommendations regarding the application of current knowledge to future VMS design, and recommendations for future research to fill the gaps in that current knowledge was provided.

Table 4. Recommended Values for VMS Characteristics, Issues and Future Research Needs

VMS Characteristic	Recommended	Issues and Future Research
Letter height for VMS on vehicles	Not less than 10 inches	• Research should be conducted to determine what letter height will optimize reading speed and legibility distance for individuals with vision impairments reading dynamic messages.
Letter height for VMS in facilities	Not less than 6 inches	
Letter Width to height ratio	0.7 to 1.0	• Existing research on this variable is fairly strong and, at a minimum, supports the use of a 5x7 versus a 4x7 character matrix.
Stroke width to height ratio	0.2	• Existing research on this variable is fairly strong and supports the use of a 1:5 ratio.
Text color	Green or yellow	• Existing research indicates that these two colors provide the best legibility for readers with vision impairments. • Additional research should be conducted to determine if other colors now available in high-brightness LEDs provide any benefit to individuals with vision impairments.
Font	5x7 for uppercase 7x9 for lowercase	• Existing research on this variable is fairly strong.
Luminance	Night: 30cd/m^2 Day: >1,000cd/m^2	• Existing research on this variable is fairly strong for individuals without vision impairments. • Additional research should be conducted to determine if these levels are sufficient for individuals with vision impairments. • European standards currently under development should be tracked to determine measurement methods/recommended levels.
Luminance contrast	(Lt-Lb)/Lb = 8 to 12	• Existing research on this variable is strong for individuals without vision impairments. • Research should be conducted to determine if these levels are sufficient for individuals with vision impairments.
Inter-character spacing	25 to 40% Letter height	• Existing research on this variable is strong.
Inter-word spacing	75-100% Letter height	• Existing research on this variable is strong.
Inter-line spacing	50 to 75% Letter height	• Existing research on this variable is strong.
Case	Uppercase or mixed-case for single words Lowercase for longer textual messages	• Existing research on this variable is strong; however attaining high-quality lowercase letterforms using a matrix format is difficult. If this cannot be attained, uppercase letters are preferable.
Contrast orientation	Positive	• Existing research on this variable is strong for individuals without vision impairments. • Research is needed to determine if the findings apply to individuals with vision impairments.
Sign width	Dynamic text should be capable of displaying 6-7 characters	• Additional research on this variable should be conducted to determine if this basic research finding holds up in real-world VMS reading by individuals with vision impairments.
Paging or streaming	Streaming	• Additional research should be conducted.

VMS Characteristic	Recommended	Issues and Future Research
Static display time	10 Seconds	• This is a very weak recommendation and very much in dispute. • Additional research must be conducted to determine appropriate reading times for sign comprehension by individuals with vision impairments

Note: Adapted from Garvey (2002).

Generally Accepted Human Factors Best Practices

Many generally accepted human factors guidelines are noted and incorporated in the information presented in the previous sections. Additional best practices are presented in this section.

***Woodson, Tillman, and Tillman* (1992).**

- Any bus that will be used by the public should be configured so that persons with disabilities and older adults are not excluded from its use and/or put under stress because of the difficulties imposed.
- The principal external feature of concern to the passenger is bus identification. Signs should be located both on the front and sides of the bus. The front sign should be positioned so that sun reflection will not obscure the information. All signs should have illumination so that they can be read at night.

***Vanderheiden* (1997).**

- Make letters and symbols on visual output as large as possible/practical.
- Use uppercase and lowercase type to maximize readability.
- Make sure that…
  - Leading (space between the letters of a word),
  - The space between lines, and
  - The distance between messages is sufficient that the letters and messages stand out distinctly from each other.
- Use high contrast between text or graphics and background.
- Keep letters and symbols on visual output as simple as possible.
- Use only black and white or use colors that vary in intensity so that the color itself carries no information (for persons with colorblindness).
- Minimize glare (e.g., by employing filtering devices on display screens and/or avoiding shiny surfaces and finishes).
- Provide the best possible lighting for displays.
- Provide adjustable speed for dynamic displays.
- Avoid the color blue to convey important information.

Federal Transit Administration Human Factors Testing

The FTA conducted human factors research to generate additional empirical data for the readability of messages presented on LED transit-vehicle destination signs. This effort continued research first documented in the FTA's *Bus Signage Guidelines for Persons with Visual Impairments* (May 1998 Final Report). The experimental approach followed, as closely as practical, the design adopted for establishing the 1998 guidelines.

TwinVision® Chromatic & All LED, automatic electronic Passenger Information Display Sign Systems (PIDSS) were used in this study. The display units were installed on an Alameda-Contra Costa Transit District (AC Transit), Oakland, California bus made available through arrangement with transit authority personnel. The front sign was mounted near the top edge of the body (above the windshield), in an enclosed but accessible compartment. The side sign was located on the curbside of the bus near the front door.

