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Symbols and Warrants for Major Traffic Generator Guide Signing

September 2009

By

Fengxiang Qiao, Lei Yu, Hui Wang, Lijin Ma, Rong Zhang, and Yan Zeng

Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration

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16. Abstract

The *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) provides the definition of regular traffic generators based on four population types but not for major traffic generators (MTGs). MTG signs have been considered to supplement the overall signing system for highways, and can direct road users to important traffic generators, resulting in improved traffic flow operation and decreasing drivers' frustration caused by missing an exit. These signs would better guide travelers on major highway "gateways" to crucial cultural, business, and recreational destinations, especially for those who are unfamiliar with the area. Minnesota, Missouri, North Carolina, and British Columbia in Canada have specific guidelines for MTGs in various forms; however, these guidelines are not applicable for direct use in Texas. It is imperative to establish MTG warrants that are suitable for the Texas environment. In this report, practices and manuals used in Texas and other states are scanned and summarized through a literature review, an engineer survey, and an MTG survey. Engineer opinions and the needs of MTGs were obtained in terms of the criteria, types of symbols used, and location and size of symbols/signs. Practices in other states and the opinions of responding engineers are synthesized through proposed fuzzy logic–based algorithms. Together with driving simulator tests and computer slide show tests, the preliminary recommendations about the types of symbols and location and size of symbols/signs for MTGs are then identified.

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The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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INTRODUCTION

1.1 Definition of Major Traffic Generator

Major traffic generators (MTGs) are important regional attractions, events, or facilities that attract persons or groups from beyond a local community, city, or metropolitan area. MTGs are significant because of their unique educational, cultural, historical, or recreational experience and public appeal.

MTG signs have been considered to supplement the overall signing system for highways. The purpose of MTG guide signs is to direct road users to such traffic generators, resulting in improved traffic flow operation and decreasing drivers' frustration caused by missing an exit. This would better guide travelers on major highway "gateways" to crucial cultural, business, and recreational destinations, especially for those who are unfamiliar with the area.

MTGs usually require adequate signs or symbols to guide unfamiliar motorists from major corridors to the venues. One of the principles of good signing is to keep the message concise. Symbols should provide short messages that are well recognized. However, signing space along these major corridors is usually very limited. In order to identify suitable symbols or signs from beyond a local community, city, or metropolitan area to MTGs, it is important to identify the warrants of MTGs. This includes the identification of MTG eligibility criteria and the selection of symbols and/or signs for MTGs.

The definition of an MTG varies with the state. Table 1 lists the most recent definitions of an MTG from the Federal Highway Administration (FHWA) and four states.

Table 1 Definition of MTG by FHWA and Different States

FHWA/States	Definition of MTG	Source
FHWA	The term "major highway traffic generator" means either an urbanized area with a population over 100,000 or a similar major concentrated land use activity that produces and attracts long-distance interstate and statewide travel of persons and goods. Typical examples of similar major concentrated land use activities would include a principal industrial complex, government center, military installation, or transportation terminal.	FHWA— FAPG (Federal-Aid Policy Guide), 23 CFR (Code of Federal Regulations) 470A, Federal-Aid Highway Systems.
Missouri	A traffic generator that attracts the following: (1) at least 300,000 visitors per year in the St. Louis or Kansas City metropolitan areas; (2) at least 250,000 visitors per year in an area with a population of at least 5,000 persons (urban areas); and (3) at least 200,000 visitors per year in an area in which the population is less than 5,000 persons (rural area).	Missouri Department of Transportation's (MoDOT's) *New Engineering Policy Guide*—903.19 Highway Signing General Information
New Hampshire	"Major traffic generator" means any establishment that generates or is projected to generate traffic that significantly lowers or could adversely affect the current level of service of a state highway.	New Hampshire Code of Administrative Rules Part Env-A 1501.04 Transportation Conformity—Definition Statutory Authority: RSA (Registration Admission Status) 125-C:4
New Jersey	"Major traffic generator" means the use or uses that generate a total of 500 or more vehicle trips per day directly accessing a state highway to and from the use or uses.	New Jersey Department of Transportation New Jersey Administrative Code Title 16 Chapter 47—1.1 Definitions
Minnesota	These traffic generators are major regional attractions, events, or facilities that attract persons or groups from beyond a local community, city, or metropolitan area.	*Traffic Engineering Manual*, July 1, 2000. Minnesota Chapter 6 Traffic Signs 6-7.07 Major Traffic Generator Signing

One important factor concerned with the definition of an MTG is the type of traffic generator. As described in MoDOT's policy on signing for traffic generators, to be eligible for traffic generator signing, the facility must qualify as being a minor, major, or super traffic generator (Missouri Department of Transportation 2006). The following policies and regulations are defined by MoDOT and can be found under the Code of State Regulations, Title 7, Division

10, Chapter 17, (7 Code of State Regulations (CSR) 10-17.010) (Missouri Department of Transportation 2006).

First, "minor traffic generator" means generators that attract at least 25,000 persons per year (only on conventional routes).

Second, "MTG" means a traffic generator that attracts the following:

- at least 300,000 visitors per year in the St. Louis or Kansas City metropolitan areas;
- at least 250,000 visitors per year in an area with a population of at least 5,000 persons (urban areas); and
- at least 200,000 visitors per year in an area in which the population is less than 5,000 persons (rural area).

Third, "super traffic generator" means a traffic generator that attracts at least 1 million visitors per year.

1.2 Traffic Generator Guide in Federal and Texas Manuals

Although the federal and Texas manuals do not develop a warrant on guide signing for MTGs, they do provide guidelines for general traffic generators.

1.2.1 Traffic Generator Criteria

Compared with the very limited definitions of MTG criteria across the nation, there are 10 states that provide criteria for traffic generators. Four of them also provide MTG criteria, while the rest only mention traffic generator criteria. Table 2 lists these criteria.

The criteria for signing traffic generators given by different states are mostly based on the American Association of State Highway and Transportation Officials (AASHTO) guideline criteria for signing traffic generators, which are shown in Table 3 (Association of American State Highway and Transportation Officials 2001).

Table 4 is from the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD), which provides the definition of regular traffic generators (Texas Department of Transportation 2006b). Predominantly retail, business, or manufacturing centers are normally not eligible for guide signing. There is no specification of MTGs in the current TMUTCD. Tables 5 through 7 list the criteria of signing traffic generators for Maryland from the Maryland Department of Transportation (MDOT).

Table 2 MTG Criteria by Different States

State/Area	MTG Criteria	Traffic Generator Criteria
Minnesota	Yes	No
Missouri	Yes	No
North Carolina	Yes	No
British Columbia, Canada	Yes	No
Texas	No	Yes
Oregon	No	Yes
Maryland	No	Yes
Florida	No	Yes
Tennessee	No	Yes
Colorado	No	Yes

Table 3 AASHTO Guideline Criteria for Signing Traffic Generator

Type of Generator	Specific Criteria	Major Metropolitan Areas[1]	Urban Areas[2]	Rural Areas
Colleges and Universities	Total enrollment full- and part-time students	4,000	2,500	1,500
	No. of trips[3] generated annually	900,000[3a] 1,200,000[3b]	550,000 750,000	300,000 450,000
	Distance from interchange (miles)[4]	3	4	5
Military Bases	No. of employees and permanently assigned military personnel	5,000	4,000	3,000,000
	No. of trips[3] generated annually	5,000,000[3c]	4,000,000	3,000,000
	Distance from interchange (miles)[4]	5	7.5	10
Arenas, Auditoriums, Convention Halls, and Stadiums	Annual attendance	300,000	250,000	200,000
	No. of seats (if applicable)	6,000	5,000	4,000
State and National Parks, Monuments, and Major Recreational Areas (Fairgrounds, Amusement, Parks, Zoos, Etc.)	Distance from interchange	5	5	5

[1] 50,000 or more population in metropolitan areas.
[2] 5,000-49,999 population in urban areas.
[3] Trip: A single or one-direction vehicle movement to the generator. The following trip generation rates are suggested:
- [3a] College or university without dorms, each student = 1.5 trips.
- [3b] College or university with dorms, each student = 2 trips.
- [3c] One employee or military personnel = 0.9 trips.

[4] The distance may be increased 0.5 miles for each 10 percent over the minimum requirement listed, to a maximum of two times the minimum distance listed.

Note: When the traffic generator is not located on the crossroad, written confirmation is required from the local government agency that they will install and maintain trailblazing signing for the logical direction.

Table 4 Texas Traffic Generator Criteria (Texas Department of Transportation 2006b)

	Population Range	Over 250,000	50,000-250,000	15,000-50,000	Under 15,000
Type of Generator	Specific Criteria	Major Metropolitan Areas	Urban Areas	Suburban and Rural Areas	Rural City
Airports (Publicly Owned)	Number of movements (one way)	15 daily	10 daily	5 daily	2 daily
	Maximum distance from intersecting highway	5 miles	8 miles	10 miles	10 miles
Airports TASP[1]	Maximum distance from intersecting highway	5 miles	10 miles	15 miles	20 miles
Colleges and Universities	Off-street parking (minimum)	500	400	200	100
	Mileage	3 miles	4 miles	5 miles	5 miles
Hospitals	See general service signs (TMUTCD 2D-45)				
Recreational[2] and Cultural Interest Areas	Facilities open to general public. Minimum annual attendance.	100,000[3] (300,000)[4]	50,000[3] (250,000)[4]	25,000[3] (100,000)[4]	10,000[3] (50,000)[4]
	Maximum distance from highway.	5 miles	5 miles	5 miles	5 miles
Government Facilities (Must Be Open for Public Access to Receive Service)	State or federal maximum distance from highway	0.5 miles	1 mile	1 mile	2 miles
Business Districts	A DOWNTOWN sign may be used if the marked route is within the city limits, or a "NEXT __ EXITS" sign may be used to provide guidance to area with multiple exits.	(1) Largest core city of urban area of 25,000 population or more. (2) A distinct CBD must exist with an established multi-street system. Strip development business centers shall not qualify. (3) Only one such supplemental sign will be permitted for each direction of travel for the best and most direct route serving the downtown core. It is not necessary that signs denoting DOWNTOWN for different directions of travel be confined to the same interchange. (4) A downtown guide sign may include the core city's name, but other town or city names should not be used on the same sign as the text "Downtown."			
Parking, Park and Ride Terminal, and Rail Terminal Facilities	Facilities shall be directly related to the operation of a multimodal transportation system. This includes parking for carpooling, mass transit, and rail terminal access maximum distance from highway.	3 miles	3 miles	1 mile	1 mile
	Minimum number of parking spaces.	200	100	100	100

NOTE: Traffic generator should be located on street or roadway which intersects the highway.

1. Listed as approved in the Texas Airport System Plan (TASP).
2. State and National Parks may be signed from the highway route nearest the park regardless of annual attendance. Refer to TMUTCD Chapter 2G. "Tourist-oriented directional signs" for additional information.
3. Applies to Conventional roads.
4. Applies to Freeways and Expressways.

Table 5 Maryland Traffic Generation Criteria—Expressways and Freeways (Maryland Department of Transportation 2006)

Type of Generator	Specific Criteria	Population of Area		
		1000,000+	100,000-1,000,000	Less than 100,000
Airports	Number of movements (one way)	60	40	20
	Mileage	5	5	10
Educational Institutions, Colleges, and Universities	Equivalent full-time enrollment	4,000	2,500	1,500
	No. of trips generated annually	900,000	550,000	200,000
	Mileage	3	5	10
Military Facilities	Employees or personnel	5,000	5,000	5,000
	Mileage	2	3	5
Miscellaneous Government Facilities	Employees	2,000	2,000	2,000
	Mileage			
Historical, Recreational, or Cultural	Annual attendance	300,000	150,000	50,000
	Mileage	Less than 5	Less than 5	Less than 5
Transportation Facilities	Agency	MDOT-approved facilities		
	Mileage	Within 2 miles of interchange		

Table 6 Maryland Traffic Generation Criteria — Conventional Highway (Maryland Department of Transportation 2006)

Type of Generator	Specific Criteria	Examples
Transportation Facilities	Airports	Those having public air service
	Railroad Stations	Those providing passenger service
	Mass Transit	Stations of the Baltimore and Washington systems
	Ferries	
Educational Institutions	Post-high school having minimum of 1,000 full-time or part-time students and 200,000 trips generated annually	Colleges—4 year, 2 year, junior, community schools, and seminars
Correction Institutions	Government operated	Correction centers and youth camps
Health Care Facilities	Any hospital or mental health care facility licensed by the state	Veterans hospitals, mental care facilities, state hospitals, and development centers
Miscellaneous	Any building complex owned and operated or specifically for a local, state, or federal government agency housing 200 employees or assigned personnel	State offices, county offices, city offices, military bases, and federal offices
	State agencies with a minimum 10,000 public transactions per year	Motor Vehicle Administration (MVA) offices and Parks and Wildlife offices

Table 7 Maryland Traffic Generation Criteria—Conventional Highways (Maryland Department of Transportation 2006)

Generator	Specific Criteria	Population of Area		
		1,000,000+	100,000-1,000,000	Less than 100,000
Airports	Number of movements (one way)	60	40	20
	Mileage	5	5	10

As shown by comparing Table 4 with Tables 5 through 7, the major differences between the traffic generator criteria for Texas and Maryland are in the classification of population range and roadway types. For Texas, the population range is divided into four parts: over 250,000; 50,000-250,000; 15,000-50,000; and under 15,000 (Texas Department of Transportation 2006b). For Maryland, only three parts—1,000,000+; 100,000-1,000,000; and less than 100,000—are used to identify the criteria of signing traffic generators (Maryland Department of Transportation

2006). Actually, even for other non-listed states, population ranges are normally different in defining the traffic generator eligibility criteria.

In terms of roadway type, Maryland defines the criteria for traffic generators depending on two different types of road: (1) conventional highways (Table 5) and (2) expressways and freeways (Tables 6 and 7). This is different from Texas, where the criteria of traffic generators for different road types are combined into one table. The specific criteria for the special generator airports for conventional highways in Maryland are listed in Table 7.

1.2.2 Traffic Generator Signs and Symbols

According to the *Manual on Uniform Traffic Control Devices* (MUTCD) Section 2E.32, "supplemental guide signs can be used to provide information regarding destinations accessible from an interchange, other than places shown on the standard interchange signing. Where two or more advance guide signs are used, the supplemental guide sign should be installed approximately midway between two of the advance guide signs. The supplemental guide sign should be installed as an independent guide sign assembly upon space availability." (FHWA, 2003) With the increasing demands for usage of various signs, there is less and less space available to independently install guide signs, including those for MTGs.

Symbol signs can convey guidance messages through an icon or graphical presentation rather than text or words. Well-designed symbols can be comprehended in a much easier and rapid way with no language preference. The MUTCD has legalized the use of symbols for general service signs (e.g., hospitals, food, and gas) in Section 2E.51 as well as for recreational and cultural interest area symbol signs (e.g., museums, art galleries, and historical sites) in Section 2H.04. Supplemental panels of general service signs illustrated in the TMUTCD and the *Freeway Signing Handbook* (Texas Department of Transportation 2008) are horizontally placed at the top of parent guide signs. These supplemental symbol signs require less space.

A series of approved symbols are recommended in the MUTCD, and their layouts are described in the *Standard Highway Signs* (SHS) (FHWA, 2004). However, the pool of symbols in existing manuals is insufficient to cover all MTG specifications. Furthermore, most of the symbols recommended in current manuals are category-oriented symbols (CS) (e.g., a symbol for amusement parks as a general concept), not specified symbols (SS) that exclusively point to any particular attraction (e.g., a symbol of one specific amusement park, such as Sea World Adventure Parks).

1.3 MTG Signing Practice in Other States

In order to further identify the practices of MTG guide signing at the state level, an e-mail survey was conducted of the state departments of transportation (DOTs) of all 49 states in the United States (with the exception of Texas, where information has been collected through other channels) on November 13, 2007. The main question was “Do you have signing practices or standards for major traffic generators in your states or agencies?” Twenty-two states effectively responded (a response rate of 44 percent). The survey responses show that Minnesota, Missouri, and North Carolina have specific guidelines for MTGs.

Each state has its own method of MTG guide signing, which is summarized in Table 8. The survey shows that:

- all states that responded use MUTCD and AASHTO guidelines;
- all states that responded have signing policies for some traffic generators;
- Minnesota, Missouri, and North Carolina have specific guidelines for MTGs;
- Rhode Island does not need to develop warrants and criteria for MTGs; and
- Nevada decides MTG signing based on “common sense,” which refers the issue to the director’s office for review and confirmation via the minutes of each meeting.

There are four categories of signs used for traffic generators in the surveyed states: (1) supplemental guide signs, (2) logo signs, (3) tourist-oriented directional signs, and (4) recreational and cultural interest area (RCIA) destination guide signs. Each state has its own favorite categories of traffic generator signing, which is summarized in Table 8. Thirteen out of the twenty-two states that responded, including the three states that have specific guidelines for MTGs (in bold in Table 8), use supplemental guide signs.

Table 8 Types of Traffic Generator Signing in Other States

State	**Type of Traffic Generator Sign**			
	Supplemental Guide Sign	**Logo Sign**	**Tourist-Oriented Directional Sign**	**RCIA Sign**
Alabama	X			
Alaska		X		X
Arkansas				
Colorado	X		X	X
Idaho	X			
Indiana	X			
Iowa	X			
Kansas	X			
Louisiana	X			
Maine		X		
Massachusetts		X		
Minnesota	**X**			
Mississippi			X	
Missouri	**X**			
Nevada		X	X	
North Carolina	**X**			
North Dakota				
Ohio	X			
Oregon	X	X	X	X
Rhode Island				
Tennessee	X			
West Virginia		X		

In the operational guidelines of the *Minnesota Traffic Engineering Manual* (State of Minnesota, 2004), the MTG eligibility criteria are set as (1) parking for a minimum of 1,000 vehicles; (2) a minimum of 10 events per year and average event attendance of at least 5,000 persons; and (3) location not more than 10 miles (16 km) from the conventional highway interchange/intersection where signs are requested.

The Missouri Highways and Transportation Commission provides the specific criteria for MTGs in the *Engineering Policy Guide*. The major traffic generator must meet the following criteria: (1) be fully operative and open to the traveling public for a minimum of three months each year, (2) be located along either the interchange crossroad or the freeway and within 6 miles of the major traffic generator in a rural area or within 2 miles in an urban or metro area, and (3) meet the annual attendance requirements as provided in the definitions section of this rule.

The North Carolina Department of Transportation’s Division of Highway, Traffic Engineering, and Safety Systems Branch provides standard practice for supplemental guide signs for MTGs as follows: (1) trip generations will be in amounts of 250,000 or more annually; (2) signs for qualifying traffic generators shall be limited to the closest freeway interchange, not to exceed 15 miles from the facility; and (3) the facility shall have adequate onsite parking during hours of operation for guests, tourists, and customers.

The Canadian province of British Columbia regulates the criteria for MTGs based on different land use types (rural/urban or suburban, Ministry of Transportation and Highways, 2000).

The manuals and practices in other states/provinces are valuable but cannot be directly applied to Texas due to its different geographical, demographic, and social features. It is imperative to establish MTG warrants that are suitable for the Texas environment.

1.4 Research Objectives

The problem to be addressed in this report consists of characterizing drivers' driving and psychological behaviors through a wide range of surveys and in-lab simulation using a driving simulator, and of developing warranting procedures and thresholds for the use of guide signs for major traffic generators.

To this end, the research entails the following specific objectives:

- to evaluate drivers' driving and psychological behaviors under different designs of symbols for major traffic generators,
- to simulate and examine the operational and safety impacts of symbols, and
- to develop warrants of symbols for major traffic generators.

In this research report, relevant manuals and practices in Texas and other states will be analyzed and necessary surveys (of engineers, MTGs, and motorists) and tests (in a driving simulator and through slide shows) will be described. Based on this research, the warrants and design of guide signs for Texas MTGs will be finally synthesized.

CHAPTER 2
LITERATURE REVIEW

In addition to the existing guidance and manuals used by the federal government, Texas, and other states, a thorough review was conducted of previous studies related to the warrant and design of guide signing for MTGs. The review of the research is presented for MTG sign design, symbol design, and sign study tools (including the driving simulator test and the slide show test).

2.1 MTG Sign Design

Currently, supplemental guide signs are used to display MTG messages in the three states (Minnesota, Missouri, and North Carolina) that have specific guidelines for MTGs. Most information was on the policy of using supplemental guide signs, including criteria, application, etc. However, little information was on the effectiveness of supplemental guide signs. A program in Kentucky (Barrett et al. 2002).evaluated post-interchange guide signs containing limited supplemental guide signs through analyzing crash data in a before and after study, conducting a survey of attraction visitors upon understanding of the signs, and reviewing the attendance records for the attractions. The researchers concluded that the signs did not result in increased crash risks for drivers, the signs were large enough to view easily, and attendance at the attractions increased due to the signs. The attractions' representatives commented that the signs were beneficial and should continue to be used.