Sign message content comprised six-letter, two-syllable, common last names not associated with transit routes or destinations in the area where the study was conducted. Digital National Television System Committee (NTSC) video images, taken along a straight, level, abandoned runway and tarmac (Figure 3) located at Alameda Point Northwest Territory, Alameda, California, were produced for subsequent controlled presentation to experiment participants.

Figure 3. Alameda Point runway

Filming occurred under the lighting conditions noted in Table 5.

Table 5. Environmental Lighting Conditions

Intensity Range (cd/m^2)		
Daytime (> 3.18×10^1)	Low Light (> 3.18×10^{-3} and ≤ 3.18×10^1)	Night (> 3.18×10^{-6} and ≤ 3.18×10^{-3})

Environmental and display condition extremes that might have induced unacceptable nuisance variables such as excessive or uncontrolled glare were avoided when possible.

This study was conducted with front- and side-sign character heights maintained at the maximum possible for the sign technology being used in the study. In the case of the Chroma IV front sign, the character height was 7.9 inches. The Chroma I side-sign presented 4.2-inch-high characters. Character case was held constant during this investigation, with all sign information presented in uppercase lettering only. Inter-character spacing was held to not less than 1.5 times stroke width during testing. Sign information displayed was double stroke (two dots wide), having stroke and character proportions complying with the ADAAG 4.30.2. All sign displays consisted of pixels utilizing high-intensity LEDs for outdoor environmental performance. The sign system had multilevel intensity changes that adjusted automatically as a function of ambient lighting conditions. The Chroma IV front sign presented sign information using five different letter-color conditions (Red–627 nm, Green–529 nm, Blue–472 nm, Amber–575 nm, RGB White–473 nm). The Chroma I side-sign presented Amber with a 590-nm wavelength only. The messages on both the front and the side-signs were presented under three character-dynamic formats: static (i.e., no movement), paging with a 2.5-second delay, and paging with a 4-second delay[4]. The sign technology available at the time the experiment was conducted did not allow for

4 Paging is defined as having a message presented for a period of time and then disappearing all at once before the same or a new message is presented in its entirety.

the testing of streaming. All messages were tested under the dynamic condition of the sign moving and the readers stationary.

Ninety individuals were recruited to complete the study. A representative sampling of age ranges for the transit-rider population was included in the study (range 18-93 years old). Both male (n = 45) and female (n = 45) participants were included in the study. As shown in Table 6, persons having binocular visual acuity better than 20/70 were categorized as having normal vision (Group 1), persons having binocular visual acuity less than or equal to 20/70 but better than 20/200 were categorized as having low vision (Group 2), and persons having binocular visual acuity less than or equal to 20/200 but better than or equal to 20/400 were categorized as legally blind (Group 3).

Table 6. Visual Acuity Categorization

	Binocular Visual Acuity
Group 1 Normal vision	Better than 20/70
Group 2 Low vision	Less than or equal to 20/70 but better than 20/200
Group 3 Legally blind	Less than or equal to 20/200 but better than or equal to 20/400

Participants afflicted with peripheral field loss, commonly due to retinitis pigmentosa[5] or glaucoma, and persons who have central field loss, commonly due to macular degeneration[6], were also included in the experiment. Participants reporting no visual ability (i.e., total blindness) were not included.

A Digital Video Disk (DVD) containing the digital NTSC recorded video was produced by a professional videographer using a Panasonic® AJ-D400P DVCPRO camera at 3 1/2-inch FIT CCD's providing 410,000 pixels and a Canon® YH18x6.7 zoom lens. Using a high-quality projector, the video was projected on a large screen maintaining the same relative size and visual angle experienced during recording. Each trial commenced with the target vehicle entering the field of view traveling at 25 miles per hour and smoothly slowing to a stop within 400 feet over 20 seconds. Participants were asked to read aloud the word they saw on either the front or the side destination sign as each came into view and was readable. Since the primary object of this research was to determine the distance at which electronic signs of different configurations can be read correctly, the participants were asked to respond as soon as they were confident they could read the sign. However, they were allowed to correct their responses during the 20 seconds if they provided an incorrect response initially. Response time was the dependent variable in this experiment. Time was converted to distance measures and is plotted in Figures 4 through 9.

5 Retinitis pigmentosa is an inherited condition of the retina in which specific photoreceptor cells, called rods, degenerate. The loss of function of these rod cells diminishes a patient's ability to see in dim light and with time can also diminish their peripheral vision.

6 An ophthalmic condition characterized by progressive destruction and dysfunction of the central retina (macula).

Front Sign Results

Figures 4 through 6 plot the mean reading distance (as computed from the response time) for the front signs against the 30-feet ADA requirement for essential information. The data suggests that current LED signage requirements may not be capable of conveying information to passengers with vision impairments reading messages on a transit vehicle as it slows and comes to a stop, even when configured to display characters in compliance with ADAAG. With very few exceptions, the two groups with the poorest visual acuity were unable to read the sign from this distance regardless of the color or format.