Another relevant study in Virginia (Perfater 1981) examined motorists' perceptions of messages on advance and supplemental guide signs by distributing questionnaires at eight rest areas on interstate highways. A total of 5,100 survey samples showed that drivers somewhat misunderstood some messages on guide signs. The most frequently confused messages were those containing the word "next." However, the destination names on supplemental guide signs should be followed by the legend "next right" or "second right" or both if interchanges are not numbered. Motorists favored the wording “this exit” for an exit ramp and the terms “first” and “second” for two ramps. The researchers found that the difficulty in interpreting the messages had an inverse relation to the driving experience of motorists.

A driving information load (DIL) model computational tool was introduced in the NCHRP research (NCHRP 2008) to evaluate and analyze information loads related to an array of guide signs on freeways. The DIL model can identify the potential information overload problems and compare alternatives for the design and placement of signs. However, it cannot address the full process of designing an informational sign system, such as the choice of destinations, the accuracy of messages, and the consideration of motorists’ information needs. In general, driving information overload (DIO) likely occurs with multiple sign panels at the same location or with short spaces between signs. Nonetheless, DIO can be minimized using a variety of principles, including information spread using supplemental signs with at least 800 ft of separation and sign repetition to provide extra opportunities for drivers to perceive the entire message. Qiao et al. (2009d) considered the impact of trailblazing sign in the dynamic traffic assignment procedure through using a specific factor: drivers’ familiarity to the network.

2.2 Symbol Design

To the best of the authors’ knowledge, no published studies have examined the use of symbol signs for MTGs. However, there are many previous studies on general symbol usage. Dewar et al. (1997) conducted a comprehensive literature review on symbol signs and evaluated the effectiveness of symbols in the MUTCD and novel symbols among drivers of all ages, including important criteria of comprehension and legibility distance. The researchers proposed that essential recreational activity messages could be conveyed with a “set” of symbols in the same way as motorist services signs. In addition, they suggested that actual comprehension could be measured in a simulator study by drivers “driving” on a scripted trip to specific destinations, where directional information was presented on symbol signs. Because of the necessity to communicate certain regulatory, warning, and guidance messages, most states and many local jurisdictions have developed a number of special sign legends, designs, and symbols. Wainwright (2005) synthesized a considerable pool of non-MUTCD traffic signs, including the non-MUTCD symbols for national park and recreational/cultural area guide signs. The National Park Service, Forest Service, and Corps of Engineers have standards for recreational and cultural symbols. These symbols, as well as the recommended guidelines, could be good references for MTG symbol design.

Few studies have been focused on the placement of guide signs and positions of symbol plaques. Li and Chimba (2006) provided a methodology to determine the advance placement of guide signs as a supplement to MUTCD guidelines. This study demonstrated that the legibility distance of guide signs does not influence the advance placement distance but is a function of visual acuity, type, and size of sign lettering. In the MUTCD, where great visibility or emphasis is needed, larger sizes should be used.

2.3 Sign Study Tools

A driving simulator, as a widely used tool, can economically and safely replicate the actual driving environment. Allen et al. (1980) used a driving simulator to examine the effects of driver age on traffic sign symbol recognition through training the participants in different ways. By measuring and calculating the recognition distance and processing time of the subjects, they concluded that older drivers can be effectively trained on the meanings of symbols. The authors also reported that the recognition distance was not correlated with dynamic acuity. Schnell et al. (2004) utilized the Traffic Sign Simulator Facility (TSSF) to determine the luminance requirements for recognition of negative contrast symbol signs by assessing threshold recognition distance (maximum correct symbol recognition distance) and confidence distance (the distance at which the signs could be recognized with ease). Hesar et al. (2007) carried out a study to investigate the effects of adding graphics to dynamic message sign (DMS) messages using a questionnaire survey and a lab driving simulation experiment. They concluded that graphics could improve the responses of older drivers and non-native English-speaking drivers, suggesting that a graphical image should be placed on the left side of the text on the signs. Mitchell et al. (2005) used a driving simulator to evaluate traffic safety countermeasures. The results of the simulation emphasized that any data analysis should focus on relative differences in driving behavior among alternate scenarios and indicated that the use of driving simulators is a promising tool for performing safety countermeasure evaluation studies. Qiao et al. (2007a) and Qiao et al. (2007b) used driving simulator to test the exit guide signs placement and the logo and sign design at interchanges.

The slide show presentation method is a compact, inexpensive, and portable testing methodology. Chrysler et al. (2007) conducted a human factors study to test driver comprehension of diagrammatic advance freeway guide signs and their text alternatives through a computer slide show. The results showed proper diagrammatic signs for different exit types. This research also contained a discussion of testing methodology and recommended testing the best-performing sign designs in a driving simulator in future research. In this case, experimenters allowed the full sign sequence to be viewed when approaching an interchange. Hummer and Maripalli (2008) conducted a slide-based experiment to determine the difficulty of drivers using nine-panel signs compared with six-panel and mixed-use signs. They concluded that nine-panel logo signs performed well and could probably be used in order to avoid extra signs and billboards. In their research, 1.0- and 2.5-second sign exposure times could represent a driver scan in heavy traffic and lighter traffic. The choice of exposure times came from the classic study by Bhise and Rockwell (1973). Qiao et al. (2010b) proposed a FLASH based sign test method, which are more flexible than the simulator test but more like real than the slide show test.

CHAPTER 3
ENGINEER SURVEY AND MTC SURVEY

In order to identify the opinions of engineers and the needs of MTGs regarding the warrants and design of MTG symbols and signs, two types of surveys were conducted: the engineer survey and the MTG survey. The engineer survey was distributed to relevant engineers in and outside of Texas, and the MTG survey included surveying MTG executives and motorists who drove to MTGs.

3.1 Survey of Opinions of Engineers

3.1.1 Purpose of Survey

The purpose of the engineer survey is to collect opinions from engineers in Texas and other states on their practical experiences in identifying symbols and warrants for MTGs, including eligibility criteria of MTGs, types of symbols, and signing location and size.

3.1.2 Survey Process

The engineer survey instrument, which was designed as an online survey, included two parts: MTG sign design and MTG criteria. The survey contents were revised several times through close and frequent communications between the research team and Project Monitoring Committee (PMC) members. It took nearly one year from the initial design of the survey instrument to the finally distributed version. The specific activities during this period are illustrated in Figure 1.

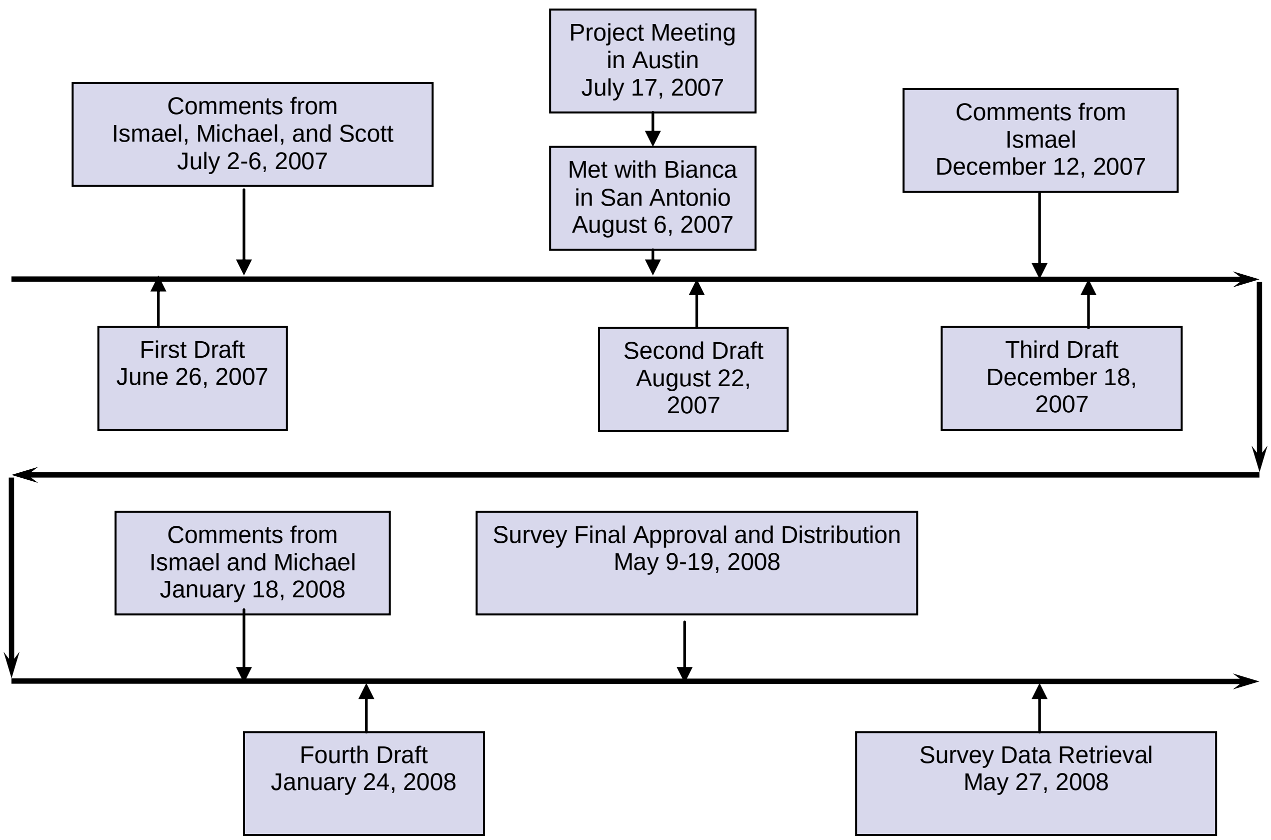


Figure 1 Engineer Survey Process

All comments from the project director (PD) and the PMC were carefully addressed in the four versions during the evolution of this survey instrument. The approval of the final version and the distribution of the survey form were conducted in May of 2008.

The major questions in the survey are:

1. Can guide sign routing plaques effectively help unfamiliar motorists navigate a regional freeway system to its MTGs?
2. What would be the most effective plaque design, i.e., symbol, text or combo, and color?
3. How many plaques could be attached to a parent sign without overloading motorists' comprehension level?
4. How to determine plaque sizes determination, i.e., the minimum text size?
5. How to place trailblazing signs for MTGs through various routes?

6. What are the engineers' opinions and practice on eligibility criteria of MTGs?

The title of the survey is "Survey on Symbols and Warrants for Major Traffic Generator Guide Signing." The detailed questionnaire can be accessed at the website: http://itri.tsu.edu/TxDOT5800/survey5800.htm. The engineer survey form is shown in Appendix A.

The survey was distributed to the following five sets of engineers:

1. A preliminary list of Texas engineers was prepared by searching the Texas Department of Transportation website name list and is named "Texas Engineers List." This list mainly includes the maintenance supervisors for each county of Texas.
2. A list of Texas engineers was recommended by the PD, Mr. Ismael Soto.
3. Based on the contacts with engineers in states other than Texas, a mailing list of engineers from other states was prepared. It covers almost all states in the United States (53 email addresses).
4. Transportation Research Board (TRB) committee AHB50 on traffic control devices.
5. American Association of State Highway and Transportation Officials (AASHTO) Subcommittee of Traffic Engineers.

3.1.3 Survey Feedback

The engineers' feedback was retrieved on May 27, 2008. A total of 17 engineers responded, with six from Texas and the rest from 11 other states: Minnesota, California, Tennessee, Illinois, Michigan, Colorado, Nevada, Massachusetts, Iowa, Mississippi, and Arizona. Engineer respondents are listed in Appendix B

3.1.3.1 MTG Sign Design

Sign design focused on four subject areas: (1) symbol sign practices, (2) symbol sign plaques, (3) trailblazing signs, and (4) MTG sign types.

Symbol Sign Practices. All responding engineers have used symbol signs for traffic generators in their practice. The most-employed symbols are standard symbols from the

MUTCD and the SHS. Only three engineers used self-designed symbols for traffic generators. Two of them are engineers from Texas, and the other one is from Minnesota. This information is based on the answers to Questions 1-1 and 1-2 of engineer survey part 1 (Appendix A) and is listed in Table 9.

Table 9 Answers to Question 1-1 and Question 1-2

Question 1-1	Total	Yes	No
Count	17	17	0
Percentage	100	100	0

Question 1-2	Symbols		
	Standard		Self-design
	MUTCD	SHS	
Count	16	2	3
Percentage	94	12	18

<u>Symbol Sign Plaques.</u> All the engineers believe that symbol signs can effectively help unfamiliar motorists navigate a regional freeway system to its MTGs if these MTG signs are installed as guide sign routing plaques, as asked in Question 2-1 and summarized in Table 10.

Table 10 Survey Data for Question 2-1

Question 2-1	Sample	Yes	No
Count	17	17	0
Percentage	100	100	0

Regarding appropriate types of MTG symbols, 53 percent of surveyed engineers prefer category-oriented symbols, 35 percent prefer specific symbols for each MTG, and 12 percent prefer a uniform symbol for all MTGs. The relevant answers to Question 2-2 are listed in Table 11.

Table 11 Survey Data for Question 2-2

Question 2-2	Uniform Symbol	Category Symbol	Specific Symbol
Count	2	9	6
Percentage	12	53	35

Regarding the legend of MTG symbol plaques, 47 percent of surveyed engineers think that the most effective legend for MTG symbol plaques should contain a symbol and the associated text at the bottom, 29 percent prefer symbols only, and 24 percent prefer a symbol with text on the top. No one considers text alone as an effective legend. The relevant answers to Question 2-3 are listed in Table 12.

Table 12 Survey Data for Question 2-3

Question 2-3	Symbol Only	Text Only	Symbol and Top Text	Symbol and Bottom Text
Count	5	0	4	8
Percentage	29	0	24	47

If taking the symbol and text into consideration as a legend for MTG signs, seven engineers think either the MTG category or the name of each MTG is the most effective text for MTG plaques, as shown in the answers to Question 2-4 in Table 13.

Table 13 Survey Data for Question 2-4

Question 2-4	Letters “MTG”	Letters “Attractions”	MTG Category	Name of Each MTG	Abbreviation of Each MTG	Other
Count	1	0	7	7	1	1
Percentage	6	0	41	41	6	6

Regarding the form of text, 71 percent of surveyed engineers think the title case is the most effective form of text, and 29 percent think uppercase is the most effective. No one likes lowercase letters. The relevant answers to Question 2-5 are listed in Table 14.

Table 14 Survey Data for Question 2-5

Question 2-5	Title Case	Uppercase	Lowercase
Count	12	5	0
Percentage	71	29	0

Regarding text font style, 35 percent of surveyed engineers think that Clearview 5WR is the most effective font, and the same percentage of engineers think Series E (Modified) is the most effective. Eighteen percent of the engineers chose Clearview 4W as the most effective font. Two engineers prefer other fonts, one Texas engineer prefers font 4C and one Nevada engineer prefers font D. Table 15 lists the relevant answers to Question 2-6.

Table 15 Survey Data for Question 2-6

Question 2-6	5WR	E Modified	4W	4C	D
Count	6	6	3	1	1
Percentage	35	35	18	6	6

Regarding text and plaque sizes, 59 percent of engineers believe that 6 inches is the minimum text size for an MTG symbol sign plaque. The answers to Question 2-7 are in Table 16. Most engineers (94 percent) agree that the size of MTG symbol plaques should be the same as that for airports and hospitals (see answers to Question 2-8 in Table 17). Forty-one percent of the engineers think the 30×30-inch size is the minimum dimensions of a symbol sign plaque for MTGs on freeways, and 41 percent think the 36×36-inch size is the minimum (see answers to Question 2-9 in Table 18).

Table 16 Survey Data for Question 2-7

Question 2-7	4 Inches	6 Inches	8 Inches	10 Inches	Other
Count	2	10	3	1	1
Percentage	12	59	18	6	6

Table 17 Survey Data for Question 2-8

Question 2-8	Sample	Yes	No
Count	17	16	1
Percentage	100	94	6

Table 18 Survey Data for Question 2-9

Question 2-9	30×30	36×36	48×48	Unknown
Count	7	7	1	2
Percentage	41	41	6	12

Regarding the location of symbol plaques, most engineers (71 percent) agree to place the MTG symbol sign at the top of the parent guide sign like airport and hospital guide sign routing plaques. The relevant answers to Question 2-10 are in Table 19. Advance guide signs and exit direction signs were selected by most engineers (82 and 94 percent, respectively) to place the MTG symbol signs on. The answers to Question 2-11 are in Table 20. Only a Nevada engineer suggests also placing the MTG sign on exit gore signs. One Minnesota engineer prefers to install the MTG sign on a supplemental guide sign; he/she also likes to place the MTG signs on advance guide and exit direction signs.

Table 19 Survey Data for Question 2-10

Question 2-10	Sample	Yes	No	No Answer
Count	17	12	3	2
Percentage		71	18	12

Table 20 Survey Data for Question 2-11

Question 2-11	Advance Guide Sign	Exit Direction Sign	Exit Gore Sign	Supplemental Guide Sign
Count	14	16	1	1
Percentage	82	94	6	6

Regarding the color of symbol plaques, the engineers have no obvious preference for blue, brown, or green. The majority (41 percent) agrees that the color of the background of a symbol and text plaque should be dependent on the category of MTG and should match the service (see answers to Question 2-12 in Table 21 and to Question 2-13 in Table 22). One Colorado engineer suggests that blue should be used on highways, while green can be used on interstate highways.

Table 21 Survey Data for Question 2-12

Question 2-12	Green	Brown	Blue	Depends on MTG	Depends on Highway	MUTCD Standard
Count	3	3	2	7	1	1
Percentage	18	18	12	41	6	6

Table 22 Survey Data for Question 2-13

Question 2-13	Green	Brown	Blue	Depends on MTG	Depends on Highway	MUTCD Standard
Count	3	3	2	7	1	1
Percentage	18	18	12	41	6	6

Regarding the number of symbol plaques, most engineers (65 percent) agree that a maximum of three plaques could be attached to an overhead freeway guide sign without overloading the motorists' comprehension level (see answers to Question 2-14 in Table 23). If a parent sign includes an exit number panel, 53 percent of engineers still think three is the maximum number (see answers to Question 2-15 in Table 24). One engineer from Minnesota and one from Massachusetts suggest no plaques on top of an overhead freeway guide sign. When the parent guide sign includes an exit number panel, two engineers from Texas do not agree to put any plaque on it.

Table 23 Survey Data for Question 2-14

Question 2-14	0	1	2	3	4
Count	2	0	4	11	0
Percentage	12	0	24	65	0

Table 24 Survey Data for Question 2-15

Question 2-15	0	1	2	3	4
Count	4	1	3	9	0
Percentage	24	6	18	53	0

Regarding the priority of plaques, the engineers evaluated the priority on placing each type of routing plaque on top of overhead freeway guide signs, with 1 as the lowest priority and 4 the highest priority. The engineers are required to consider the space availability and the workload of drivers. One engineer did not complete this question, and one engineer selected no priority by making decisions simply based on the application order. Through averaging the score of each plaque, the exit number panel receives the first priority, while the MTG symbol plaque receives the lowest (see the answers to Question 2-16 in Table 25).

Table 25 Survey Data for Question 2-16

Question 2-16	Hazardous Cargo	General Service	Exit Number	MTG Symbol
Average Weight	2.3	2.4	2.9	2.1
Priority	2	3	**4**	1

<u>Trailblazing Signs</u>. Most engineers (71 percent) believe that the trailblazing sign (TS) is necessary for MTGs, as asked in Question 3-1 (Table 26). Of the 12 engineers who think the trailblazing sign is necessary, 42 percent think the maximum number of trailblazing signs provided for each MTG along one approach should depend on the location, distance, and how many turns to the MTG (see answers to Question 3-2 in Table 27). The engineers have different opinions on the maximum radius of an MTG where trailblazing signs should be provided. Four of them prefer 5 miles, and three prefer 10 miles. The relevant answers to Question 3-3 are in Table 28.

Table 26 Survey Data for Question 3-1

Question 3-1	Sample	Yes	No
Count	17	12	5
Percentage	100	71	29

Table 27 Survey Data for Question 3-2

Question 3-2	Sample	One TS	Two TSs	Three TSs	Four TSs	Depends on Turns, Location, or Distance
Count	12	3	2	1	1	5
Percentage	100	25	17	8	8	42

Table 28 Survey Data for Question 3-3

Question 3-3	Sample	3 Miles	5 Miles	10 Miles	15 Miles	20 Miles
Count	12	1	4	3	2	2
Percentage		8	33	25	17	17

MTG Sign Types. In addition to the symbol sign plaque, several other sign types can also be used for MTGs. Based on the engineers' responses, symbol sign plaques, supplemental guide signs, and specific service signs are preferred and obtained the same number (11) of the engineers' support (see the answers to Question 4 in Table 29).

Table 29 Survey Data for Question 4

Question 4	Symbol Sign	Supplemental Guide Sign	Specific Service Sign	Tourist-Oriented Directional Sign	Recreational Sign
Count	11	11	11	3	7
Percentage	65	65	65	18	41

3.1.3.2 MTG Criteria

The second part of the survey was mainly on the following information: the definition, criteria of MTGs, types of MTGs, and the related manuals and methods of MTG criteria. The parameters of the MTG criteria have been derived from the criteria of existing traffic generators and from major traffic generators in other states where MTG is already defined. The main parameters in identifying the MTG criteria are (1) the minimum number of parking spaces, (2) the minimum distance from the highway, (3) the minimum annual attendance, and (4) the minimum number of events that happen per year. From the survey responses, 71 percent of engineers have certain knowledge of MTG criteria, and almost 50 percent of engineers have experience in developing MTG criteria. In addition, 89 percent of engineers prefer to develop

MTG criteria through discussion and meetings with experts, or through referring to existing MTG criteria from other states and further study by surveys of experts.

The survey was designed to ask the engineers about the population divisions, and more than 99 percent of engineers prefer to develop the MTG criteria based on four different population divisions for Texas: (1) metropolitan, (2) urban, (3) suburban, and (4) rural areas.

3.2 Survey of Needs of MTGs

3.2.1 Purpose of Survey

The purpose of the MTG survey is to survey typical MTGs on their possible needs for symbol sign designs, including sign content, types, and location. In addition to the survey of MTG executives, motorists going to MTGs were also surveyed on their feelings and needs for freeway guide signs. MTG survey form and motorist survey form are shown in Appendix C and Appendix E.

3.2.2 Survey of MTG Executives

The survey form for MTG executives was designed in a Microsoft Word file, containing 12 questions, including symbol sign design and the basic information relevant to MTG criteria. This instrument was emailed to 11 selected potential MTGs in Texas on June 17, 2008. The title of the survey is “Questions about Your Need for MTG Guide Signing.”

3.2.3 Survey of Motorists Going to MTGs

Besides surveying the management sectors of potential MTGs in Texas, the opinions of motorists going to these MTGs are also very important. Two surveys were conducted of motorists driving to (1) Robertson Stadium at the University of Houston (RSUH) on July 4, 2008; and (2) the Houston Toyota Center (TC) on July 22, 2008, and on August 10, 2008.

3.2.4 Survey Feedback

Four MTGs responded to the survey: (1) Sam Houston Race Park, (2) Schlitterbahn Waterpark in New Braunfels, (3) Schlitterbahn Waterpark in South Padre Island, and (4) the Toyota Center. The response rate is 36 percent. MTG survey respondents are listed in Appendix D. There were 148 motorists responding to the survey at RSUH on July 4, 2008, and 104 responders at TC on July 22, 2008, and August 10, 2008. The total of surveyed motorists for these two MTGs is 252.

3.2.4.1 Feedback from the Survey of MTG Executives

From the MTG executives' survey, all four MTGs would like to place guide signs for their facility to inform motorists along freeways. None of them want to pay all the costs of their guide signs. If classifying MTGs, Schlitterbahn Waterpark in New Braunfels and Schlitterbahn Waterpark in South Padre Island claimed themselves to be amusement parks; Sam Houston Race Park claimed itself to be a horse track or concert venue; and the Toyota Center claimed itself to be an arena. Regarding the background color of guide signs, Schlitterbahn Waterpark in New Braunfels and Schlitterbahn Waterpark in South Padre Island liked blue and white, while Sam Houston Race Park and the Toyota Center preferred green.

Except for Sam Houston Race Park, three of the other responding MTGs would like to display a symbol on their guide signs. Regarding the form of symbols displayed in the guide signs, the two Schlitterbahn Waterparks and the Toyota Center would like to display specific symbols for their facilities. Schlitterbahn Waterpark in South Padre Island would also like to display a category-oriented symbol based on the classification of the MTG. Sam Houston Race Park skipped this question. Except for Sam Houston Race Park, three of the responding MTGs agreed that symbols would be helpful to direct motorists to their destinations.

Regarding the elements displayed on guide signs, all wanted to show the names of their facilities and messages about their events. In addition, Schlitterbahn Waterpark in New Braunfels liked displaying the distance information and its logo. The Toyota Center wanted to display a symbol. Schlitterbahn Waterparks in New Braunfels and in South Padre Island preferred to use two or three small guide signs at the freeway interchange approaching their sites. This can be implemented by using MTG symbol plaques on top of the standard interchange signs. However, Sam Houston Race Park and the Toyota Center preferred one large guide sign, i.e., using an independent supplemental guide sign.

The Toyota Center liked installing its guide signs at the nearest freeway exit only in each direction. The other three MTGs wanted to install their guide signs not only at the nearest freeway exit but also in other places such as on other highways and on mile markers. This means that these three MTGs preferred trailblazing signs. None of the responding MTGs provided additional comments on the guide signs for MTGs.

The MTG survey identified that (1) Sam Houston Race Park and the Toyota Center have more than 1,300 parking spaces each, and the Schlitterbahn Waterparks in both New Braunfels and South Padre Island have more than 900 parking spaces; (2) there are more than 20 events per year at both Sam Houston Race Park and the Toyota Center, and more than 12 events per year at Schlitterbahn Waterparks in both New Braunfels and South Padre Island; (3) there are more than 450,000 attendees annually at both Sam Houston Race Park and the Toyota Center, and more than 250,000 annual attendees at Schlitterbahn Waterparks in both New Braunfels and South Padre Island; and (4) the distance from the nearest freeway exit is less than 2 miles for Sam Houston Race Park and the Toyota Center, the distance from the nearest freeway exit to Schlitterbahn Waterpark in New Braunfels is more than 10 miles, and the Schlitterbahn Waterpark in South Padre Island is located between 3 miles and 5 miles from the nearest freeway exit.

3.2.4.2 Feedback from the Survey of MTG Motorists

Based on the feedback from the survey of MTG motorists, 12 percent of responding motorists located their destinations based on the information provided by freeway guide signs only. Thirty-one percent of motorists depended on online maps before travel. Forty-five percent depended mostly on their driving experience. Even for those who relied on online maps and/or their own experience, they still needed to follow the freeway guide signs. At least 43 percent of motorists rely on freeway signs.

Eighty-eight percent of responders felt that it was necessary to place specific signs for MTGs on freeways. Only 10 percent held the opposite opinion. The most-needed information to be displayed on the specific signs for MTGs, according to the responding motorists, is the name of the destination (36 percent), the action information such as “exit” (26 percent), and distance (13 percent). Nearly half (49 percent) of the responders preferred to use blue as the background color for specific signs for MTGs, 35 percent preferred green, and 5 percent preferred brown. The motorists cared more about the position (34 percent) and an adequate number of signs (32 percent) for MTGs, while some cared less about how the guide signs were designed (21 percent).

CHAPTER 4
FUZY LOGIC–BASED MTG CRITERIA IDENTIFICATION FOR TEXAS

4.1 Problem Statement

Based on the practices in states that have established MTG criteria in their manuals, possible factors that affect MTG criteria could include community population, site-generated traffic, parking, proximity to major corridors, attractions of MTGs, etc. As seen in the literature review, MTG criteria in other states are generally based on the engineers' experiences and opinions with no quantified and formulated way to define.

Engineers' experiences and opinions are human knowledge, which is difficult to represent in crisp values in calculations. This motivates the idea to develop a methodology that can synthesize expert knowledge from engineers and existing practices in other states.

Fuzzy logic (Zadeh 1965), which has been widely used in almost all aspects of transportation systems (e.g. Qiao et al. 2002, Lee et al, 2006, Qiao et al. 2009a, Qiao et al. 2009b, Qiao et al. 2009c, Qiao et al. 2010a, Qiao et al. 2010c), is able to conduct the so-called "soft computing" of human knowledge from experts and engineering practices and is thus an ideal tool to synthesize the MTG criteria for Texas, provided that the experts' knowledge and practices have been collected through necessary surveys and literature reviews.

4.2 Development of Fuzzy Logic–Based Algorithms

Figure 2 is an illustration of the proposed approach. The existing criteria of MTGs by other states are synthesized first, and the survey results from engineers in and outside of Texas are then synthesized. Both are supported by the different strategies of fuzzy logic.

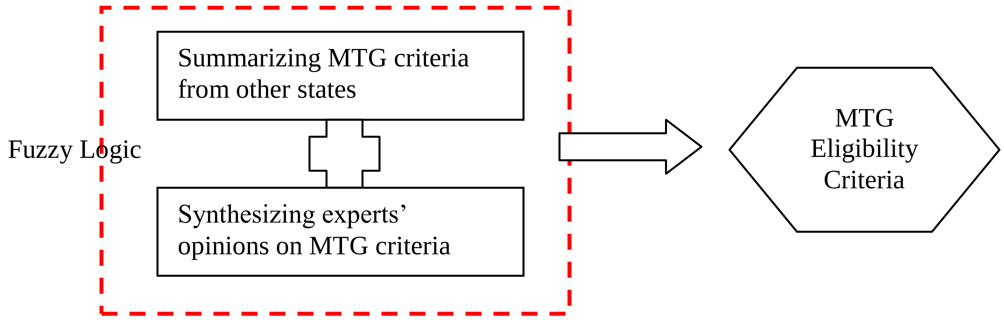


Figure 2 Fuzzy Logic–Based Syntheses of MTG Criteria for Texas

The proposed methodology is based on the following three steps:

- step 1: synthesize the MTG criteria based on existing MTG criteria from other states using fuzzy logic,
- step 2: synthesize MTG criteria based on an engineer survey using an algorithm developed by the fuzzy system, and
- step 3: finalize the MTG criteria generated in the previous steps.

For step 1 of the methodology, since there is only a very limited number of states providing MTG criteria, the way to synthesize those existing criteria was based on the fundamental concept of fuzzy logic.

Step 2 is based on the engineer survey results that have been reported in Chapter 3. A specific approach should be developed to synthesize the knowledge from all responding engineers.

Step 3 is the final procedure to merge the results of steps 1 and 2 and then finally synthesize the eligible MTG criteria for Texas.

4.2.1 Synthesize MTG Criteria Based on Existing Manuals from Other States

In this section, existing MTG criteria in other states (Missouri and Minnesota) will be used to build separate fuzzy rules. Then, similar rules from different states are synthesized together to form the rules for Texas MTG criteria.

4.2.1.1 Develop Rules for MTG Criteria of Missouri

The model for evaluation of Missouri's criteria has three principal input variables, which are city size, distance from the highway, and annual attendance. Researchers marked these three variables as x_1, x_2, and x_3, respectively, in the following process. From the existing manual (*Freeway and Expressway Guide Signs—Engineering Policy Guide*), the following ranges of fuzzy sets can be defined.

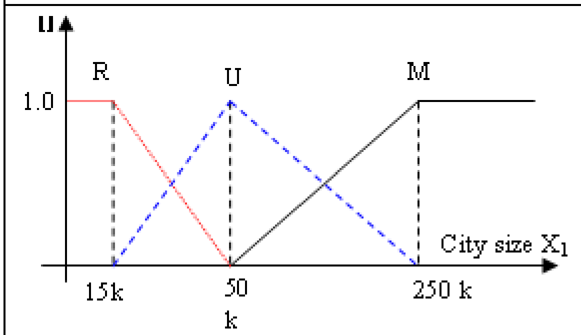
City size (x_1) has three levels, which are measured by the population of the subject city: rural (R) (with a population less than 15,000), urban (U) (with a population between 15,000 and 250,000), and metropolitan (M) (with a population more than 250,000).

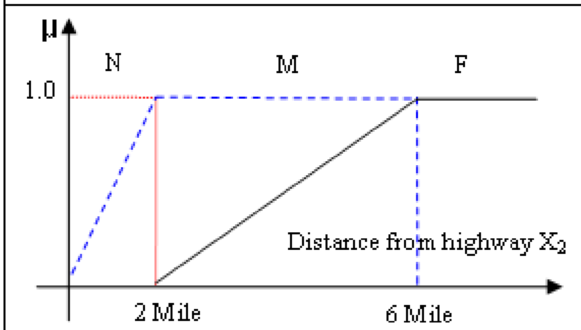
Distance from the highway (x_2) demonstrates the distance from a nearby highway to the generator considered. It also has three levels: near (N) (when the distance from the highway is less than 2 miles), medium (M) (when the distance from the highway is between 2 miles and 6 miles), and far (F) (when the distance from the highway is more than 6 miles).

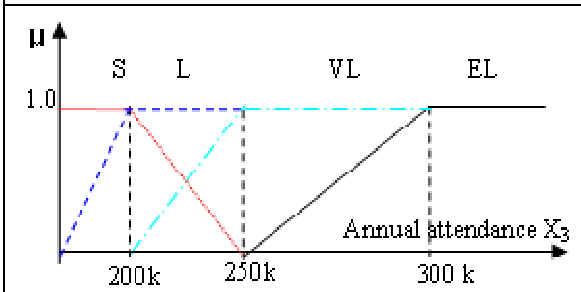
Annual attendance (x_3) means the volume of people visiting the generator every year. It has four levels: small (S) (when the annual attendance is less than 200,000), large (L) (when the annual attendance is between 200,000 and 250,000), very large (VL) (when the annual attendance is between 250,000 and 300,000), and extremely large (EL) (when the annual attendance is more than 300,000).

The output variable Y is the evaluated criterion, which has two levels: eligible (E) and not eligible (NE). The membership function for each input variable and the rule base generated from Missouri's criteria are listed in Table 30. Each rule is a combination of input variables.

Table 30 Rules of MTG Criteria in Missouri







Membership Function	Rule	Input (If)			Output (Then)
		x_1	x_2	x_3	**Y**
	1	*R*	*N*	*S*	*NE*
	2	*U*	*N*	*S*	*NE*
	3	*M*	*N*	*S*	*NE*
	4	*R*	*N*	*L*	*E*
	5	*U*	*N*	*L*	*NE*
	6	*M*	*N*	*L*	*NE*
	7	*R*	*N*	*VL*	*E*
	8	*U*	*N*	*VL*	*E*
	9	*M*	*N*	*VL*	*NE*
	10	*R*	*N*	*EL*	*E*
	11	*M*	*N*	*EL*	*E*
	12	*U*	*N*	*EL*	*E*
	13	*R*	*M*	*S*	*NE*
	14	*U*	*M*	*S*	*NE*
	15	*M*	*M*	*S*	*NE*
	16	*R*	*F*	*S*	*NE*
	17	*U*	*F*	*S*	*NE*
	18	*M*	*F*	*S*	*NE*
	19	*R*	*M*	*L*	*E*
	20	*U*	*M*	*L*	*NE*
	21	*M*	*M*	*L*	*NE*
	22	*R*	*M*	*VL*	*E*
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	26	*U*	*F*	*L*	*NE*
	27	*M*	*F*	*L*	*NE*
	28	*R*	*F*	*VL*	*NE*
	29	*U*	*F*	*VL*	*NE*
	30	*M*	*F*	*VL*	*NE*
	31	*R*	*M*	*EL*	*E*
	32	*U*	*M*	*EL*	*NE*
	33	*M*	*M*	*EL*	*NE*
	34	*R*	*F*	*EL*	*NE*
	35	*U*	*F*	*EL*	*NE*
	36	*M*	*F*	*EL*	*NE*

4.2.1.2 Develop Fuzzy Rules for MTG Criteria of Minnesota

The model for Minnesota has three variables to evaluate the eligibility of its criteria: number of parking spaces, distance from the highway, and annual attendance. The three input variables are marked with x_1, x_2, and x_3, respectively, as well. From the existing manual (*Minnesota Traffic Engineering Manual* [Minnesota Department of Transportation 2000]), the following ranges of fuzzy sets can be identified.

The number of parking space (x_1) indicates the parking ability of the subject generator and measures the maximum number of parking spaces for vehicles. It has two levels: small (S) (when the number of parking spaces is less than 1,000) and large (L) (when the number of parking spaces is more than 1,000).

Distance from the highway (x_2) also has the same meaning as in the previous section and consists of two levels: near (N) (when the distance from the highway is less than 10 miles) and far (F) (when the distance from the highway is more than 10 miles).

Annual attendance (x_3) has the same meaning as in the previous section but only has two levels: small (S) (when the annual attendance is less than 50,000) and large (L) (when the annual attendance is more than 50,000).

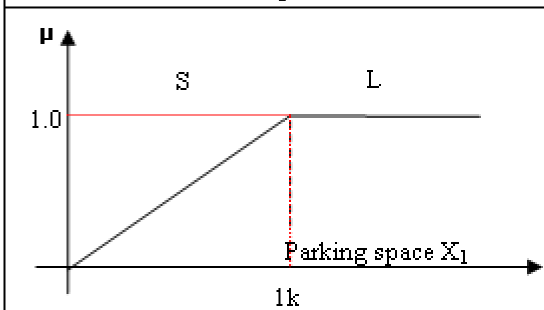
The model output is the evaluated criteria, which are marked as Y, and has two levels: eligible (E) and not eligible (NE).

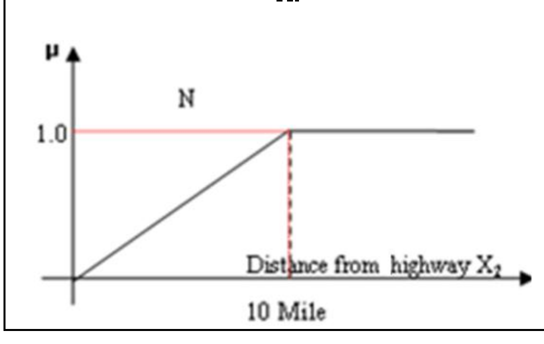
The rule base for Minnesota's criteria is listed in Table 31. Each rule is a combination of the parking size, annual attendance, and distance from the highway.

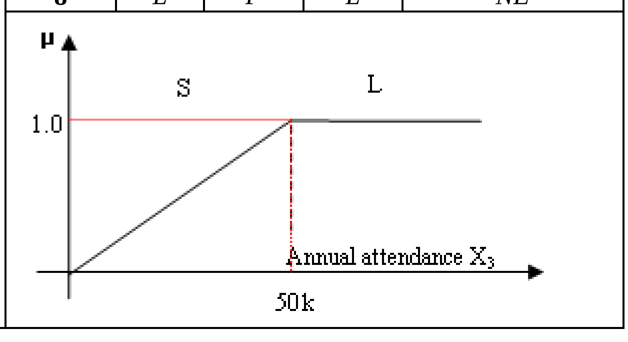
Table 31 Rules of MTG Criteria in Minnesota

Rule	Input (If)			Output (Then)
	x_1	x_2	x_3	**Y**
1	*S*	*N*	*S*	*NE*
2	*L*	*N*	*S*	*NE*
3	*S*	*N*	*L*	*NE*
4	*L*	*N*	*L*	*E*
5	*S*	*F*	*S*	*NE*
6	*L*	*F*	*S*	*NE*
7	*S*	*F*	*L*	*NE*
8	*L*	*F*	*L*	*NE*

Membership Function







4.2.1.3 Combine Fuzzy Rules of Missouri and Minnesota

In order to generate suitable criteria for Texas, the rule bases of Missouri and Minnesota are combined. The major input variables for the combined model are city size, parking size, annual attendance, and distance from the highway. The output of the model is the criteria evaluation result. The definitions of all terms are the same as that explained in the previous sections, but the levels of input variables are different. When mapping the Minnesota model levels with Missouri model levels, the input variables are defined as follows.

City size (x_1) is divided into rural (R) (with a population less than 15,000), urban (U) (with a population between 15,000 and 250,000), and metropolitan (M) (with a population more than 250,000).

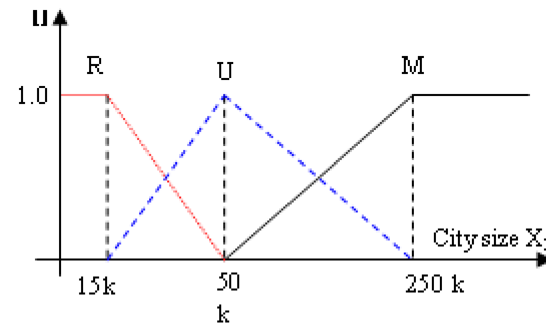
Parking space (x_2) is divided into small (S) (when the number of parking spaces is less than 1,000) and large (L) (when the number of parking spaces is more than 1,000).

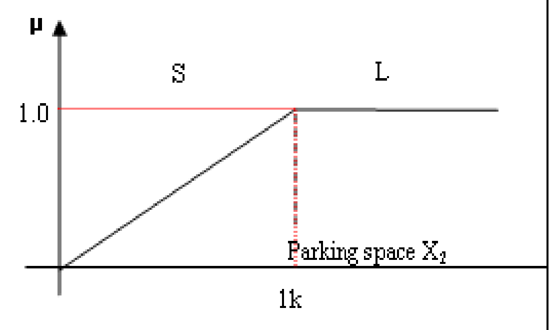
Distance from the highway (x_3) is divided into near (N) (when the distance from the highway is less than 2 miles), medium (M) (when the distance from the highway is between 2 and 6 miles), and far (F) (when the distance from the highway is more than 6 miles).