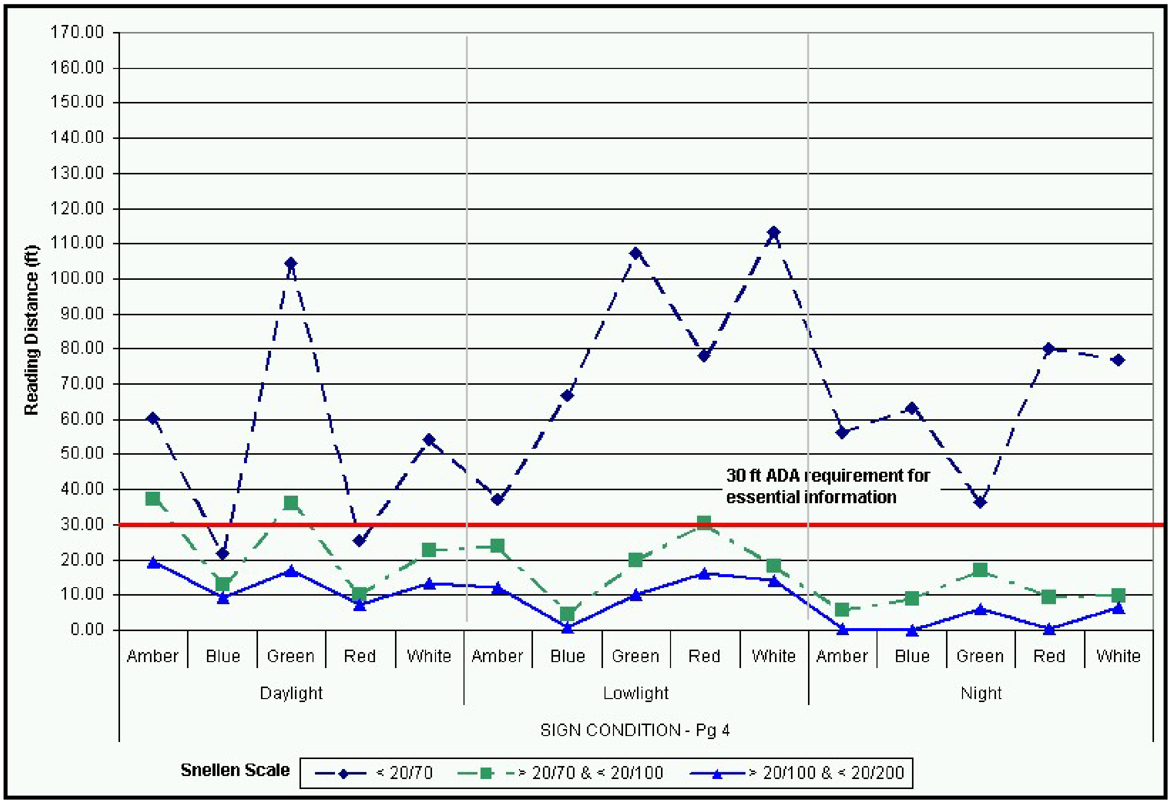


Figure 4. Paging at 2.5 seconds: Mean reading distance (front) by lighting, acuity group, color, and format.