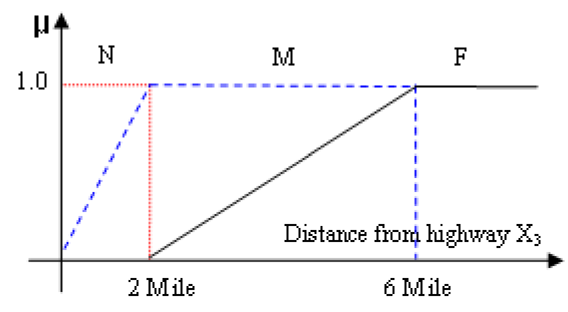
Annual attendance (x_4) is divided into small (S) (when the annual attendance is less than 200,000), large (L) (when the annual attendance is between 200,000 and 250,000), very large (VL) (when the annual attendance is between 250,000 and 300,000), and extremely large (EL) (when the annual attendance is more than 300,000).

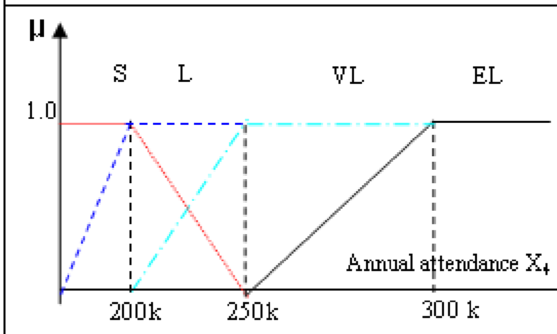
The evaluation criterion (Y) is divided into two levels: eligible (E) and not eligible (NE). Table 32 lists the parts of the eligible output.

Table 32 Rule Base for Evaluating MTG Criteria in Both Missouri and Minnesota

Membership Function	Rule	Input (If)				Output (Then)
		x_1	x_2	x_3	x_4	Y
	1	R	L	N	L	E
	2	R	L	N	VL	E
	3	U	L	N	VL	E
	4	R	L	N	EL	E
	5	M	L	N	EL	E
	6	U	L	N	EL	E
	7	R	L	M	L	E
	8	R	L	M	VL	E
	9	R	L	M	EL	E







4.2.1.4 Identify MTG Criteria for Texas Based on Existing Manuals in Other States

After combining the Missouri and Minnesota evaluation models, this combined model may be able to evaluate the Texas criteria. However, the definition of city size for Texas and other states is different. As shown in the previous models, Missouri and Minnesota divide city size into three categories: rural, urban, and metropolitan. In Texas, city size is defined in four categories: rural, suburban, urban, and metropolitan. In order to generate a fuzzy system to evaluate MTG criteria in Texas, the city type “urban” in the combination model is split into two levels: suburban and urban.

When comparing the definition of city size in Texas and other cities, rural (R) in Texas is related to rural (R) in the combined system, suburban (S) in Texas is related to urban (U) in the combined system, urban (U) in Texas is related to urban (U) in the combined system, and metropolitan (M) in Texas is related to metropolitan (M) in the combined system.

After splitting the levels of city size, the fuzzy rule bases are extended from 9 rules to 11 rules. Table 33 lists these rules for Y = E only.

Table 33 Rules for Evaluation of MTG Criteria in Texas

Fuzzy System for Texas					
Rule	**Input (If)**				**Output (Then)**
	x_1	x_2	x_3	x_4	**Y**
1	*R*	*L*	*N*	*L*	*E*
2	*R*	*L*	*N*	*VL*	*E*
3	*U*	*L*	*N*	*VL*	*E*
4	*R*	*L*	*N*	*EL*	*E*
5	*M*	*L*	*N*	*EL*	*E*
6	*U*	*L*	*N*	*EL*	*E*
7	*R*	*L*	*M*	*L*	*E*
8	*R*	*L*	*M*	*VL*	*E*
9	*R*	*L*	*M*	*EL*	*E*
10	*S*	*L*	*N*	*VL*	*E*
11	*S*	*L*	*N*	*EL*	*E*

When taking into consideration the MTG criteria in North Carolina, the annual attendance should be 250,000 for all land use types. In North Carolina, signs for qualifying traffic generators are limited to the closest freeway interchange, not to exceed 15 miles from the facility, without considering the population range. The MTG criteria in North Carolina are similar to those generated by the rules. After combining the MTG criteria generated from existing manuals with the rules of MTG criteria in North Carolina, the eligibility criteria of MTGs in Texas can then be temporarily identified as followed:

1. parking: a minimum of 1,000 vehicles;
2. a location along either the interchange crossroad or the freeway and within 6 miles of the major traffic generator in a rural area or within 2 miles in an urban, suburban, or metropolitan area; and
3. at least 300,000 annual attendees in metropolitan areas, at least 250,000 annual attendees per year in urban and suburban areas, and at least 200,000 annual attendees per year in rural areas.

4.2.2 Synthesize MTG Criteria Based on Engineers' Opinion

This section describes the second step of algorithm development in detail. The algorithm for synthesizing engineer survey results is addressed first, followed by the detailed procedure of applying this algorithm to a real case.

4.2.2.1 Develop Algorithm for Synthesizing Engineers' Knowledge

Let $\{x_1^p, x_2^p, ...x_n^p\}$ be a set of variables that are potential input variables for MTG criteria: x_i^p is the opinion on the i^{th} variables that the p^{th} expert provided; $i = 1, 2..., n$ such as parking space, distance of MTG from the nearest freeway, annual attendance, number of events per year, etc.; and n is the total number of parameters. $p = 1,2...N$. N is the total number of experts that responded to the survey. $x_1^p, x_2^p, x_3^p ...x_n^p \in U = [\alpha_1, \beta_1] \times ... \times [\alpha_n, \beta_n] \in R^n$, where $[\alpha_i, \beta_i]$ is the universe of discourse of x_i^p.

Let y be a binary variable indicating whether a generator is qualified to be an MTG or not.

$$y = \begin{cases} 1, & \text{If a generator is an MTG} \\ 0, & \text{If a generator is not an MTG} \end{cases} \qquad (1)$$

Any single expert survey response can be represented by a pair of input-output data: $(x_1^p, x_2^p, x_3^p ..., x_n^p; y^p)$, $p = 1, 2... N$. The purpose of such defining is to identify a fuzzy system $f(x)$ based on these N input-output pairs. The following is a six-step procedure illustrating the algorithm.

<u>Step 1</u>. *Define fuzzy sets to cover the input and output spaces.*

Specifically, for each $[\alpha_i, \beta_i], i = 1, 2, ..., n,$ define N_i fuzzy sets $A_i^p (p = 1, 2, ..., N_i)$, which are required to be complete in $[\alpha_i, \beta_i]$; that is, for any $x_i \in [\alpha_i, \beta_i]$, there exists A_i^p such that $\mu_{A_i^p}(x_i) \neq 0$. Similarly, define N_y fuzzy sets $B^p, p = 1, 2, ..., N_y$ that are complete in $[\alpha_y, \beta_y]$. Specifically, there are a total of three inputs (x_1^p, x_2^p, x_3^p) and one output y^p in the fuzzy system. Correspondingly, every input has a different fuzzy set (A_1, A_2, A_3). Fuzzy sets are required to be complete in several discrete fuzzy sets

$[\alpha_1, \beta_1], [\alpha_2, \beta_2], [\alpha_3, \beta_3]$. In total there are N experts providing their opinions to support different fuzzy sets for inputs (x_1, x_2, x_3).

Step 2. *Calculate the number of input supporters for the same fuzzy set.*

Suppose the discreet fuzzy sets with different inputs are:

$$A_1 = \{\alpha_1, \alpha_1 + a_2, \alpha_1 + b_1, \beta_1\}$$
$$A_2 = \{\alpha_2, \alpha_2 + a_2, \alpha_2 + b_2, \beta_2\}$$
$$A_3 = \{\alpha_3, \alpha_3 + a_3, \alpha_3 + b_3, \beta_3\} \tag{2}$$

Then the fuzzy set A_1 "several" may be defined as:

$$A_1 several = \frac{n_1}{\alpha_1} + n_2 / (\alpha_1 + a_1) + n_3 / (\alpha_1 + b_1) + (N - n_1 - n_2 - n_3) / \beta_1 \tag{3}$$

In this case, there are n_1 experts supporting the fuzzy set α_1, n_2 experts supporting the fuzzy set $(\alpha_1 + a_1)$, n_3 experts supporting the fuzzy set $(\alpha_1 + b_1)$, and $(N - n_1 - n_2 - n_3)$ experts supporting the fuzzy set β_1. This process is similarly applied to A_2 and A_3.

Step 3. *Calculate the sum of the weight value of the opinion with the same fuzzy set for different inputs.*

Suppose the first n_1 expert's opinion provides the same fuzzy set α_1, the following n_2 expert's opinion provides the same fuzzy set $(\alpha_1 + a_1)$, the next n_3 expert's opinion provides the same fuzzy set $(\alpha_1 + b_1)$, and the last $(N - n_1 - n_2 - n_3)$ experts' opinion provides the same fuzzy set β_1. Then, the sum of weight value W_i of inputs x_1 with different fuzzy set range should be:

$$W_{A_1[\alpha_1, \beta_1]} = W_{x_1^1} + W_{x_1^2} + W_{x_1^3} + \ldots + W_{x_1^p} = \sum_{i=1}^{N} W_{x_1^i} \tag{4}$$

$$W_{\alpha_1} = W_{x_1^1} + W_{x_1^2} + \ldots + W_{x_1^{n_1}} = \sum_{i=1}^{n_1} W_{x_1^i} \tag{5}$$

$$W_{\alpha_1 + a_1} = W_{x_1^{n_1+1}} + W_{x_2^{n_1+2}} + \ldots + W_{x_1^{n_1+n_2}} = \sum_{i=n_1+1}^{n_1+n_2} W_{x_1^i} \tag{6}$$

$$W_{\alpha_1+b_1} = W_{x_1^{n_1+n_2+1}} + W_{x_1^{n_1+n_2+2}} + \ldots + W_{x_1^{n_1+n_2+n_3}} = \sum_{i=n_1+n_2+1}^{n_1+n_2+n_3} W_{x_1^i} \tag{7}$$

$$W_{\beta_1} = W_{x_1^{n_1+n_2+n_3+1}} + W_{x_1^{n_1+n_2+n_3+2}} + \ldots + W_{x_1^p} = \sum_{i=n_1+n_2+n_3+1}^{N} W_{x_1^i} \tag{8}$$

<u>Step 4.</u> *Define the membership function for different inputs.*

The support of a fuzzy set A_i in the universe of discourse U is a crisp set that contains all the elements of U with nonzero membership values in A_i . That is,

$$supp(A_i) = \{x \in U \,|\, \mu_{A_i(x_i)} > 0\} \tag{9}$$

where $supp(A_i)$ denotes the support of fuzzy set A_i and $\mu_{A_i(x_i)}$ denotes the percentage of weight value for different fuzzy set ranges to the sum weight value. The maximum value of $\mu_{A_i(x_i)}$ should be converted to 1. The following equations indicate how to calculate $\mu_{A_1(x_1)}$.

$$\mu_{A_1(x_1)} = \{\mu_{\alpha_1}, \mu_{\alpha_1+a_1}, \mu_{\alpha_1+b_1}, \mu_{\beta_1}\} \tag{10}$$

$$\mu_{\alpha_1} = W_{\alpha_1} / (W_{\alpha_1} + W_{\alpha_1+a_1} + W_{\alpha_1+b_1} + W_{\beta_1}) \Big/ \max_{\mu_{[\alpha_1,\beta_1]}} (\mu_{\alpha_1}, \mu_{\alpha_1+a_1}, \mu_{\alpha_1+b_1}, \mu_{\beta_1}) \tag{11}$$

$$\mu_{\alpha_1+a_1} = W_{\alpha_1+a_1} / (W_{\alpha_1} + W_{\alpha_1+a_1} + W_{\alpha_1+b_1} + W_{\beta_1}) \Big/ \max_{\mu_{[\alpha_1,\beta_1]}} (\mu_{\alpha_1}, \mu_{\alpha_1+a_1}, \mu_{\alpha_1+b_1}, \mu_{\beta_1}) \tag{12}$$

$$\mu_{\alpha_1+b_1} = W_{\alpha_1+b_1} / (W_{\alpha_1} + W_{\alpha_1+a_1} + W_{\alpha_1+b_1} + W_{\beta_1}) \Big/ \max_{\mu_{[\alpha_1,\beta_1]}} (\mu_{\alpha_1}, \mu_{\alpha_1+a_1}, \mu_{\alpha_1+b_1}, \mu_{\beta_1}) \tag{13}$$

$$\mu_{\beta_1} = W_{\beta_1} / (W_{\alpha_1} + W_{\alpha_1+a_1} + W_{\alpha_1+b_1} + W_{\beta_1}) \Big/ \max_{\mu_{[\alpha_1,\beta_1]}} (\mu_{\alpha_1}, \mu_{\alpha_1+a_1}, \mu_{\alpha_1+b_1}, \mu_{\beta_1}) \tag{14}$$

For example, if $W_{\alpha_1} = 0.4$, $W_{\alpha_1+a_1} = 0.9$, $W_{\alpha_1+b_1} = 0.6$, and $W_{\beta_1} = 0.2$, then $\mu_{\alpha_1} = W_{\alpha_1} / (W_{\alpha_1} + W_{\alpha_1+a_1} + W_{\alpha_1+b_1} + W_{\beta_1}) \big/ W_{\alpha_1+a} / (W_{\alpha_1} + W_{\alpha_1+a_1} + W_{\alpha_1+b_1} + W_{\beta_1}) = W_{\alpha_1} / W_{\alpha_1+a_1}$ $= 0.4 / 0.9 = 0.44$.

Similarly, $\mu_{\alpha_1+a_1} = W_{\alpha_1+a_1} / W_{\alpha_1+a_1} = 1$, $\mu_{\alpha_1+b_1} = W_{\alpha_1+b_1} / W_{\alpha_1+a_1} = 0.67$, and $\mu_{\beta_1} = W_{\beta_1} / W_{\alpha_1+a_1} = 0.22$.

<u>Step 5.</u> *Create one rule for each input-output pair.*

First, for each input-output pair $(x_1^p, x_2^p, x_3^p ..., x_n^p; y^p)$, the membership values of x_i^p should be determined in fuzzy sets A_i. If $x_1^p, x_2^p, x_3^p ..., x_n^p$ are all satisfied with a certain fuzzy set, then y^p is in the given fuzzy set. That is, $\mu_{A_i(x_i)}$ is calculated. In the meantime, the degree of this pair of data $(x_1^p, x_2^p, x_3^p ..., x_n^p; y^p)$ is defined as:

$$D(rule) = \prod_{i=1}^{n} \mu_{A_i}(x_i^p) * \mu_B(y^p) \tag{15}$$

Step 6. *Locate the expert opinion with maximum degree.*

The input-output pair with the maximum degree is selected as the most representative one for synthesizing the MTG criteria. The maximum degree is calculated in Equation (16).

$$D(final) = \max_{p\in[1,N]}[\prod_{i=1}^{n} \mu_{A_i^p}(x_i^p) * \mu_B(y^p)] \tag{16}$$

4.2.2.2 Define Fuzzy Inputs and Outputs

The input variables of MTG criteria have been derived from the existing criteria for traffic generators and MTGs in different states in previous sections. The main important variables in identifying the MTG criteria are minimum parking spaces, minimum distance from the highway, minimum annual attendance, and minimum events per year. In summary, the following parameters are considered in developing MTG criteria in Texas: parking spaces, distance from the highway, annual attendance, and minimum events per year.

These parameters are then defined as input variables for the fuzzy system:

- x_1: minimum number of parking spaces of the MTG,
- x_2: maximum distance from the nearest highway to the MTG,
- x_3: minimum annual attendance of the MTG,
- x_4: minimum number of events per year, and
- y: the eligibility criteria of MTGs for Texas.

The following procedures are considered to design a four-inputs single-output fuzzy system.

4.2.2.3 Define Fuzzy Sets to Cover the Input and Output Spaces

Since the final inputs should be crisp values, the fuzzy sets for different inputs are created as discrete values. After research on the criteria of traffic generators and MTGs from different states, the fuzzy sets for every input have been defined. Table 34 describes the specific fuzzy set for every input identified based on the engineers' opinion from the survey.

Table 34 Discrete Fuzzy Set for Each Input of Fuzzy System

	Fuzzy Set			
Inputs	**Metropolitan Areas**	**Urban Areas**	**Suburban Areas**	**Rural Areas**
x_1	{1,000, 1,300, 1,500}	{750, 800, 900, 1,000, 1,200}	{500, 600, 700, 800, 900, 1,000}	{250, 300, 400, 500, 600, 1,000}
x_2	{1, 2, 3, 5}	{1, 2, 5, 8}	{3, 5, 8, 10}	{3, 5, 10, 25}
x_3	{200k, 300k, 400k, 450k}	{150k, 200k, 250k, 300k}	{100k, 150k, 200k, 250k}	{50k, 100k, 135k, 150k}
x_4	{10, 12, 20}	{8, 10, 12}	{5, 8, 10, 12}	{3, 5, 10}

Table 34 shows some potential values for each input in different population ranges. It has considered not only the MTG criteria in the three states listed in the literature review section but also takes into account the traffic generator criteria in other states that have them.

4.2.2.4 Calculate the Number of Inputs Supporter

According to the survey, some engineers may provide the same opinions as the others. In this step, the number of engineers with the same opinion for each fuzzy set number has been calculated, indicted by "No. of P." In addition, every engineer has been asked to provide the specific number to evaluate the importance for every input. In order to determine the membership values in different fuzzy sets, the weighted values with the same fuzzy set for each input have been combined, specified by the weighted sum. Thus the membership value can be determined based on a ratio of the weighted value with the same fuzzy set over the total sum. Finally the maximum membership value is converted to 1.0. The membership values are now noted as μ. Tables 35, 36, 37, and 38 indicate the process of how to calculate μ in different fuzzy sets for each input with the four different population ranges.

Table 35 Process to Calculate μ_{x_1} for the Input Parking Space (PS) x_1

x_1	Major Metropolitan					
PS	**No. of P.**	**Weight Sum**	**Frequency**	μ_{x_1}	**PS** $\bullet\ \mu_{x_1}$	
1,000	7	4.5	0.78	1.00	1,000	**Average PS** 1,102 **corresponding μ** 0.71
1,300	1	0.9	0.15	0.20	260	
1,500	1	0.7	0.11	0.16	233	
Sum	9	6.1	1.00			
	Urban					
750	1	0.9	0.15	0.31	233	**Average PS** 947 **corresponding μ** 0.72
800	2	0.8	0.13	0.28	221	
900	1	0.8	0.13	0.28	248	
1,000	4	2.9	0.48	1.00	1,000	
1,200	1	0.7	0.11	0.24	290	
Sum	9	6.1	1.00			
	Suburban					
500	1	0.9	0.15	0.50	250	**Average PS** 766 **corresponding μ** 0.31
600	1	0.7	0.11	0.39	233	
700	2	1.6	0.26	0.89	622	
800	1	0.2	0.03	0.11	89	
900	3	1.8	0.30	1.00	900	
1,000	1	0.9	0.15	0.50	500	
Sum	9	6.1	1.00			
	Rural					
250	1	0.9	0.15	0.53	132	**Average PS** 373 **corresponding μ** 0.90
300	1	0.7	0.11	0.41	124	
400	3	1.7	0.28	1.00	400	
500	1	0.9	0.15	0.53	265	
600	2	1.0	0.16	0.59	353	
1,000	1	0.9	0.15	0.53	529	
Sum	9	6.1	1.00			

Table 36 Process to Calculate μ_{x_2} for the Input Distance from Highway (DFH) x_2

x_2	Major Metropolitan					
DFH (Mile)	**No. of P.**	**Weight Sum**	**Frequency**	μ_{x_2}	**DFH** $\bullet \mu_{x_2}$	
1	1	1.0	0.12	0.24	0.24	**Average DFH** 2.87 **corresponding μ** 0.25
2	5	4.1	0.48	1.00	2.00	
3	2	0.9	0.11	0.22	0.66	
5	3	2.5	0.29	0.61	3.05	
Sum	11	8.5	1.0			
	Urban					
1	1	1.0	0.12	0.25	0.25	**Average DFH** 3.86 **corresponding μ** 0.97
2	3	2.7	0.32	0.68	1.35	
5	6	4.0	0.47	1.00	5.00	
8	1	0.8	0.09	0.20	1.6	
Sum	11	8.5	1.00			
	Suburban					
3	3	2.7	0.32	0.75	2.25	**Average DFH** 5.57 **corresponding μ** 0.87
5	5	3.6	0.42	1.00	5.00	
8	1	0.4	0.05	0.11	0.89	
10	2	1.8	0.21	0.50	5.00	
Sum	11	8.5	1			
	Rural					
3	3	2.7	0.32	1.00	3.00	**Average DFH** 7.84 **corresponding μ** 0.99
5	3	2.3	0.27	0.85	4.26	
10	4	2.7	0.32	1.00	10.00	
25	1	0.8	0.09	0.30	7.41	
Sum	11	8.5	1.00			

Table 37 Process to Calculate μ_{x_3} for the Input Annual Attendance (AA) x_3

x_3	Major Metropolitan					
AA	**No. of P.**	**Weight Sum**	**Frequency**	μ_{x_3}	**AA** $\bullet \mu_{x_3}$	
100,000	3	2.6	0.31	1	200,000	**Average AA** 325,000 **corresponding μ** 0.76
200,000	2	2.0	0.24	0.51	102,564	
300,000	3	2.0	0.24	0.77	230,769	
400,000	2	2.0	0.24	0.77	307,692	
450,000	2	1.8	0.21	0.69	311,538	
Sum	10	8.4	1.00			
	Urban					
150,000	2	1.6	0.19	0.57	85,714	**Average AA** 233,735 **corresponding μ** 0.62
200,000	3	2.3	0.28	0.82	164,286	
250,000	2	1.6	0.19	0.57	142,857	
300,000	3	2.8	0.34	1.00	300,000	
Sum	10	8.3	1.00			
	Suburban					
100,000	5	3.9	0.46	1	100,000	**Average AA** 149,405 **corresponding μ** 0.41
150,000	2	1.6	0.19	0.4102564	61,538	
250,000	1	0.9	0.11	0.2307692	57,692	
Sum	10	8.4	1.00			
	Rural					
50,000	7	5.5	0.65	1.00	50,000	**Average AA** 76,786 **corresponding μ** 0.53
100,000	1	1.0	0.12	0.18	18,182	
135,000	1	1.0	0.12	0.18	24,545	
150,000	1	0.9	0.11	0.16	24,545	
Sum	10	8.4	1.00			

Table 38 Process to Calculate μ_{x_4} for Input Number of Events (NOE) x_4

x_4	Major Metropolitan					
NOE	**No. of P.**	**Weight Sum**	**Frequency**	μ_{x_4}	**NOE** $\bullet \mu_{x_4}$	
10	4	2.9	0.45	1.00	10	**Average NOE** 15 **corresponding μ** 0.43
12	1	0.7	0.11	0.24	3	
20	4	2.9	0.45	1.00	20	
Sum	9	6.5	1.00			
	Urban					
8	2	1.3	0.20	0.42	3	**Average NOE** 11 **corresponding μ** 0.76
10	3	2.1	0.32	0.68	7	
12	4	3.1	0.48	1.00	12	
Sum	9	6.5	1.00			
	Suburban					
5	3	1.8	0.28	0.95	5	**Average NOE** 8 **corresponding μ** 0.99
8	2	1.9	0.29	1.00	8	
10	2	1.6	0.25	0.84	8	
12	2	1.2	0.18	0.63	8	
Sum	9	6.5	1.00			
	Rural					
3	4	2.8	0.50	1.00	3	**Average NOE** 6 **corresponding μ** 0.32
5	1	0.9	0.16	0.32	2	
10	3	1.9	0.34	0.68	7	
Sum	8	5.6	1.00			

During this step, the average minimum number of parking spaces, maximum distance from the highway, annual attendance, and number of events per year have also been calculated through the equation sum (fuzzy set *μ)/sum (μ). The corresponding μ for each average minimum number of parking spaces, maximum distance from the highway, annual attendance, and number of events per year can be directly read through the figures of the membership function for each input.