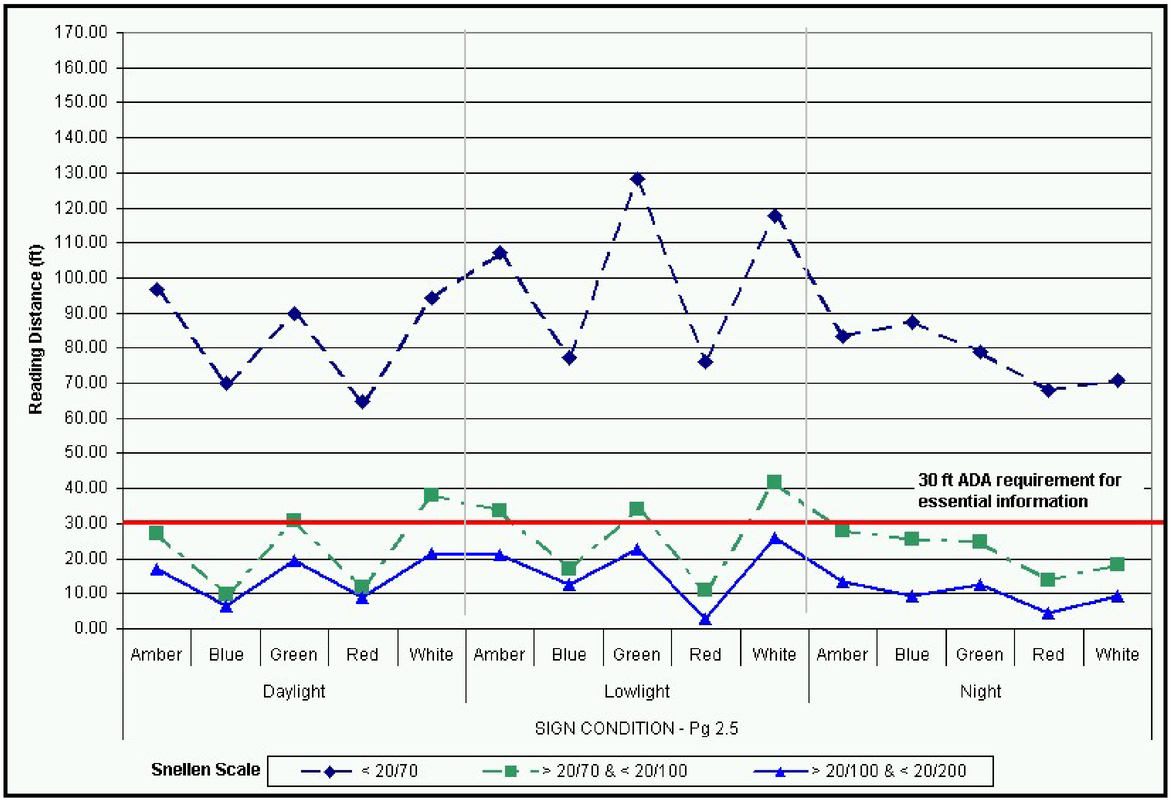


Figure 5. Paging at 4 seconds: Mean reading distance (front) by lighting, acuity group, color, and format.

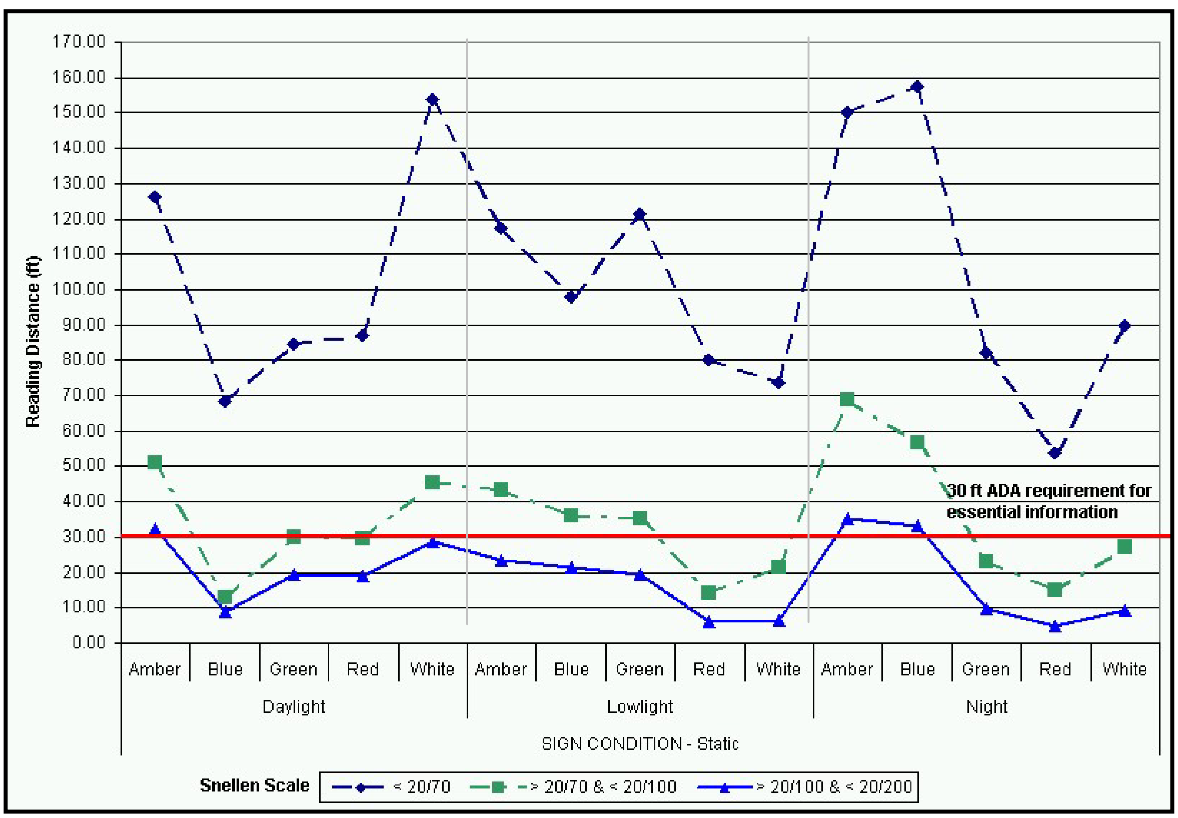


Figure 6. Static: Mean reading distance (front) by lighting, acuity group, color, and format.

Front sign results indicate that the static/amber display was the only configuration that appeared consistently readable across all lighting types and acuity groups. The static/blue display was readable in the low light and night conditions although not as readable in the daylight condition. The static format appears to be readable regardless of the environmental lighting condition or participant acuity. Other configurations were found to be readable across all acuity levels in the low light condition (e.g., Pg 2.5/Amber, Static/Green, Pg 2.5/Green). However, these configurations were not as readable for all acuity groups in any other lighting condition. Red appears least readable for any group in any condition[7].

Upon investigation of the study results, a pattern emerges in which colors in the blue range, and, to a certain extent, the green range, of the visual spectrum appear more readable in lower lighting conditions while those in yellow range appear more readable across all lighting conditions (see Figure 7).

Figure 7. Visual light spectrum and results.

Side Sign Results

Figures 8 through 10 plot the data for the side-sign component of the study. This portion of the study was limited due to the fact that only one color was used. In considering the analysis of the side-sign configurations, no single configuration was found to be readable for all three lighting conditions. However, 4-second paging (Figure 9) was generally found to be readable from the greatest distance for the acuity groups and lighting conditions.

It was not obvious why the results for paging signs were better than the static sign; however, one hypothesis is that paging allowed participants to separate the sign from other visual noise on the bus such as writing above the sign, window, and door structures. Additionally, the 4-second paging (Figure 9) condition gave participants more time to read the sign once the signal had been detected, which may account for why it was the better format across all lighting conditions. Unfortunately, the empirical evidence from this study and the documented literature resources appear to be inconclusive for this configuration.

This study also revealed that visual angle most likely impacted the ability of people to read the side-sign. In fact, the average participant could not read the side-sign from 30 feet away under any condition and thus the signage did not meet the ADA specifications for display of essential information even for persons with unimpaired vision.

7 *For more information regarding the test plan and experimental results please contact Mr. Brian Cronin, P.E.; Federal Transit Administration, 400 7th Street, S.W. Room 9402, Washington, DC 20590;* brian.cronin@fta.dot.gov

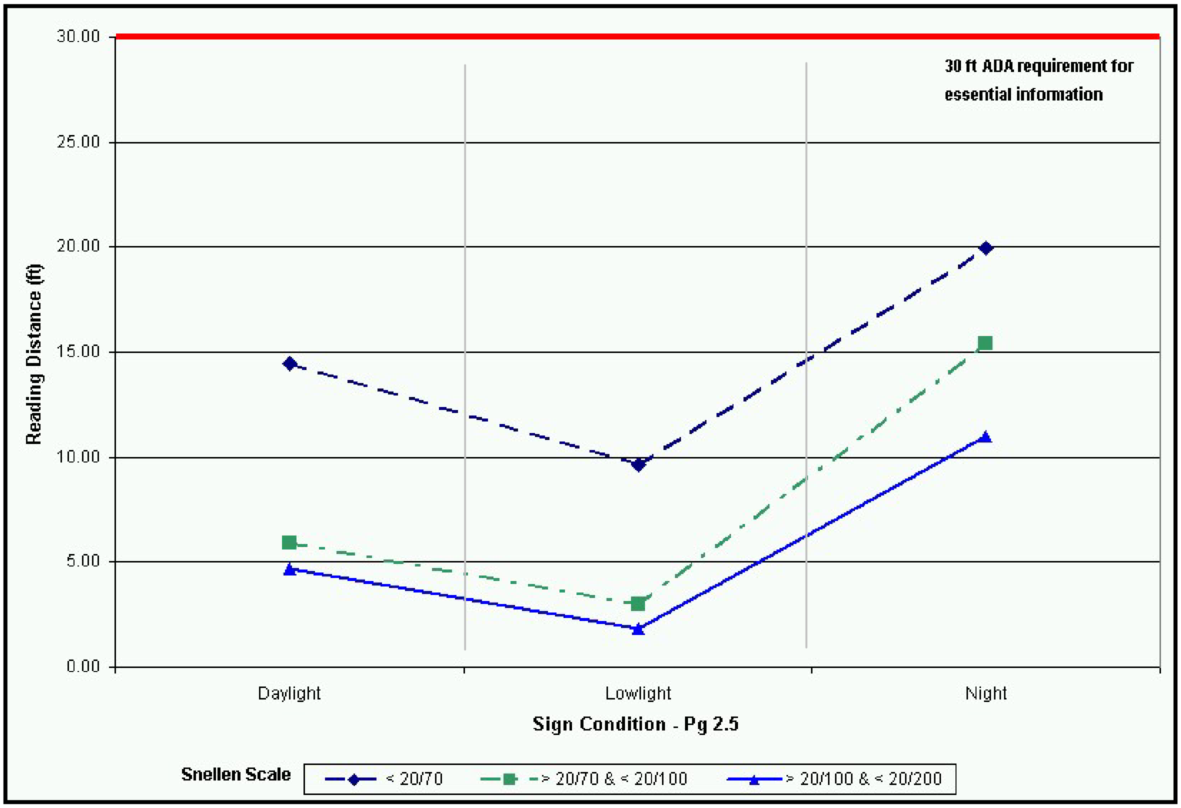


Figure 8. Paging at 2.5 seconds: Mean reading distance (side) by lighting, acuity group, and format.