From Table 35, since the engineers are being asked to provide their opinions on the importance of each input from 0 to 1, the weighted values for different fuzzy set numbers such as 1,000, 1,300, and 1,500 for the minimum number of parking spaces (x_1) in a metropolitan area varies. The weighted sum for the fuzzy number 1,000 can be conducted by applying the weighted values provided by all the engineers who favor 1,000 as the minimum number of parking spaces in a metropolitan area. In summary, most engineers (seven out of nine who responded to this question) prefer 1,000 as the minimum number of parking spaces in a metropolitan area, so the corresponding weight value is higher than that of other fuzzy set numbers (0.9 and 0.7). Thus, 1,000 is the minimum number of parking spaces in a metropolitan area that is preferred by the engineers. Similarly 1,000 and 400 are the minimum numbers of parking spaces most selected as criteria for urban areas and rural areas, respectively.

As summarized in Table 36, another parameter of inputs, the maximum distance from the highway (DFH) (x_2), has been calculated. The weighted sum is 4.1 for DFH as 2 miles in metropolitan areas, meaning that most engineers prefer 2 miles as the maximum distance from the highway in a metropolitan area. Similarly, the maximum distance from the highway is selected as 5 miles in an urban and 10 miles in suburban or rural areas.

In Table 37, the minimum annual attendance x_3 for different population ranges has been calculated. Following a procedure similar to that for parking spaces and for distance from the highway, the average of the minimum annual attendance in metropolitan areas is selected as 3,250,000. For other population ranges, minimum annual attendance is 300,000 for an urban area, 100,000 for a suburban area, and 5,000 for a rural area.

In Table 38, the minimum number of events (x_4) for different population ranges has been calculated. In conclusion, a minimum of 20 events in a metropolitan area, 12 in an urban area, 8 in a suburban area, and 3 in a rural area are selected.

4.2.2.5 Design the Membership Function for Different Inputs

The membership functions have been developed by the relationship between μ and the fuzzy set number for each input with four population ranges. The curve in Figure 3 addresses the relationship between μ and the fuzzy set number, whereas the vertical lines in Figures 3-6 indicates the average value of each input with four population divisions. Figures 3-6 present individually the membership function for the minimum number of parking spaces, minimum distance from the highway, minimum annual attendance, and minimum number of events per year with four population divisions, which are metropolitan areas, urban areas, suburban areas, and rural areas.

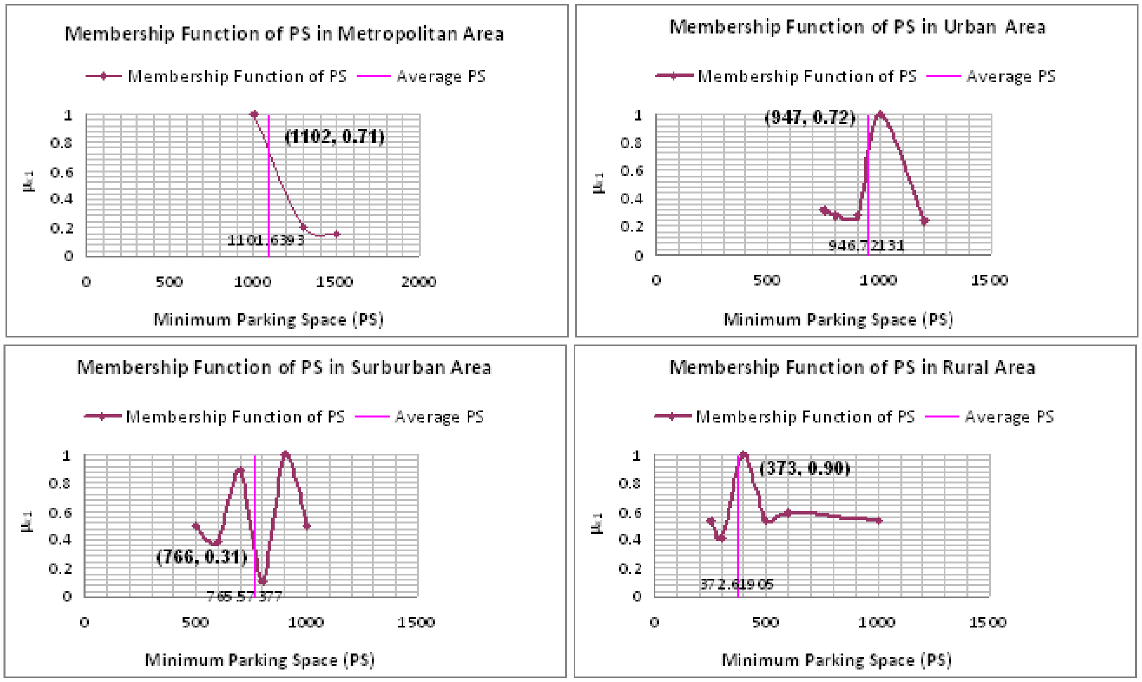


Figure 3 Membership Function for Input x_1 (Parking Space)

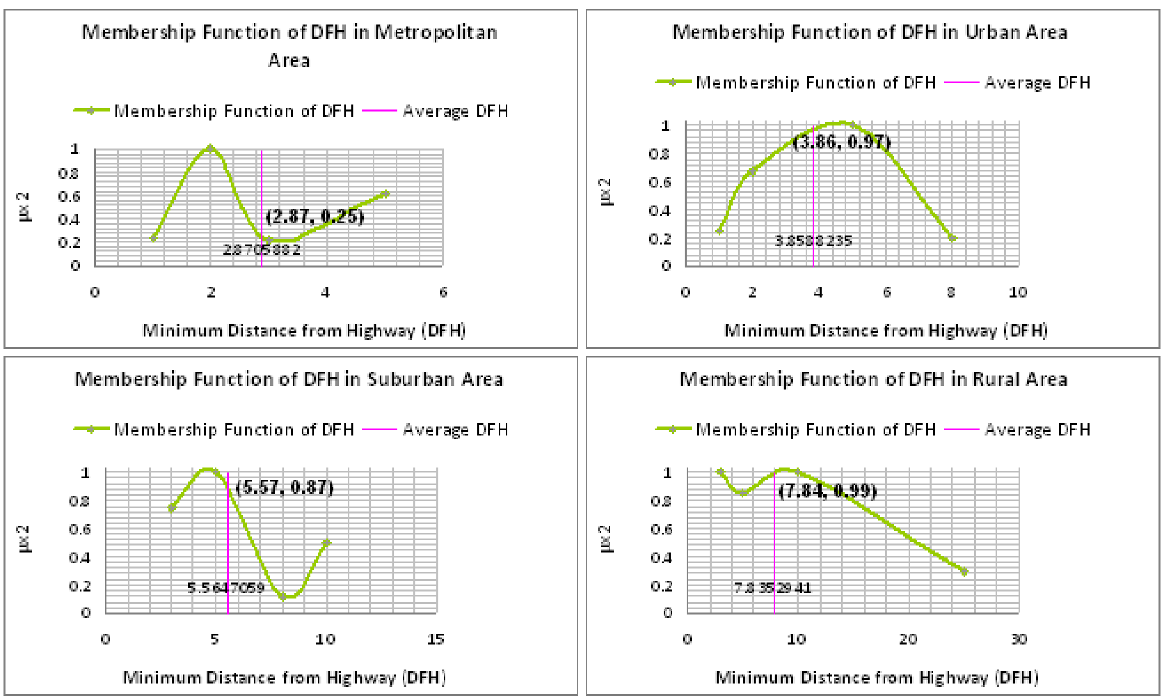


Figure 4 Membership Function for Input x_2 (Distance from Highway)

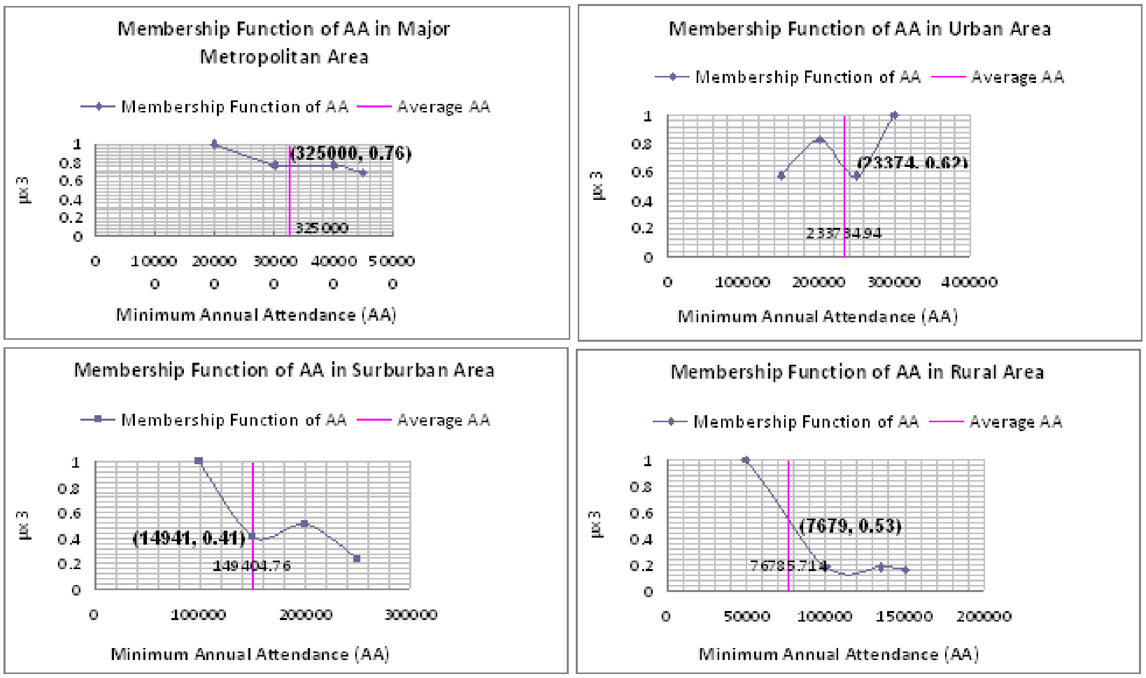


Figure 5 Membership Function for Input x_3 (Annual Attendance)

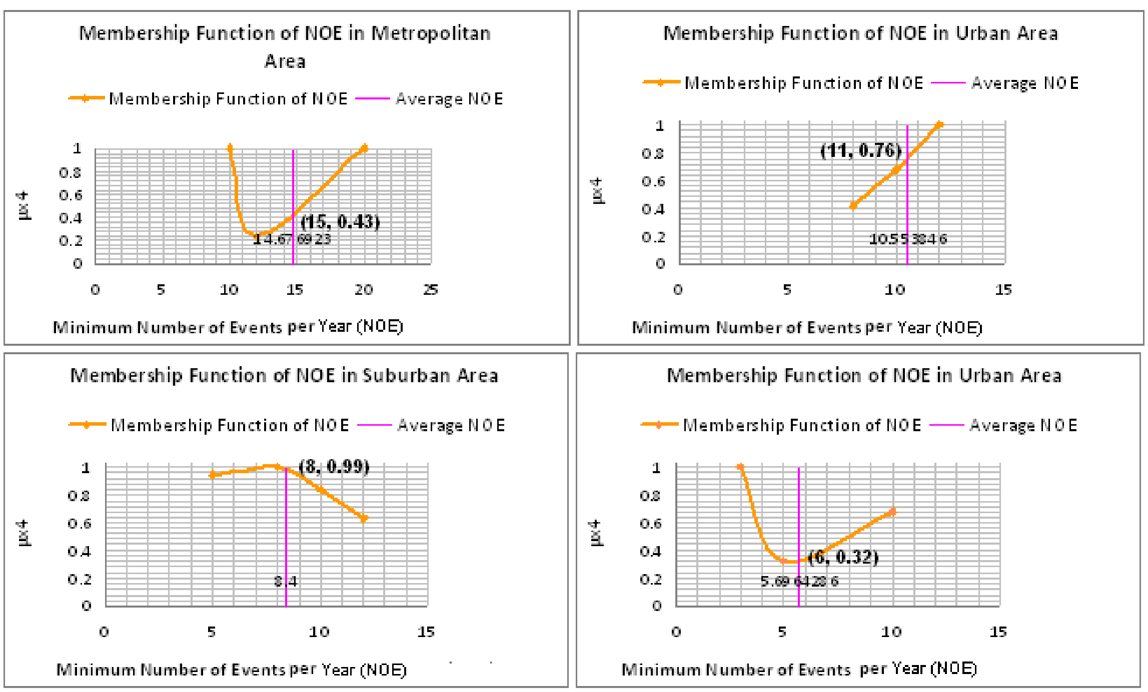


Figure 6 Membership Function for Input x_4 (Number of Events per Year)

Figure 3 describes the membership function for the minimum number of parking spaces in metropolitan areas, urban areas, suburban areas, and rural areas. The average value for minimum number of parking spaces in each population range is marked as a vertical line intersected by the membership function. There is a μ value in each crossing point. We define this μ value as the average μ that should be used to consider the missing data. From Figure 3, the average μ for parking spaces should be 0.71 in metropolitan areas, 0.72 in urban areas, 0.31 in suburban areas, and 0.9 in rural areas.

Figure 4 describes the membership function for maximum distance from the highway in metropolitan areas, urban areas, suburban areas, and rural areas. The red vertical line describes the average value of the maximum distance from the highway in each population range. Based on the information provided by this figure, the average μ for maximum distance from the highway should be 0.25 in metropolitan areas, 0.97 in urban areas, 0.87 in suburban areas, and 0.99 in rural areas.

Figure 5 describes the membership function for minimum annual attendance in metropolitan areas, urban areas, suburban areas, and rural areas. The red vertical line explains the average value of minimum annual attendance considered as MTG criteria for each population range. Based on the information provided by this figure, the average μ for minimum annual attendance should be 0.76 in metropolitan areas, 0.62 in urban areas, 0.41 in suburban areas, and 0.53 in rural areas.

Figure 6 gives details about the membership function for the minimum number of events per year in metropolitan areas, urban areas, suburban areas, and rural areas. The corresponding μ for the average value of minimum number of events per year should be 0.43 in metropolitan areas, 0.76 in urban areas, 0.99 in suburban areas, and 0.32 in rural areas.

In conclusion, in the calculation of membership functions, the average fuzzy set number in each membership function has a corresponding μ, which could be used to interpret the missing data.

4.2.2.6 Create One Rule from Each Input-Output Pair

In this step, each rule is generated from each input-output pair. Since there are 17 engineers who responded to the survey and four different population divisions, the total number of the rule should be $17 \times 4 = 68$. In Table 39, the degree of rule D(rule), which is marked by an asterisk, specifies that this rule is generated by engineers in Texas. There are five rules generated from Texas in each population division. The degree of each rule is created based on Equation (15).

Table 39 Membership Values for Each Rule

	Major Metropolitan Area					
	μ_{x_1}	μ_{x_2}	μ_{x_3}	μ_{x_4}	μ_y	**D (Rule)**
Rule 1	1.00	1.00	1.00	1.00	1	1.00
***Rule 2**	0.71	0.25	0.76	0.43	1	0.06
***Rule 3**	0.20	1.00	0.69	1.00	1	0.14
***Rule 4**	0.71	0.25	0.76	0.43	1	0.06
***Rule 5**	0.71	0.25	0.76	0.43	1	0.06
Rule 6	1.00	1.00	0.77	1.00	1	0.77
Rule 7	0.71	0.25	0.76	0.43	1	0.06
Rule 8	1.00	0.22	0.77	1.00	1	0.17
Rule 9	0.71	0.61	0.77	0.43	1	0.14
Rule 10	1.00	0.24	0.77	1.00	1	0.19
Rule 11	0.16	0.22	0.69	1.00	1	0.02
***Rule 12**	1.00	1.00	0.76	0.43	1	0.33
Rule 13	0.71	0.25	0.76	0.43	1	0.06
Rule 14	0.71	0.61	1.00	0.43	1	0.19
Rule 15	0.71	0.25	0.76	0.24	1	0.03
Rule 16	1.00	1.00	0.77	1.00	1	0.77
Rule 17	1.00	0.61	1.00	1.00	1	0.61
	Urban Area					
	μ_{x_1}	μ_{x_2}	μ_{x_3}	μ_{x_4}	μ_y	**D (Rule)**
Rule 1	1.00	1.00	0.57	0.68	1	0.39
***Rule 2**	0.72	0.97	0.62	0.76	1	0.33
***Rule 3**	1.00	0.68	1.00	0.68	1	0.46
***Rule 4**	0.72	0.97	0.62	0.76	1	0.33
***Rule 5**	0.72	0.97	0.62	0.76	1	0.33
Rule 6	0.28	1.00	0.82	1.00	1	0.23
Rule 7	0.72	0.97	0.62	0.76	1	0.33
Rule 8	0.28	1.00	0.82	0.42	1	0.10
Rule 9	0.72	1.00	1.00	0.76	1	0.55
Rule 10	0.31	0.25	1.00	1.00	1	0.08
Rule 11	0.24	1.00	0.57	0.68	1	0.09
***Rule 12**	1.00	0.68	0.62	0.76	1	0.32
Rule 13	0.72	0.97	0.62	0.76	1	0.33
Rule 14	0.72	0.20	0.57	0.76	1	0.06
Rule 15	0.72	0.97	0.62	1.00	1	0.43
Rule 16	1.00	0.68	0.57	1.00	1	0.39
Rule 17	0.28	1.00	0.82	0.42	1	0.10

Table 39 Membership Values for Each Rule (Continued)

	Suburban Area					
	μ_{x_1}	μ_{x_2}	μ_{x_3}	μ_{x_4}	μ_y	**D (Rule)**
Rule 1	0.50	0.50	0.41	0.84	1	0.09
***Rule 2**	0.31	0.87	0.41	0.99	1	0.11
***Rule 3**	0.89	0.75	0.51	1.00	1	0.34
***Rule 4**	0.31	0.87	0.41	0.99	1	0.11
***Rule 5**	0.31	0.87	0.41	0.99	1	0.11
Rule 6	1.00	0.11	1.00	0.84	1	0.09
Rule 7	0.31	0.87	0.41	0.99	1	0.11
Rule 8	0.39	1.00	1.00	0.95	1	0.37
Rule 9	0.31	1.00	0.23	0.99	1	0.07
Rule 10	0.50	1.00	0.41	1.00	1	0.21
Rule 11	0.89	1.00	1.00	0.95	1	0.84
***Rule 12**	1.00	0.75	0.41	0.99	1	0.30
Rule 13	0.31	0.87	0.41	0.99	1	0.11
Rule 14	0.31	0.50	1.00	0.99	1	0.15
Rule 15	0.31	0.87	0.41	0.63	1	0.07
Rule 16	0.11	0.75	1.00	0.63	1	0.05
Rule 17	1.00	1.00	0.51	0.95	1	0.49
	Rural Area					
	μ_{x_1}	μ_{x_2}	μ_{x_3}	μ_{x_4}	μ_y	**D (Rule)**
Rule 1	0.53	1.00	1.00	0.68	1	0.36
***Rule 2**	0.90	0.99	0.53	0.32	1	0.15
***Rule 3**	1.00	1.00	0.18	0.32	1	0.06
***Rule 4**	0.90	0.99	0.53	0.32	1	0.15
***Rule 5**	0.90	0.99	0.53	0.32	1	0.15
Rule 6	0.59	1.00	1.00	0.32	1	0.19
Rule 7	0.90	0.99	0.53	0.32	1	0.15
Rule 8	1.00	1.00	1.00	1.00	1	1.00
Rule 9	0.90	0.85	0.16	0.32	1	0.04
Rule 10	0.53	0.85	1.00	1.00	1	0.45
Rule 11	0.41	0.85	1.00	1.00	1	0.35
***Rule 12**	0.53	1.00	0.53	0.32	1	0.09
Rule 13	0.90	0.99	0.53	0.32	1	0.15
Rule 14	0.90	0.30	1.00	0.32	1	0.09
Rule 15	0.90	0.99	0.53	0.68	1	0.32
Rule 16	0.59	1.00	1.00	0.68	1	0.40
Rule 17	1.00	1.00	0.18	1.00	1	0.18

Note: The rule numbers with "*" are those from Texas engineers. The membership function of y is a singleton function, meaning that its value $\boldsymbol{\mu}_y$ with claimed rule is 1 and thus not listed in Table 39.