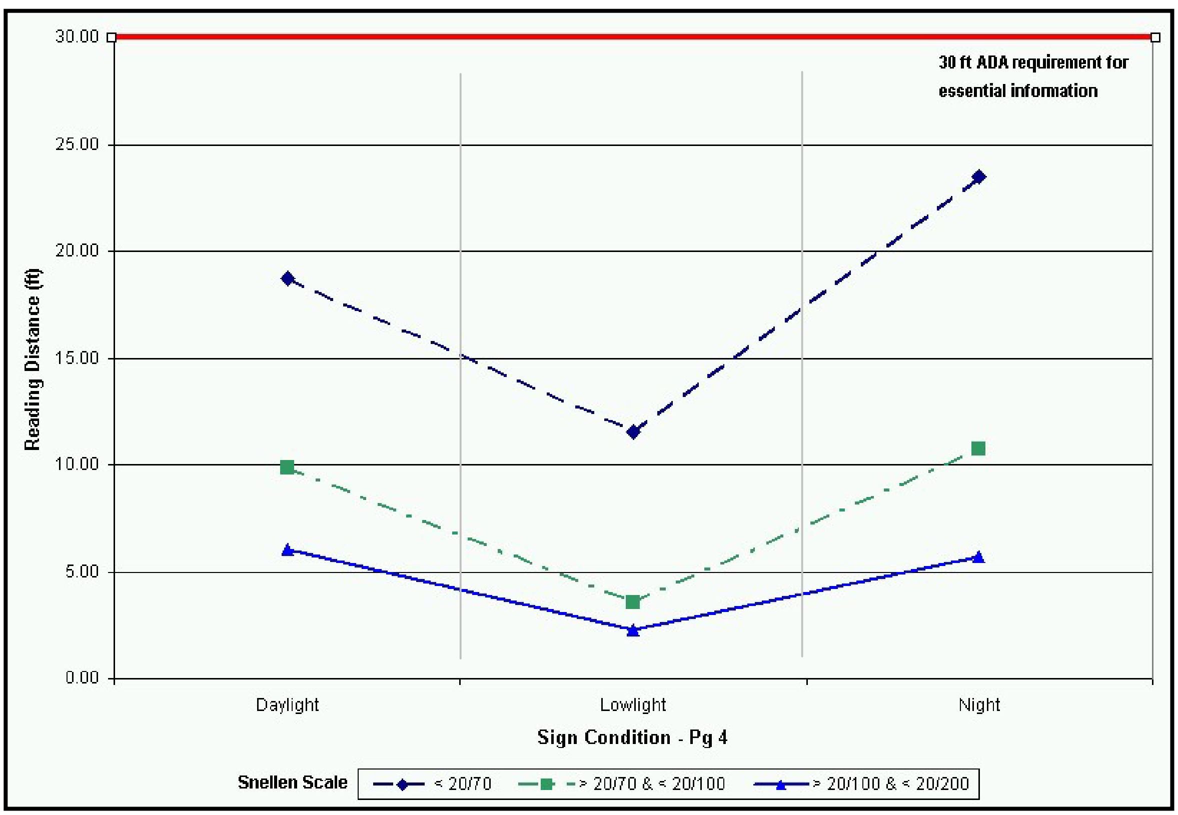


Figure 9. Paging at 4 seconds: Mean reading distance (side) by lighting, acuity group, and format.