Regarding missing data, such as engineers who do not provide their opinion on specific input values, the μ corresponding to the average value for each input is used for interpretation.

Table 39 presents the membership value μ of each input rule and value μ of output y. These rules have been divided into two categories: rules from Texas (R_{Texas}) and rules from non-Texas ($R_{Non\text{-}Texas}$).

From Table 39, rule 1 in non-Texas and rule 12 in Texas should be selected in metropolitan areas; rule 9 in non-Texas and rule 3 in Texas should be selected in urban areas; rule 11 in non-Texas and rule 3 in Texas should be selected in suburban areas; and rule 8 in non-Texas and rules 2, 4, and 5 in Texas should be selected in rural areas. The next subsection explains the final rule in detail.

The most representative rule is picked by the maximum degree based on Equation (16). There are two representative rules for each population range: one is generated from R_{Texas}, and the other is generated from $R_{Non\text{-}Texas}$. The rule generated by Texas engineers is close to the rule generated by Non-Texas engineers. Since the situation in Texas is different from that in other states, the opinions provided by engineers from Texas are more reliable for this research.

4.2.3 Combine and Finalize MTG Criteria for Texas

The final criteria of MTG should be identified from both $R_{Non\text{-}Texas}$ and R_{Texas} by the following equation:

$$R(final) = a(R_{Texas}) + b(R_{Non-Texas}) \tag{17}$$

In Equation (17), parameters $a \in [0,1]$ and $b \in [0,1]$ satisfy $a + b = 1$, and the selection of a and b are determined by the preferences of whether or not knowledge from Texas engineers is more important than that from engineers from other states. For example a = 1 and b = 0 means the final criteria are based on experiences from Texas engineers only. a = 0 and b = 1 excludes all Texas engineers and only considers opinions from non-Texas engineers. Table 40 describes the specific MTG criteria for each population range based on different value of a and b.

Table 40 MTG Criteria Generated by Different Values of *a* and *b*

		Major Metropolitan Area	Urban Area	Suburban Area	Rural Area
D($R_{Non-Texas}$) (*a* = 0, *b* = 1)	x_1	1,000	950	700	400
	x_2	2	5	5	10
	x_3	200,000	300,000	100,000	50,000
	x_4	15	12	5	3
D(R_{Texas}) (*a* = 1, *b* = 0)	x_1	1,000	1,000	700	400
	x_2	2	2	3	8
	x_3	325,000	300,000	200,000	80,000
	x_4	15	10	8	6
***a* = 0.125, *b* = 0.875**	x_1	1,000	956.25	700	400
	x_2	2	4.625	4.75	9.75
	x_3	215,625	300,000	112,500	53,750
	x_4	15	11.75	5.375	3.375
***a* = 0.25, *b* = 0.75**	x_1	1,000	962.5	700	400
	x_2	2	4.25	4.5	9.5
	x_3	231,250	300,000	125,000	57,500
	x_4	15	11.5	5.75	3.75
***a* = 0.375, *b* = 0.625**	x_1	1,000	968.75	700	400
	x_2	2	3.875	4.25	9.25
	x_3	246,875	300,000	137,500	61,250
	x_4	15	11.25	6.125	4.125
***a* = 0.4, *b* = 0.6**	x_1	1,000	970	700	400
	x_2	2	3.8	4.2	9.2
	x_3	250,000	300,000	140,000	62,000
	x_4	15	11.2	6.2	4.2
***a* = 0.5, *b* = 0.5**	x_1	1,000	975	700	400
	x_2	2	3.5	4	9
	x_3	262,500	300,000	150,000	65,000
	x_4	15	11	6.5	4.5
***a* = 0.6, *b* = 0.4**	x_1	1,000	980	700	400
	x_2	2	3.2	3.8	8.8
	x_3	275,000	300,000	160,000	68,000
	x_4	15	10.8	6.8	4.8

Table 40 MTG Criteria Generated by Different Values of *a* and *b* (Continued)

		Major Metropolitan Area	Urban Area	Suburban Area	Rural Area
***a* = 0.625, *b* = 0.375**	x_1	1,000	981.25	700	400
	x_2	2	3.125	3.75	8.75
	x_3	278,125	300,000	162,500	68,750
	x_4	15	10.75	6.875	4.875
***a* = 0. 75, *b* = 0.25**	x_1	1,000	987.5	700	400
	x_2	2	2.75	3.5	8.5
	x_3	293,750	300,000	175,000	72,500
	x_4	15	10.5	7.25	5.25
***a* = 0.875, *b* = 0.125**	x_1	1,000	993.75	700	400
	x_2	2	2.375	3.25	8.25
	x_3	309,375	300,000	187,500	76,250
	x_4	15	10.25	7.625	6

4.2.3.1 Analysis for Metropolitan Areas

The following table presents the MTG criteria for major metropolitan areas based on different values for *a* and *b*. Here value *a* is considered from 0 to 1, whereas *b* is considered from 1 to 0 to satisfy relationship $a + b = 1$ always. The minimum number of parking spaces, the maximum distance from the highway, and minimum number of events per year are not affected by different values of *a*. This means that the opinion of Texas engineers is similar to that of non-Texas engineers. Table 41 lists the MTG criteria with different values of *a* and *b* in major metropolitan areas.

From Table 41, the following information on MTG criteria could be concluded: (1) the minimum number of parking spaces in major metropolitan areas is 1,000 regardless of different values; (2) the maximum distance from the highway is 2 miles in major metropolitan areas for different values of *a*; (3) the minimum annual attendance in major metropolitan areas increases with an increase of value *a*; and (4) the minimum number of events per year is 15 events for different values of *a* and *b*.

Figure 7 shows how the different input variables of MTG criteria are affected by differing values of *a*.

Table 41 MTG Criteria of Different Values of *a* and *b* in Major Metropolitan Areas

Index		Major Metropolitan Area			
a	***b***	x_1	x_2	x_3	x_4
0	1	1,000	2	200,000	15
0.125	0.875	1,000	2	215,625	15
0.25	0.75	1,000	2	231,250	15
0.375	0.625	1,000	2	246,875	15
0.4	0.6	1,000	2	250,000	15
0.5	0.5	1,000	2	262,500	15
0.6	0.4	1,000	2	275,000	15
0.625	0.375	1,000	2	278,125	15
0.75	0.25	1,000	2	293,750	15
0.875	0.125	1,000	2	309,375	15
1	0	1,000	2	325,000	15

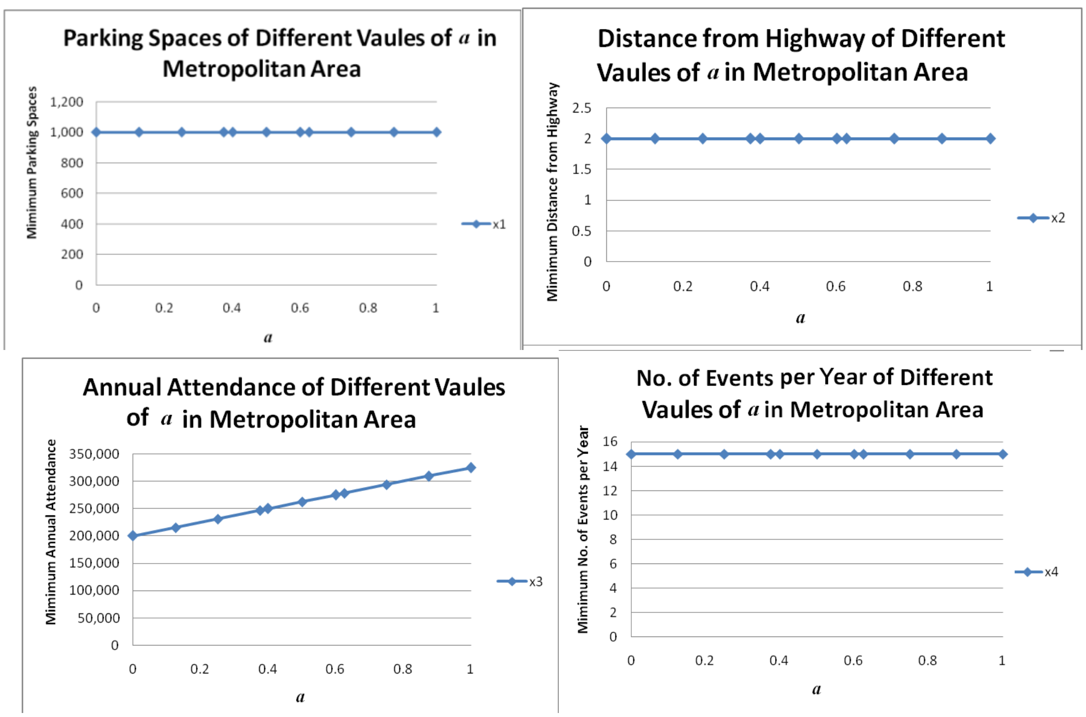


Figure 7 Comparison between Different Parameters of MTG Criteria in Metropolitan Areas

4.2.3.2 Analysis for Urban Areas

Table 42 describes the MTG criteria for urban areas based on different values for *a* and *b*. The minimum number of parking spaces, maximum distance from the highway, and minimum number of events per year increase with an increase of value *a*, and the minimum annual attendance is not affected by value *a*. This means that the opinion on minimum annual attendance from Texas engineers is similar to that of non-Texas engineers, and other MTG criteria parameters differ in opinions from Texas engineers and non-Texas engineers.

Table 42 MTG Criteria of Different Values of *a* and *b* in Urban Areas

Index		**Urban Area**			
a	***b***	x_1	x_2	x_3	x_4
0	1	950	5	300,000	12
0.125	0.875	956.25	4.625	300,000	11.75
0.25	0.75	962.5	4.25	300,000	11.5
0.375	0.625	968.75	3.875	300,000	11.25
0.4	0.6	970	3.8	300,000	11.2
0.5	0.5	975	3.5	300,000	11
0.6	0.4	980	3.2	300,000	10.8
0.625	0.375	981.25	3.125	300,000	10.75
0.75	0.25	987.5	2.75	300,000	10.5
0.875	0.125	993.75	2.375	300,000	10.25
1	0	1,000	2	300,000	10

From Table 42, the following information could be concluded: (1) the minimum number of parking spaces in urban areas is less than 1,000 and is reduced with a reduction of value *a*; (2) the maximum distance from the highway is less than 5 miles and more than 2 miles in urban areas and changes with different values of *a*; (3) the minimum annual attendance in urban areas is 300,000 and is not affected by the value of *a*; and (4) the minimum number of events per year is between 10 and 12 events in urban areas. Figure 8 shows the relationship of different input variables of MTG criteria varying with the value of *a*.

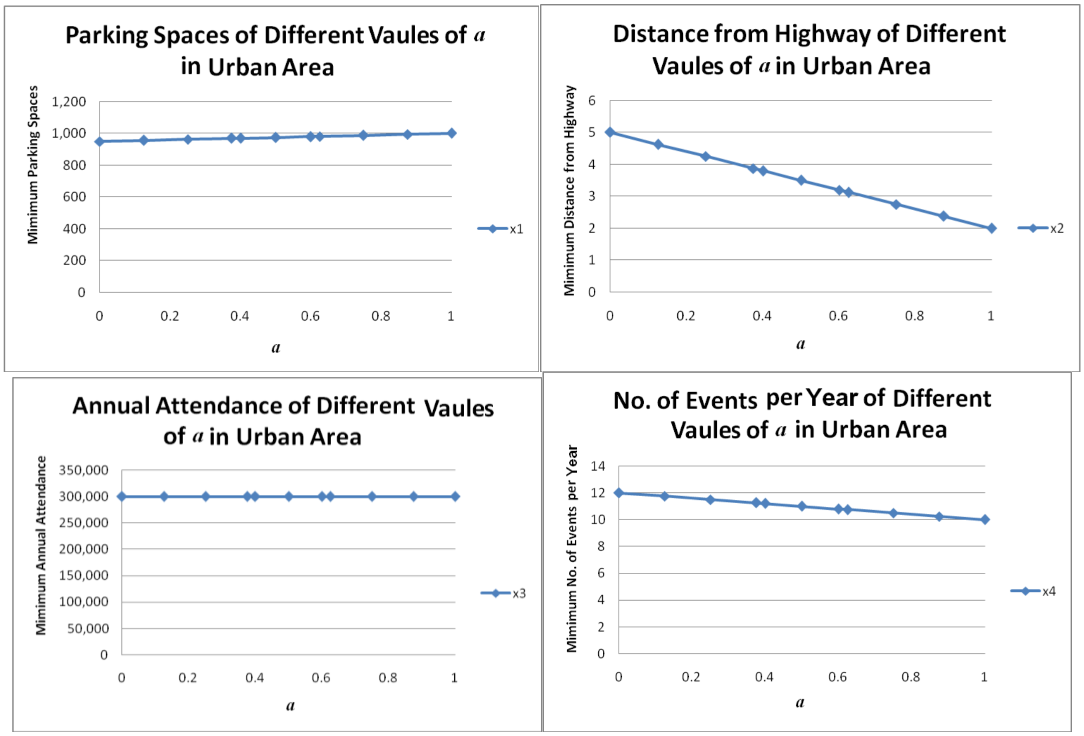


Figure 8 Comparison between Different Parameters of MTG Criteria in Urban Areas

4.2.3.3 Analysis for Suburban Areas

Table 43 presents the MTG criteria for different suburban areas based on different values of *a* and *b*. The minimum number of parking spaces is not influenced by different values of *a*. The values of *a* do not have an effect on the maximum distance from the highway, the minimum annual attendance, and the minimum number of events per year. It illustrates that the opinion on the minimum parking spaces from Texas engineers is similar to that of non-Texas engineers, and the opinion on other MTG criteria parameters is different for Texas engineers and non-Texas engineers.

From Table 43, the following information can be summarized: (1) the minimum number of parking spaces in suburban areas is 700 for any value of *a*; (2) the maximum distance from the highway is between 3 and 5 miles in suburban areas for different values of *a*; (3) the minimum annual attendance in suburban areas increases with an increase in the values of *a* and is between 100,000 and 200,000 attendees; and (4) the minimum number of events per year is from five to eight events based on different values of *a*. Figure 9 compares different input variables of MTG criteria varying with *a* in suburban areas.

Table 43 MTG Criteria of Different Values of *a* and *b* in Suburban Areas

Index		Suburban Area			
a	***b***	x_1	x_2	x_3	x_4
0	1	700	5	100,000	5
0.125	0.875	700	4.75	112,500	5.375
0.25	0.75	700	4.5	125,000	5.75
0.375	0.625	700	4.25	137,500	6.125
0.4	0.6	700	4.2	140,000	6.2
0.5	0.5	700	4	150,000	6.5
0.6	0.4	700	3.8	160,000	6.8
0.625	0.375	700	3.75	162,500	6.875
0.75	0.25	700	3.5	175,000	7.25
0.875	0.125	700	3.25	187,500	7.625
1	0	700	3	200,000	8

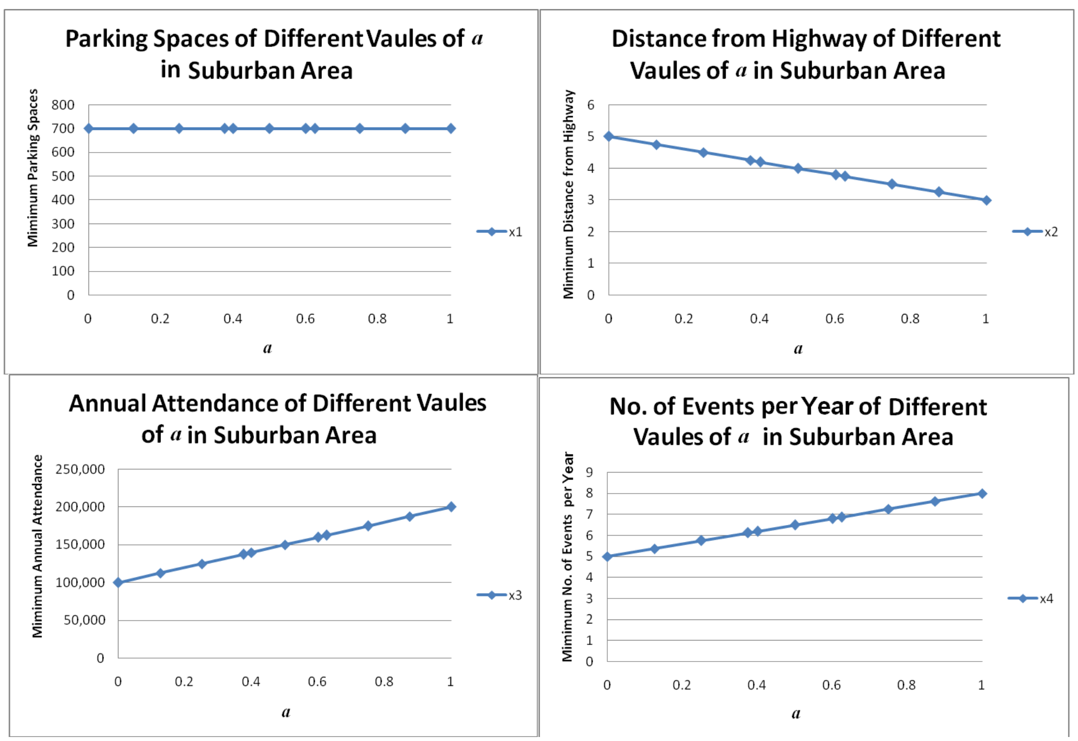


Figure 9 Comparison between Different Parameters of MTG Criteria in Suburban Areas

4.2.3.4 Analysis for Rural Areas

Table 44 depicts the MTG criteria for rural areas based on different values of *a* and *b*. The minimum number of parking spaces is not affected by different values of *a*, the minimum annual attendance and minimum number of events per year increase with an increase in the values of *a*, and the maximum distance from the highway is reduced with an increase in the values of *a*. It indicates that the opinion on minimum annual attendance, minimum number of events per year, and maximum distance from the highway is different for Texas engineers and non-Texas engineers, and the opinion on minimum number of parking spaces is the same for Texas engineers and non-Texas engineers.

Table 44 MTG Criteria of Different Value *a* in Rural Areas

Index		**Rural Area**			
a	***b***	x_1	x_2	x_3	x_4
0	1	400	10	50,000	3
0.125	0.875	400	9.75	53,750	3.375
0.25	0.75	400	9.5	57,500	3.75
0.375	0.625	400	9.25	61,250	4.125
0.4	0.6	400	9.2	62,000	4.2
0.5	0.5	400	9	65,000	4.5
0.6	0.4	400	8.8	68,000	4.8
0.625	0.375	400	8.75	68,750	4.875
0.75	0.25	400	8.5	72,500	5.25
0.875	0.125	400	8.25	76,250	6
1	0	400	8	80,000	6

From Table 44, the following information can be determined: (1) the minimum number of parking spaces in rural areas is 400 in spite of different values of *a*; (2) the maximum distance from the highway is more than 8 miles in rural areas; (3) the minimum annual attendance in rural areas increases with an increase in the values of *a*; and (4) the minimum number of events per year is between three and six events for different *a* and *b*. Figure 10 describes the relationship between different MTG criteria parameters and values of *a* in rural areas.

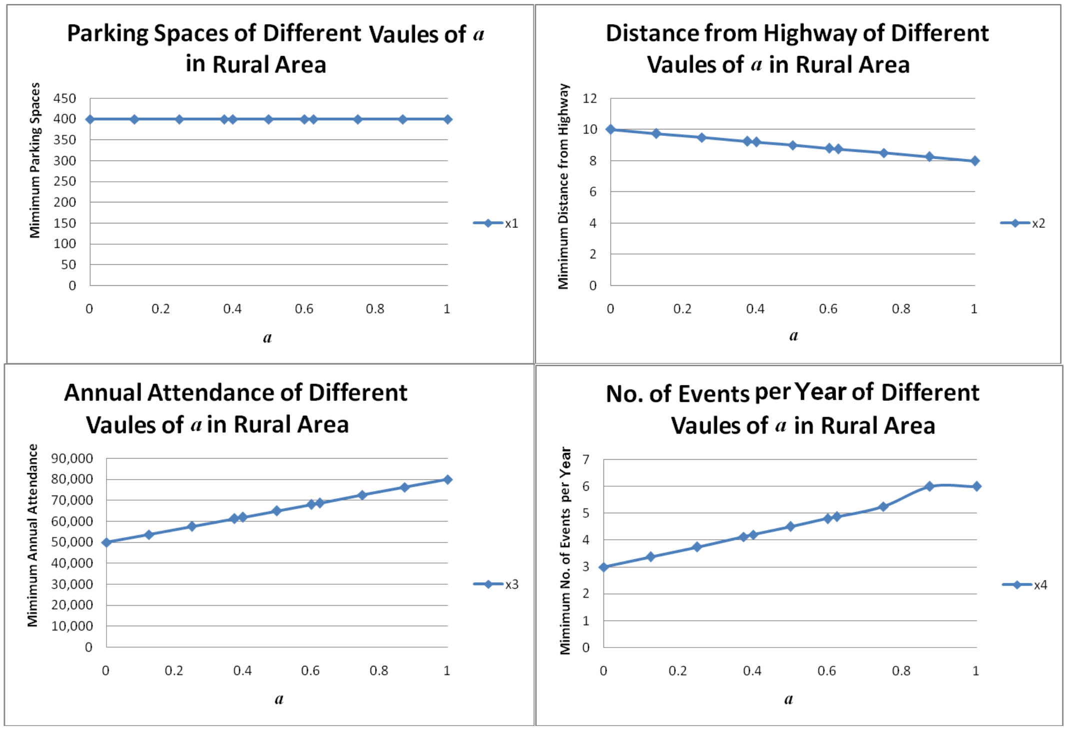


Figure 10 Comparison between Different Parameters of MTG Criteria in Rural Areas

4.3 Eligibility Criteria Synthesizing for MTGs in Texas

This section involves synthesizing MTG criteria based on the results of existing manuals from other states and engineer survey analysis results, and then finalizing MTG criteria for Texas.

When comparing the results calculated by different values of *a* and *b* with the MTG criteria generated from the existing manual, the following information can be concluded.

In metropolitan areas, the results of $a = 0.75$, $a = 0.875$, and $a = 1$ are close in value to the criteria generated from the existing manual. Since the annual attendance in metropolitan areas should be larger than that in urban areas, the results of $a = 0.75$ should be discarded.

In urban areas, the best result should be $a = 0.875$ or 1.

In suburban areas, the best result should be $a = 1$.

In rural areas, the best result should be $a = 1$.

The rule generated by Texas engineers is closer to the real case.

Based on the established rule base and analyses, if considering the opinions mostly from Texas engineers (i.e., $a = 1$ and $b = 0$), the eligibility criteria of MTGs in Texas can be identified as the following:

1. parking: a minimum of 1,000 vehicles in metropolitan and urban areas, 700 in suburban areas, and 400 in rural areas;
2. being located along either the interchange crossroad or the freeway and within 8 miles of the major traffic generator in a rural area, within 3 miles in a suburban area, or within 2 miles in metropolitan and urban areas;
3. at least 325,000 annual attendees in metropolitan areas, at least 300,000 annual attendees in urban areas, at least 200,000 annual attendees in suburban areas, and at least 80,000 annual attendees per year in rural areas; and
4. the number of events per year: a minimum of 15 events in metropolitan areas, 10 in urban areas, 8 in suburban areas, and 6 in rural areas.

4.4 Case Studies of Typical Texas Traffic Generators

This section examines the eligibility of several traffic generators in Texas using the criteria proposed in the previous section. The background information of potential MTGs is collected through the typical MTG survey in Texas, which is described in Section 3.2.

The four traffic generators that responded to the survey are (1) Sam Houston Race Park (metropolitan area), (2) the Toyota Center (metropolitan area), (3) Schlitterbahn Waterpark in New Braunfels (suburban area), and (4) Schlitterbahn Waterpark in South Padre Island (suburban area). The information used to examine the eligibility of MTGs is defined as (1) the number of parking spaces, (2) the distance from the highway, (3) the annual attendance, and (4) the number of events per year.

Recall that Sam Houston Race Park and the Toyota Center have over 1,300 parking spaces each, and the Schlitterbahn Waterparks in both New Braunfels and South Padre Island have more than 900 parking spaces each.

The distance from the nearest freeway exit is less than 2 miles for both Sam Houston Race Park and the Houston Toyota Center. The distance from the nearest freeway exit to Schlitterbahn Waterpark in New Braunfels is more than 10 miles. The Schlitterbahn Waterpark in South Padre Island is located between 3 and 5 miles from the nearest freeway exit.

There are more than 450,000 attendees annually at both Sam Houston Race Park and the Houston Toyota Center, and more than 250,000 annual attendees at Schlitterbahn Waterparks in New Braunfels and South Padre Island.

There are more than 20 events per year at both Sam Houston Race Park and the Toyota Center, and more than 12 events per year at Schlitterbahn Waterparks in both New Braunfels and South Padre Island. Table 45 lists the background information for surveyed generators.

Table 45 Background Information of Typical Surveyed Traffic Generators

Variables	Metropolitan Area		Suburban Area	
	Sam Houston Race Park	**Toyota Center**	**Schlitterbahn Waterpark in New Braunfels**	**Schlitterbahn Waterpark in South Padre Island**
Parking Spaces	More than 1,300	More than 1,300	More than 900	More than 900
Distance from Highway	Less than 2 miles	Less than 2 miles	More than 10 miles	Between 3 and 5 miles
Annual Attendance	More than 450,000	More than 450,000	More than 250,000	More than 250,000
No. of Events per Year	More than 20	More than 20	More than 12	More than 12

Sam Houston Race Park and the Toyota Center are in metropolitan areas. As is suggested in Section 4.3, the synthesized MTG criteria for Texas in metropolitan areas are described as follows:

1. parking: a minimum of 1,000 vehicles;
2. a location along either the interchange crossroad or the freeway and within 2 miles of the major traffic generator;
3. at least 325,000 annual attendees; and
4. number of events per year: a minimum of 15 events.

Sam Houston Race Park and the Toyota Center have over 1,300 parking spaces, which matches the synthesized MTG criteria: a minimum of 1,000 vehicles. There are more than

450,000 attendees annually, and the distance from the nearest freeway exit is less than 2 miles at both Sam Houston Race Park and the Houston Toyota Center. Since the synthesized MTG criteria for metropolitan area like Houston area are: at least 325,000 attendees and within 2 miles of the freeway, these two attractions are MTGs. Corresponding to the number of events per year, the synthesized MTG criteria in metropolitan areas are not less than 15 events. According to Sam Houston Race Park and the Toyota Center, there are more than 20 events per year, which satisfies the criteria defined as not less than 15 events as well.

Therefore, Sam Houston Race Park and the Houston Toyota Center are eligible major traffic generators.

Recall that for suburban areas, the synthesized MTG criteria described in the previous section is:

1. parking: a minimum of 700 vehicles;
2. a location along either the interchange crossroad or the freeway and within 3 miles of the major traffic generator;
3. at least 200,000 annual attendees;
4. number of events per year: a minimum of eight events.

The Schlitterbahn Waterparks in both New Braunfels and South Padre Island have over 900 parking spaces, which matches the synthesized MTG criteria: a minimum of 700 vehicles. The distance from the nearest freeway exit to Schlitterbahn Waterpark in New Braunfels is more than 10 miles, and the Schlitterbahn Waterpark in South Padre Island is located between 3 and 5 miles from the nearest freeway exit, both of which do not match the synthesized MTG criteria: within 3 miles. There are more than 250,000 attendees annually at both New Braunfels and South Padre Island Schlitterbahn Waterparks, along with at least 200,000 annual attendees in the synthesized MTG criteria, which are also a best fit. Corresponding to the number of events per year, the synthesized MTG criteria in suburban areas are not less than eight events. According to New Braunfels and South Padre Island Schlitterbahn Waterparks, there are more than 12 events per year, which satisfies the criteria as well.

Comparing the background information of Schlitterbahn Waterparks in both New Braunfels and South Padre Island with the corresponding criteria, variables including the annual attendance, parking spaces, and number of events per year meet the criteria, but the distance from the highway does not since both are beyond the 3-mile limitation.

Thus Schlitterbahn Waterparks in New Braunfels and South Padre Island, which are both located in suburban areas, are not eligible major traffic generators.

CHAPTER 5
SYMBOL AND GUIDE SIGN DESIGN FOR TEXAS MAJOR TRAFFIC GENERATORS

5.1 Types of Symbols/Signs for Texas MTGs

5.1.1 Manuals and Current Practices

The type of symbol used for MTG signs is relevant to the type of MTG sign. In the following sections, the types of MTG signs are analyzed first, and then symbols are analyzed.

The MUTCD and TMUTCD allow the use of four types of signs for important traffic generators, including (1) supplemental guide signs, (2) specific service signs, (3) tourist-oriented directional signs, and (4) recreational and cultural interest area signs.

Section 2E.32 of the MUTCD and TMUTCD says that supplemental guide signs can be used to provide information regarding destinations accessible from an interchange, other than places shown on the standard interchange signing. The *AASHTO Guidelines for the Selection of Supplemental Guide Signs for Traffic Generators Adjacent to Freeways* is incorporated by reference in this section.

In Chapter 2F of the MUTCD, specific service signs shall be defined as guide signs that provide road users with business identification and directional information for services, including GAS, FOOD, LODGING, CAMPING, and ATTRACTION. The attraction services sign shall include only facilities that have the primary purpose of providing amusement, historical, cultural, or leisure activities to the public. However, ATTRACTION services are not contained in this signing program of the TMUTCD.

In Chapter 2G of the MUTCD and TMUTCD, tourist-oriented directional signs are guide signs with one or more panels that display the business identification of and directional information for business, service, and activity facilities. These businesses are involved with seasonal agricultural products. When used, tourist-oriented directional signs shall be used only on rural conventional roads and shall not be used on conventional roads in urban areas nor at interchanges on freeways or expressways. Tourist-oriented directional signs may be used in conjunction with general service signs. The general service sign symbols (Section 2D.45) and the symbols for recreational and cultural interest area signs (Chapter 2H) may be used. Generic icons for specific businesses, services, and activities may also be used.

Section 2H. 01 and Section 2H.09 of the MUTCD and TMUTCD also provide guidance on the use of recreational and cultural interest area signs that depict significant traffic generators on freeways and expressways where there is direct access to these areas. The signs show recreational or cultural interest area destinations on supplemental guide signs. RCIAs are attractions or traffic generators that are open to the general public for the purpose of play, amusement, or relaxation. In Chapter 2H, the TMUTCD establishes criteria in Section 2H.10 to justify which traffic generators should be depicted on supplemental guide signs that are not specified in the MUTCD.

In an e-mail survey of other states, each state had its own favorite in the categorization of traffic generator signing, which has been summarized in Table 2 in Section 1.3.

According to the current guidance in the TMUTCD, logo signs and tourist-oriented directional signs are improper to display the MTG information. Unlike in the MUTCD, logo signs in the TMUTCD do not add to the category of attractions, which are the main candidates for MTGs. As guided by Chapter 2G of the TMUTCD, tourist-oriented directional signs shall be used only on rural conventional roads and shall not be used on conventional roads in urban areas nor at interchanges on freeways or expressways, which would be the primary location of MTG signing. As guided in Chapter 2H of the TMUTCD, RCIA signs show recreational or cultural interest area destinations on supplemental guide signs. In addition, three states (Minnesota, Missouri, and North Carolina) that have specific guidelines for MTGs use supplemental guide signs.

Therefore, the Texas MTG signs could be supplemental guide signs on freeways. However, such supplemental guide signs are constrained by the availability of sufficient space. A symbol sign plaque on top of a parent guide sign is proposed by the research team. Based on the engineer survey, symbol sign plaques and supplemental guide signs are preferred and obtained the same number of engineers' (11) support. In the MTG survey, Sam Houston Race Park and the Toyota Center preferred one large guide sign, i.e., using an independent supplemental guide sign. However, Schlitterbahn Waterpark in New Braunfels and Schlitterbahn Waterpark in South Padre Island prefer to use two or three small guide signs at freeway interchanges approaching their sites. This can be implemented by using MTG symbol plaques on top of the standard interchange signs.

Symbol designs shall be essentially similar to those that are shown in the TMUTCD and in the book *Standard Highway Sign Designs for Texas* (Texas Department of Transportation 2006a). New symbol designs shall be adopted by the Federal Highway Administration based on research evaluations to determine road user comprehension, sign conspicuity, and sign legibility. Table 2H-1 of the MUTCD and TMUTCD lists the symbols within each series category. Design details are found in *Standard Highway Sign Designs for Texas*. Figure 2H-5 of the MUTCD and TMUTCD shows RCIA symbol signs.

5.1.2 Preliminary Identification of Type of Symbols

According to the guidance in the manuals and current practices, symbols used in three types of signs for traffic generators (supplemental guide signs, tourist-oriented directional signs, and RCIA destination guide signs) are category oriented, while symbols used in logo signs are specific. Some states like Massachusetts use a general word "ATTRACTIONS," which is attached to a logo, trademark, or name.

Three types of symbols that can possibly be used for MTG signs are therefore identified:

- a uniform symbol for all MTGs,
- a category-oriented symbol according to the classification of MTG, and
- a specific symbol for each MTG.

The identified three types of MTG symbols were presented to engineers in the engineer survey. The survey result shows that 53 percent of surveyed engineers prefer category-oriented symbols, 35 percent prefer specific symbols for each MTG, and 12 percent prefer a uniform symbol for all MTGs.

MTG survey results show that three MTGs (Schlitterbahn Waterpark in New Braunfels, Schlitterbahn Waterpark in South Padre Island, and the Toyota Center) would like to display specific symbols for their facilities. Schlitterbahn Waterpark in South Padre Island also would like to display a category-oriented symbol based on the classification of the MTG. Sam Houston Race Park skipped this question.

5.1.3 Simulator Tests on Types of Symbols

Since a uniform symbol for all MTGs obtained the least preference from engineers and MTGs, in the simulator test the category-oriented symbols (including MUTCD symbols, non-MUTCD symbols, and self-designed symbols) and specified symbols for MTGs at freeway interchanges were examined. The objective of this test is to identify the drivers' responses to various symbols for MTG guide signing at freeway interchanges in the driving simulator under different symbol sign positions and sizes.

5.1.3.1 Experiment Process

In this experiment, both the category-oriented symbols (representing a type of attraction) and specified symbols (representing a specific attraction) for MTGs at freeway interchanges were examined through a simulation experiment based on drivers' responses. The experiment was conducted in a driving simulator followed by a posterior questionnaire survey of subjects. Tested MTG symbols with various sizes (regular, large, and extra large) were mounted at different positions on parent sign boards (on left top, middle top, and right top) and were placed in advance of right-lane exits and left-lane exits, separately.

Driving Simulator. The experiment was undertaken in a DriveSafety 600C fixed-base driving simulator located at Texas Southern University (TSU). This dynamic driving simulator is comprised of five components: a cab, high-resolution (1024×768 pixels) projectors, three large high-reflectance projection screens, a set of computers for simulation, and a major workstation for creating various scenarios. The driving apparatus is similar to that found in an actual vehicle. Participants in the cab can operate the brake and accelerator pedals, steering wheel, and so forth, exactly the same as if driving in the real world. The simulator also generates realistic auditory effects, which include traffic, engine, and exterior noises, and provides tactile motion to mimic road vibration or vehicle pitching. Researchers created the customized driving environments on roadway tiles using the HyperDrive™ software (DriveSafety, 2005). The simulator provides participants with a “real-world” interactive driving experience (Qiao et al. 2007a, Qiao et al. 2007b). Figure 11 is a photo of the TSU driving simulator.

Figure 11 Driving Simulator in Department of Transportation Studies at Texas Southern University

<u>Test Sign Design.</u> All candidate signs were prepared using the professional software SignCAD™ (SignCAD Systems, 2001). The plotted sign images were imported into the driving simulator for various scenario tests. Figure 12 illustrates all tested symbols.

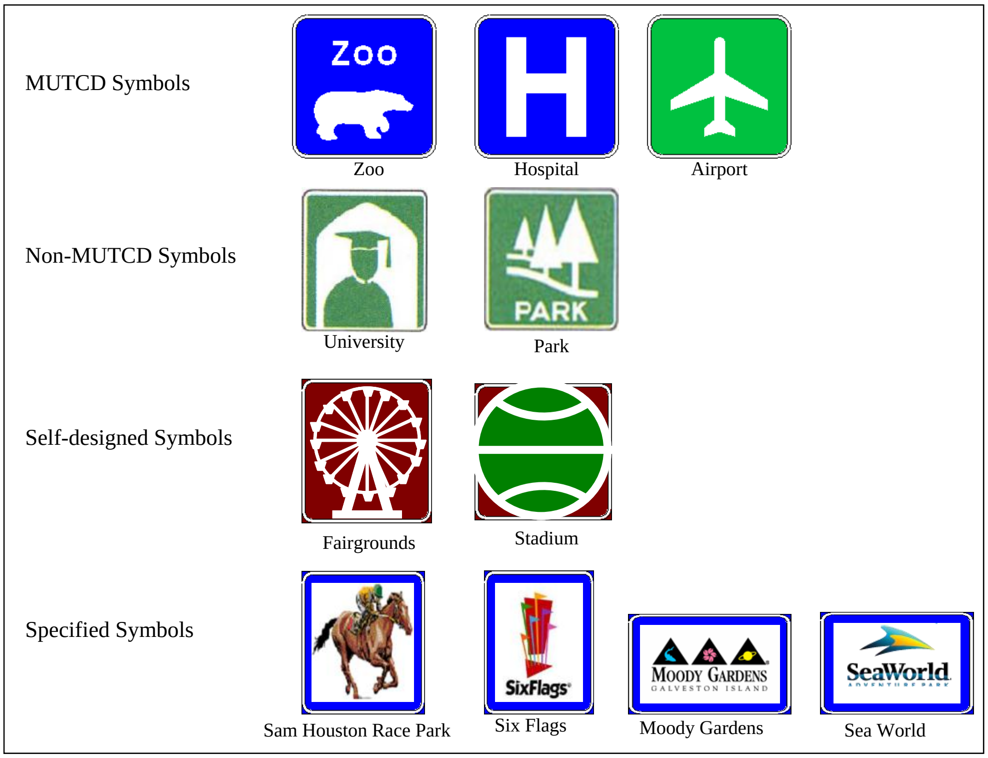


Figure 12 Test Symbols for Four Different Groups

In Figure 12, the four groups of symbols include (1) three MUTCD symbols: a bear-viewing symbol (used for a zoo on Highway 288 in Texas), a hospital symbol, and an airport symbol according to the SHS; (2) two non-MUTCD symbols (university and park) from the study that Wainwright (2005) conducted; (3) two novel self-designed symbols (fairgrounds and stadium); and (4) four specified symbols reproducing typical MTGs (Sam Houston Race Park of Houston, Six Flags and Sea World of San Antonio, and Moody Gardens of Galveston, all in Texas). The first three groups in Figure 12 belong to category-oriented symbols, while the last group is specified symbols.

Symbols were placed on the top of general guide signs. Figure 13 displays some of the typical assemblies.