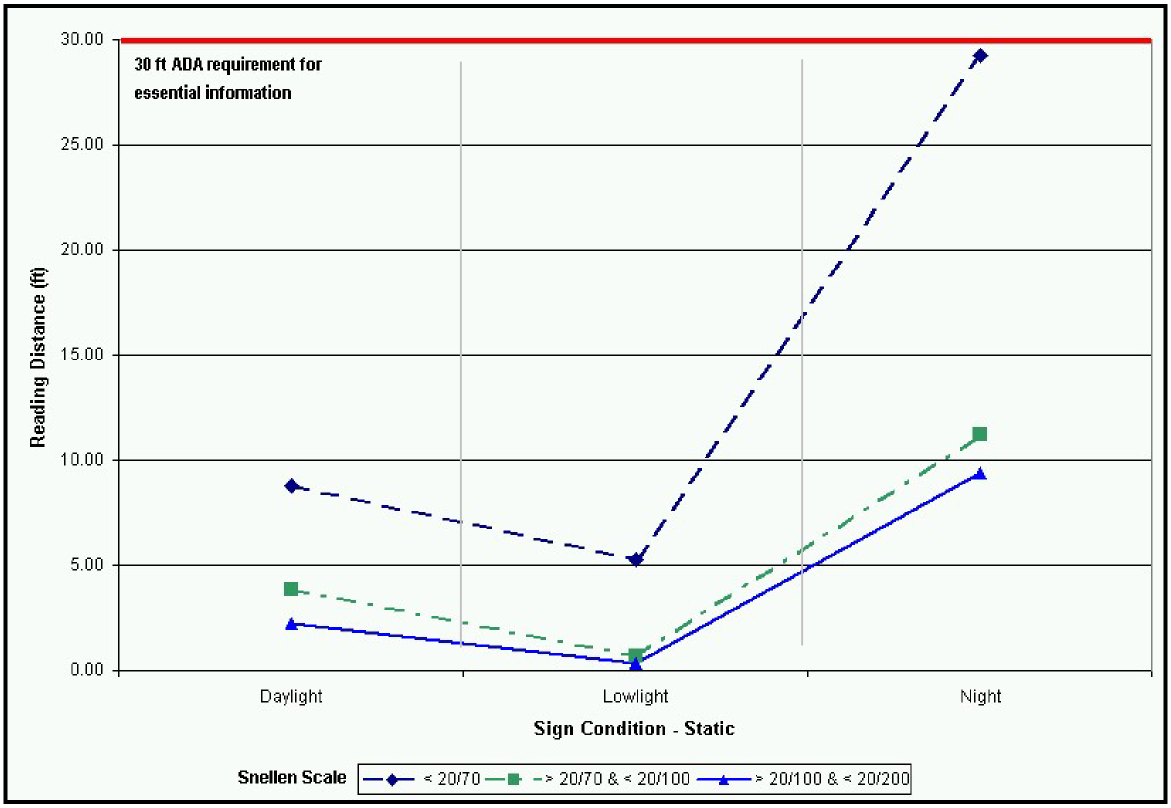


Figure 10. Static: Mean reading distance (side) by lighting, acuity group, and format.

The above sections summerize the overall experimental method, approach, and gathered results. The following section draws on these results to form conclusions and recommendations or how to implement these as best practices.

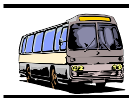
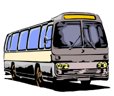
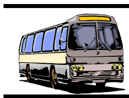
CONCLUSIONS AND RECOMMENDATIONS

The literature review, gap analysis, survey results, and human factors research provide the evidence and support to generate the best practices found in the table below (Table 7).

Table 7. Recommended Best Practices for LED Transit Vehicle Signs

Best Practices for LED Transit Vehicle Signs		
Recommended Best Practices	**Current ADA Specifications**	**Discussion**
Letter Height		
Front sign not less than 8 inches	Not less than 2 inches	• Literature and research indicate larger letters on front signs (even as large as 10 inches or more) provide better viewing for persons with visual impairments. • This recommendation and actual letter size may be limited by the current sign technology and the space provided on the vehicle for sign placement. • Research is needed to determine whether, if space does not permit displaying a whole message in one line, greater legibility can be obtained with two-line message, scrolling or paging.
Side sign not less than 5 inches	Not less than 1inch	• Literature and research indicate larger letters on side signs (even as large as 6 inches or more) provide better viewing for persons with visual impairments. • Viewing distance is limited by extreme visual angles associated with reading the side-signs.
Letter Width-to-Height Ratio		
5:7 to 1:1	3:5 to 1:1	• Existing research on this variable is fairly strong. • Research indicates that the more legible ratios are slightly larger than the minimum 3:5 width-to-height required by ADA Accessibility Guidelines (ADAAG) and that legibility tends to decrease as the ratio approaches the maximum 1:1 width-to-height permitted under ADAAG.
Stroke Width-to-Height Ratio		
Not less than 1:5	1:5 to 1:10	• There is general (but not complete) agreement on values in and around this range for application to text readability.
Text Color		
Amber/Yellow	No current specification	• Literature and current research appear to indicate a general advantage for colors from the middle of the visual light spectrum (~ 570 – 590 nm wavelengths) across all environmental lighting conditions. • Some study results appear to indicate a shift to the longer wavelengths (e.g., green and blue)

Best Practices for LED Transit Vehicle Signs

	Recommended Best Practices	Current ADA Specifications	Discussion
			provides adequate legibility under lower lighting and night conditions. • All colors appear best when presented under positive contrast conditions (i.e., light letters on dark (black or dark blue) background). • White appears to provide decent visibility under daylight conditions but not under low light or night.
	**Luminance**		
	Night $30cd/m^2$ Day $>1,000cd/m^2$	No current specification	• Existing research on this variable is fairly strong for individuals without vision impairments. • Additional research should be conducted to determine if these levels are sufficient for individuals with vision impairments. • European standards currently under development should be tracked to determine measurement methods/recommended levels.
	**Luminance Contrast Percentage**		
	$[(L_c-L_b)/L_b] \times 100 \geq 70\%$	No current specification	• Where: L_c = Luminance (brightness) of characters; L_b = Luminance (brightness) of background. • This formula produces "negative" contrast for signs and publications when the letters are dark against a light background, and "positive" contrast otherwise. • Existing research on this variable is strong for individuals without vision impairments. • Additional research should be conducted to determine if these levels are sufficient for individuals with vision impairments.
	**Inter-character Spacing**		
	1.5 to 2.0 times stroke width	1/16 of uppercase letter height	• Research supports significantly wider spacing than that provided by the ADAAG.
	**Inter-word spacing**		
	75-100% letter height	No current specification	• Existing research on this variable is strong but available sign space, especially for longer destination/route messages, may be a limiting factor.
	**Inter-line spacing**		
	50 to 75% of letter height	No current specification	• Existing research on this variable is strong but available sign space will result in letters that are significantly smaller than the recommended 8 inches height. • Need additional research on whether messages should have multiple lines or scrolling if unable to fit on a single line.

Best Practices for LED Transit Vehicle Signs

	Recommended Best Practices	Current ADA Specifications	Discussion
Case			
	Uppercase	No current specification	• Use all capital letters (uppercase) for stop designations, terminals, and other short labels. • Neither the literature review nor the current research present any evidence that lower case LED messages are legible to persons with visual impairments in any of the research conditions here.
Message Dynamics			
	Static	No current specification	• Where possible, complete route/destination messages should be presented in static (i.e., not moving) format. • Additional research is necessary to determine relative advantages of streaming versus paging message dynamics for persons with visual impairments if route and destination messages are longer than can be presented in one sign.
Message Dynamic Display Time			
	2.7 - 10 seconds	No current specification	• Research is not adequate to indicate the relative advantages and tradeoffs of display times for dynamic messages (e.g., streaming, paging). • There appears to be a tradeoff of display time and reading distance for dynamic messages. That is, longer display time may not allow the entire message to be communicated in the distance a vehicle travels within the range of legibility for persons with visual impairments. Shorter display times may not allow for adequate exposure to determine the message.
Sign Placement on Vehicle			
	Front	No current specification	• Sign should be placed above the windscreen or as low as practicable within the windscreen area (noting influence of glare on sign legibility), above the driver's field of view.
	Side	No current specification	• Sign should be placed on side of vehicle, adjacent to the entrance that is closest to the front of the vehicle at a height of not less than 4 ft. to the lower edge of the display characters and not more than 8 ft. to the upper edge of the display characters measured from the ground.

Other Considerations

Glare and Fog Abatement

- Signs should be positioned at an angle to minimize unavoidable glare.
- Sign-covering material should be designed to minimize glare.
- Signs should not be placed directly behind windscreen if possible.
- Utilize a defogger, fresh air blower, or electric strip on the destination sign glass/covering surface to reduce fogging and improve readability.

Visual Clutter Abatement

- Competing alphanumeric information should not be displayed in proximity to bus route and destination signs where it may confuse passengers.
- Message content should be limited to route and destination information. Advertising and "Have a Nice Day" messages should be avoided as they may confuse passengers.

Cleanliness

- Route and destination signs should be kept clean from surface dirt and contaminants.

Maintenance

- Destination and route signs should be maintained according to the manufacturer's recommended preventive maintenance intervals and repair practices.

The best-practices table displays the relevant recommendations as noted in the literature reviewed and research conducted during this project and should help transit agencies to choose and implement LED transit sign systems that will improve readability by persons with visual impairments. The content has been appended in part or in its entirety from the authors cited in this document. Since sign design itself will not adequately address the full needs of persons with visual impairments, it is important that the use of additional information technologies (e.g., auditory, tactile) to facilitate access to route and destination information be provided. In addition, less technology-driven solutions (e.g., improved driver training) may be considered to provide additional assistance and accessibility to all public transit users.

This effort represents a further refinement of the existing literature for the presentation of information on LED signage and expands the body of research knowledge in the transportation accessibility environment. In many cases, the existing documentation is difficult to identify and the issues too numerous to address in any single empirical study. The results of this effort capture the most current understanding and application of human factors principles to the use of LED signage for the presentation of route and destination information on public transit vehicles. However, future research is needed with LED signs in the following areas, under the environmental lighting and vehicle dynamic conditions described in this report:

- The influence of glare and background visual clutter on sign readability
- The readability tradeoffs associated with message-paging and message-streaming dynamics, including recommended display times
- The readability tradeoffs associated with two-line messages versus paging/streaming
- The limits of readability as a function of LED luminance and luminance contrast conditions

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