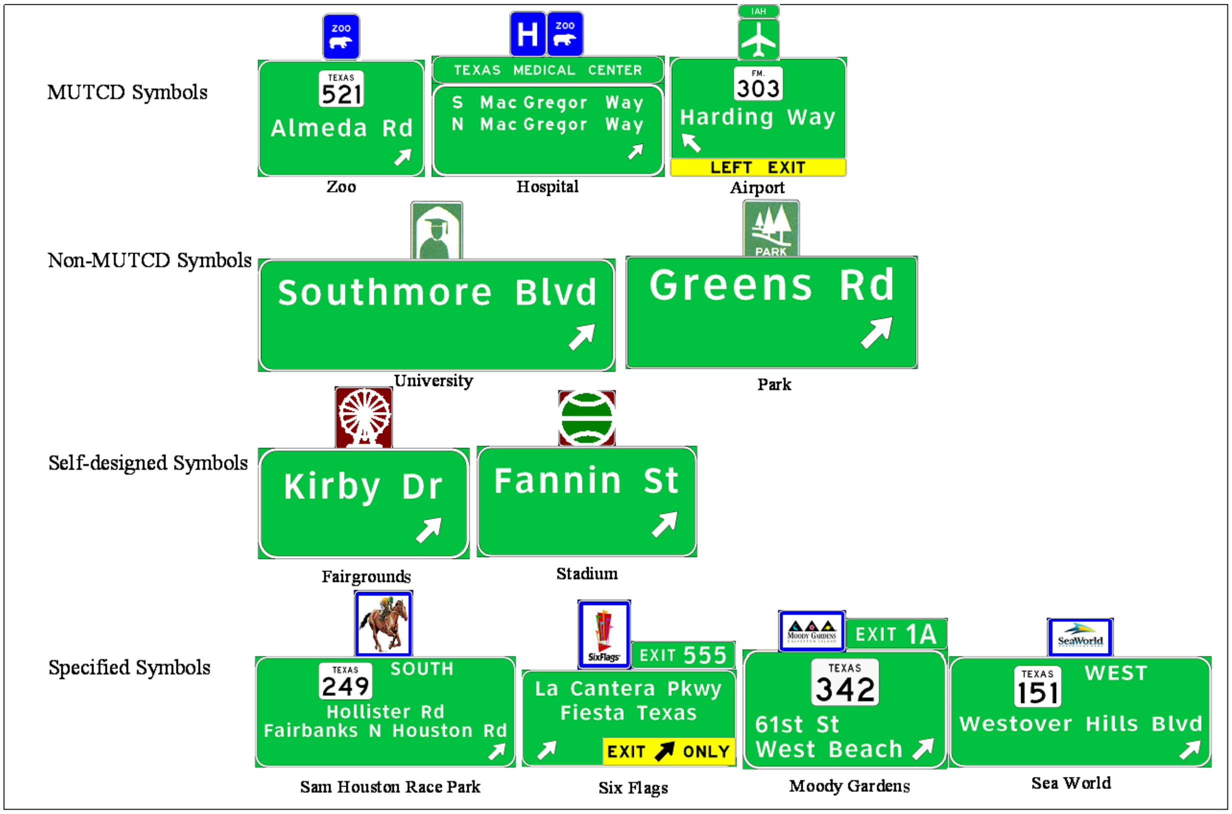


Figure 13 Test Symbols on Top of Various Guide Signs

In Figure 13, the four types of symbols were placed on top of various guide signs, including the guide signs listed in the *Freeway Signing Handbook* (Texas Department of Transportation 2008) and several real guide signs with crossroad names on Texas highways. In this case, the parent signs paired with MTG symbols provided the realistic sign environment. Although the complexity of the parent signs varied, participants were asked to focus on the symbols in the experiment so that the process time of the parent signs was somehow counterbalanced. In the driving simulator, all the tested symbol signs were imported as images into the entities of custom signs with three sizes: regular, large, and extra large.

Test Scenarios. In tests, symbols positioned on advance guide signs and exit direction signs were placed on six-lane (three lanes in each direction) freeways (lane width 11.81 feet and shoulder width 9.84 feet) within 2 miles (3.22 km) from the exits in the driving simulator. Symbol signs were positioned at right, center, or left above the corresponding guide signs. Regulatory speed limit signs were 65 mph (29 m/second), posted along testing routes. Designed scenarios considered guide sign installation methods (overhead- and ground-mounted installations). Signs were placed near right-lane exits and left-lane exits, with regular, large, and extra large symbols.

Driving scenarios were implemented in the driving simulator by using customizable signs, tiles (units of simulated highway pieces), simulation start locations, triggers (for vehicle simulation purposes), and script commands. Twelve scenarios were conceived as listed in Table 46.

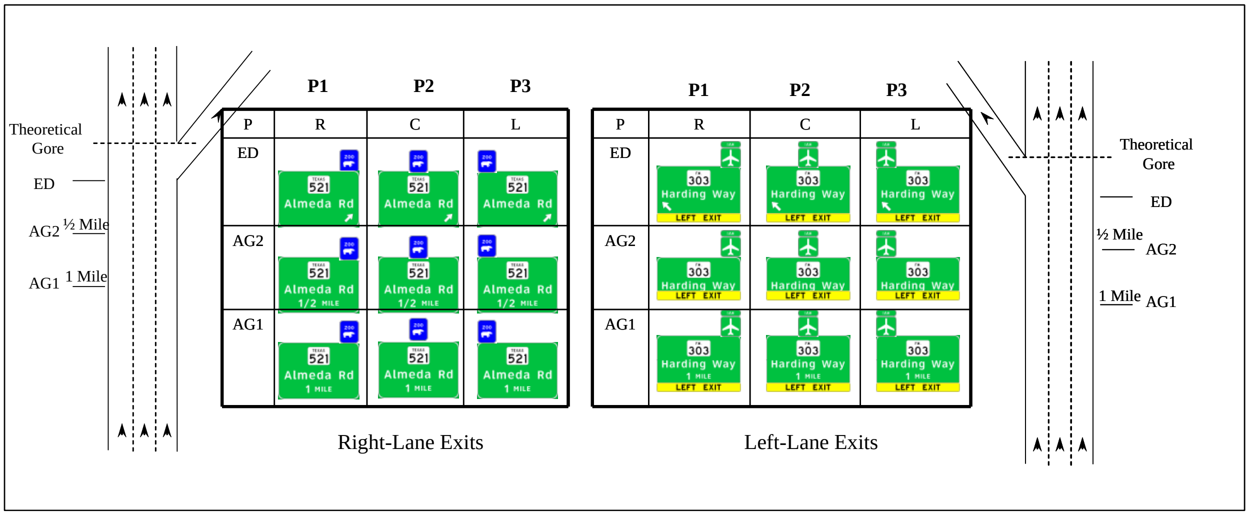
Table 46 Test Scenarios

Scenario	Purpose of Test	Exit Lane	Support	Symbol	AG & ED
1	Position	Right	G	Zoo	1 mile, 0.5 miles AG & ED
2	Position	Right	O	Hospital	1 mile, 0.5 miles AG & ED
3	Position	Right	G	Stadium	1 mile, 0.5 miles AG & ED
4	Position	Right	O	Fairgrounds	1 mile, 0.5 miles AG & ED
5	Position	Right	G	Specified Symbols	NA
6	Position	Left	O	Airport	1 mile, 0.5 miles AG & ED
7	Size	NA	O	Airport	Regular, large, & extra large
8	Size	NA	G	Park, University	Regular, large, & extra large
9	Size	NA	O	Airport	Regular, large, & extra large
10	Size	NA	G	Park, University	Regular, large, & extra large
11	Size	NA	O	Airport	Regular, large, & extra large
12	Size	NA	G	Park, University	Regular, large, & extra large

Note: AG: advance guide signs; ED: exit direction signs; NA: not applicable; O: overhead; G: ground mounted. It was assumed that all sizes were the same for the position test and all positions were at the center of the parent signs for the size test.

In Table 46, six scenarios were designed for the symbol position test; the other six were for the size test. Within the position tests, there were five right-lane tests and one left-lane test. It was assumed that all positions were at the center of the parent signs for the size test. Half of the test signs had overhead-mounted installation; the other half of the test signs had ground-mounted installation.

The symbols were those listed in Figure 12. In the test, the zoo, hospital, airport, fairgrounds, and stadium symbol signs were placed upon both the advance guide signs and exit direction signs, while others were placed on either the exit direction signs or guide signs along the freeways. The positions of symbol signs in three projects (P1, P2, and P3) are illustrated in Figure 14.



Note: AG: advance guide signs; ED: exit direction signs; P1, P2, P3: three different testing projects.

Figure 14 Positions of Symbol Signs on Advance Guide Signs and Exit Direction Signs.

In Figure 14, guide signs with symbols were placed at three freeway sections: 1 mile (AG1) and 0.5 miles (AG2) in advance of the exits and at the exit gore. At each sign placement, symbols were at the right (R), center (C), and left (L) top of the guide signs. Tests were conducted on both the right-lane exits and left-lane exits. In each driving simulation, the subject vehicle was initially positioned on highway sections approximately 1 mile (1.61 km) away from the first advance guide sign.

Testing Procedure. A total of 24 subjects with valid driver licenses were recruited to evaluate the symbol signs for MTGs. All participants had normal or corrected-to-normal vision with ages ranging from 23 to 45 years old. Participants were randomly grouped into three groups due to the three types of positions, sizes, and weather conditions. Each subject was exposed to the 12 scenarios with different positions and sizes of symbol signs. Each of the subjects took approximately 30 minutes to complete the task.

At the beginning of each experiment, the participants went through a practice trial to familiarize them with the driving simulator. The tested symbols were explored with the subjects before the simulator run. After the participants became accustomed to the testing environment, they were instructed to drive on the designed freeways. Subjects were assigned major traffic generators and asked to maintain their lane position. They followed guide signs and/or symbols and, based on their responses to presented signs, made their own decisions to exit.

Participants were asked to press the programmable buttons beside the steering wheel when clearly identifying the target symbols (corresponding to the assigned MTG) during driving. Drivers' behaviors and responses were recorded in the simulator system at a time precision of 10 Hz, including time (seconds), velocity (m/second), lane index (1 = leftmost lane, 3 = rightmost lane), and the trajectory of the subject vehicle (m). At the end of each scenario, they were asked about their confidence of exiting (how confident they made a correct exit to the assigned MTG).

Questionnaire Survey. After the simulator test, each participant was asked to complete a questionnaire to acquire (1) the evaluation of symbol performance based on their experience in the simulation test, (2) the information they depended on to make an exit choice, and (3) the subjective preferences for symbol sign positions. The questionnaire was designed in Microsoft PowerPoint and shown as a booklet. The participants wrote down their opinions and preferences on an answer sheet. The questionnaire results were further compared with the experimental results.

5.1.3.2 Results and Analysis

The results of each study were provided separately based on the data obtained from the simulation experiment and posterior questionnaire. The computer program SPSS 14.0 (Field, 2000) was used for statistical analysis. All statistical tests were evaluated with a 95 percent confidence interval. The primary measurements of effectiveness for the experiment were:

- recognition distance,
- correct responses,
- comprehension, and
- evaluation and preference.

Driving Simulation Results and Analysis. Measures of effectiveness (MOEs) of symbol signs for MTGs obtained from the simulation experiment were recognition distance (RD) and correct exit operation. Recognition distance is the distance between the subject and the symbol sign where the participant starts to correctly identify the features of that symbol. In the simulation test, subjects did not need to interpret the meaning of the sign other than to clearly identify the elements of the test symbols. This meant that the subjects distinguished which of the test symbols they were looking for. The recognition distances were calculated based on the coordinates of the subject vehicle and symbol signs in the simulator.

The relative recognition distances in various scenarios were assessed. Overall results were partly a function of the sign sizes and individual sign designs. The recognition distance was also influenced by the resolution of the driving simulation. However, in the result analysis, the main concern was the function of the symbol groups. Figure 15 illustrates average recognition distance and velocity for test symbols along with the corresponding standard deviations.

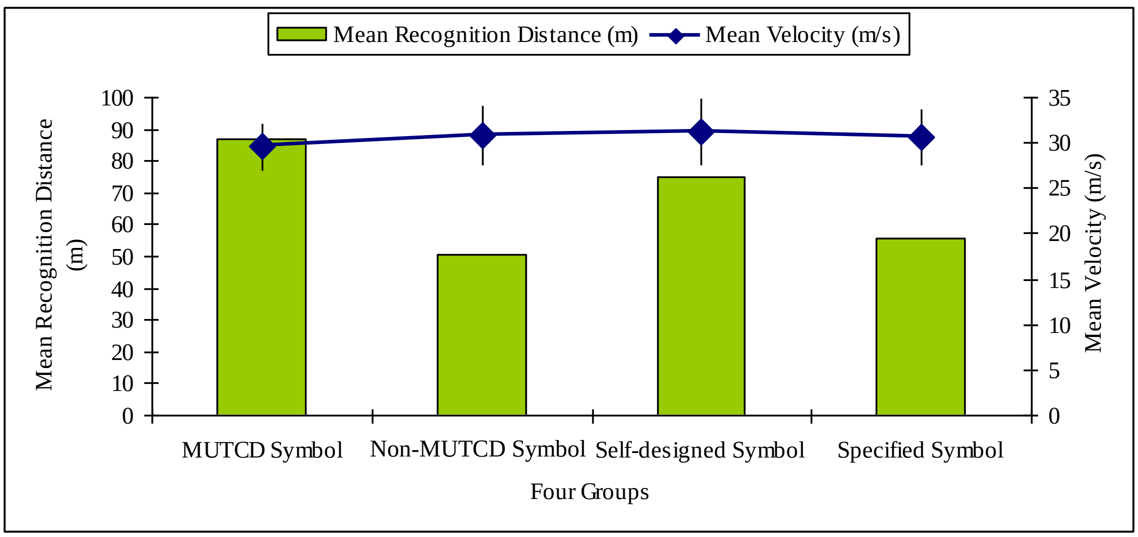


Figure 15 Mean Recognition Distance and Velocity for Test Symbol Groups

Figure 15 shows that the recognition distances for the four groups (MUTCD symbols, non-MUTCD symbols, self-designed symbols, and specified symbols) were 284.58 feet (86.74 m), 165.06 feet (50.31 m), 245.54 feet (74.84 m), and 183.4 feet (55.9 m), respectively.

The non-MUTCD symbols had the shortest recognition distance, with the mean value M = 165.68 feet (50.5 m). Among all symbols, the hospital symbol had the greatest average recognition distance, with the mean value M = 343.83 feet (104.8 m) The differences among all driving speeds under different symbol scenarios were not statistically significant ($F_{6, 298} = 1.363$, $p > 0.05$).

The recognition distance for self-designed symbols was shorter than that of MUTCD symbols, while there was no significant difference between them via the nonparametric test ($p = 0.064$). In other words, the novel self-designed symbols performed as well as MUTCD symbols in recognition distance measurement. Compared to the specified symbols, self-designed symbols demonstrated a greater recognition distance ($t_{100} = 3.399$, $p = 0.001$).

The participants were asked to rate their confidence in the correctness of their exit maneuvers. Eighty-two percent of the participants (20 out of 24 participants) had an average of 90 percent confidence to exit toward the assigned destinations in the scenarios with MUTCD symbols. Seventy-seven percent of the subjects exited with an average of 70 percent confidence in self-designed symbol scenarios, while 72 percent of the subjects left freeways with an average of 80 percent confidence in specified symbols.

In the test, all recruited subjects had no pre-knowledge of the self-designed and specified symbols; however, they all are acquainted with the MUTCD symbols for the zoo, hospital, and airport. It is foreseen that if the subjects were prepared with a certain pre-knowledge of the self-designed and specified symbols, the recognition distance and confidence to properly exit would be increased. This is possible in real practice since drivers may have more or less knowledge of the target MTG symbols (such as the symbol for Sea World Adventure Park that the drivers are heading to) to some extent.

Questionnaire Survey Results and Analysis. Through the posterior questionnaire survey, 21 of the 24 participants believed that the symbol signs placed at the freeway interchanges were helpful to direct them to the assigned destinations, while only three subjects thought those symbol signs were not helpful at all. Eighty-two percent of participants reported that they maneuvered to the exit by relying on symbol signs, parent guide signs, and arrows.

Participants' comprehension of tested symbols was also evaluated in the questionnaire survey. The subjects were asked the meanings or representations of each symbol. When provided with tested symbols only, each subject understood, on average, 71 percent of the symbols. However, when the subjects were provided with both options, the symbols and their meanings, the average comprehension level increased to 90 percent.

The comprehension levels for MUTCD symbols, non-MUTCD symbols, self-designed symbols, and specified symbols were 91 percent, 64 percent, 68 percent, and 61 percent, respectively, when provided with tested symbols only. This is reasonable since people may be more familiar with MUTCD symbols than other types of symbols, and the tested MUTCD symbols are simpler than the other three types of symbols. Therefore, the designed MTG symbol should be as simple as possible and should be pre-perceived by at least the drivers who need these symbols to assist them in their navigation.

In addition to the comprehension and recognition distances, other important criteria in symbol usage for MTGs include conspicuity, legibility, and representability. The simple definition of these terms was explained to the subjects. MTG signs and symbols must be attractive and should be easily caught by drivers (conspicuity). They must be legible so that drivers can take action in a timely fashion at a sufficient distance (legibility). As such, the alternative symbols must effectively represent relevant MTGs (representability) and be easily understood (understandability). Table 47 shows the mean scores that subjects rated for the criteria of two MTG candidate signs, with 1 as poor and 5 as excellent.

Table 47 Drivers' Evaluation of the Performance of MTG Signs

Criteria	**Conspicuity**	**Legibility**	**Representabilityl**	**Understandability**	**Overall Performance**
Category-Oriented Symbol	4.18	4.27	3.82	3.91	**4.05**
Specified Symbol	3.36	3.27	3.91	3.45	**3.48**

If equal weights are assigned to all criteria listed in Table 47, the overall performance of both CS and SS symbols in the last column (mean value of all previous columns) indicates that category-oriented symbols received higher scores than specified symbols. This does not mean that SS symbols can be substituted with CS symbols for MTG guide signs since the tested SS and CS symbols did not imply the same guide intentions.

5.1.3.3 Primary Findings

This test presented a simulation experiment, examining symbol sign usage at freeway interchanges to navigate motorists to MTGs. Recognition distance and comprehension for different groups of symbols were both tested in the driving simulator and through a posterior questionnaire survey. The following is a summary of some preliminary findings.

There was no significant difference among driving speeds in all test scenarios. Almost all driving speeds were around the posted speed in the simulation. It provided the base for recognition evaluation.

The overall performance of category-oriented symbols was better than specified symbols, determined through ratings by participants. MUTCD symbols always performed the best. Better performance is normally associated with simply designed symbols that drivers are familiar with. This suggests selecting and/or designing simple and driver-acquainted symbols for MTG guide signing.

5.2 Location and Size of Symbols/Signs for Texas MTGs

5.2.1 Manuals and Current Practices

The study of location and size of symbols/signs for Texas MTGs are focused on two types of MTG signs: supplemental guide signs and symbol sign plaques.

If sufficient space exists to accommodate the placement of the sign without interfering or conflicting with required signing, Texas MTG signs are installed as supplemental guide signs. In this case, the location and size of symbols/signs for Texas MTGs are in accordance with guidelines for other supplemental guide signs, which are addressed in Chapter 2E of the MUTCD, TMUTCD, and AASHTO guidelines.

The location of other supplemental guide signs is addressed in Section 2E.32 of the MUTCD and TMUTCD. Where two or more advance guide signs are used, the supplemental guide sign should be installed approximately midway between two of the advance guide signs. If only one advance guide sign is used, the supplemental guide sign should follow it by at least 800 feet (245 m). If the interchanges are numbered, the interchange number should be used for the action message.

Normally, supplemental guide signs for MTGs should not be installed at freeway-to-freeway interchanges. Signs for MTGs shall be located in advance of the interchanging road that provides the most direct route to the facility. Only one supplemental guide sign for an MTG may be used on each interchange approach. If used, it is normally installed as an independent guide assembly. A supplemental guide sign should not list more than two MTGs. When more than two MTGs meet the signing criteria, MTGs having the greatest need for signing should be shown.

AASHTO guidelines note that when the traffic generator is not located on the crossroad, written confirmation is required from the local government agency that they will install and maintain trailblazing signing for the logical direction of traffic to the facility.

Sign size is determined primarily in terms of the length of the message and the size of the lettering necessary for proper legibility. As guided in the MUTCD and Texas *Freeway Signing Handbook* (as listed in Table 2E-2.1 of the TMUTCD), the size and style of letters and signs, and the minimum numeral and letter sizes for freeway and expressway supplemental guide signs are summarized in Table 48.

Table 48 Minimum Letter and Numeral Size for Supplemental Guide Signs

Supplemental Guide Signs	Minimum Size (Inches)
Exit Number Word	10
Exit Number Numeral and Letter	15
Place Name—Uppercase Letters	13.3
Place Name—Lowercase Letters	10
Action Message	10

The legend of MTG supplemental signing shall be the same as other supplemental guide signs. As guided in Section 2E.32 of the MUTCD and TMUTCD, destination names should be followed by the interchange number (and suffix) or, if interchanges are not numbered, by the legend NEXT RIGHT or SECOND RIGHT, as appropriate.

As guided in Section 2E.04, guide signs on freeways and expressways, except as noted, shall have white letters, symbols, and borders on a green background. When a park or recreational or cultural interest area is signed as a significant destination for users of these roads, supplemental guide signs with a white legend and border on a brown background may be used on an expressway or freeway, as guided by AASHTO guidelines.

If the space is limited, MTG symbol sign plaques can be placed. The location of symbol sign plaques is instructed following the Texas *Freeway Signing Handbook*. Guide sign routing plaques provide supplemental information on travel routes for selected destinations or types of vehicles. Traffic Engineering Standard Sheet addresses the design and layout of guide sign routing plaques. Figure 16 shows the placement for guide sign routing plaques, the same as

Figure 3-18 in the handbook and Figure 2D-11a in Section 2D.45, General Service Signs, of the TMUTCD.

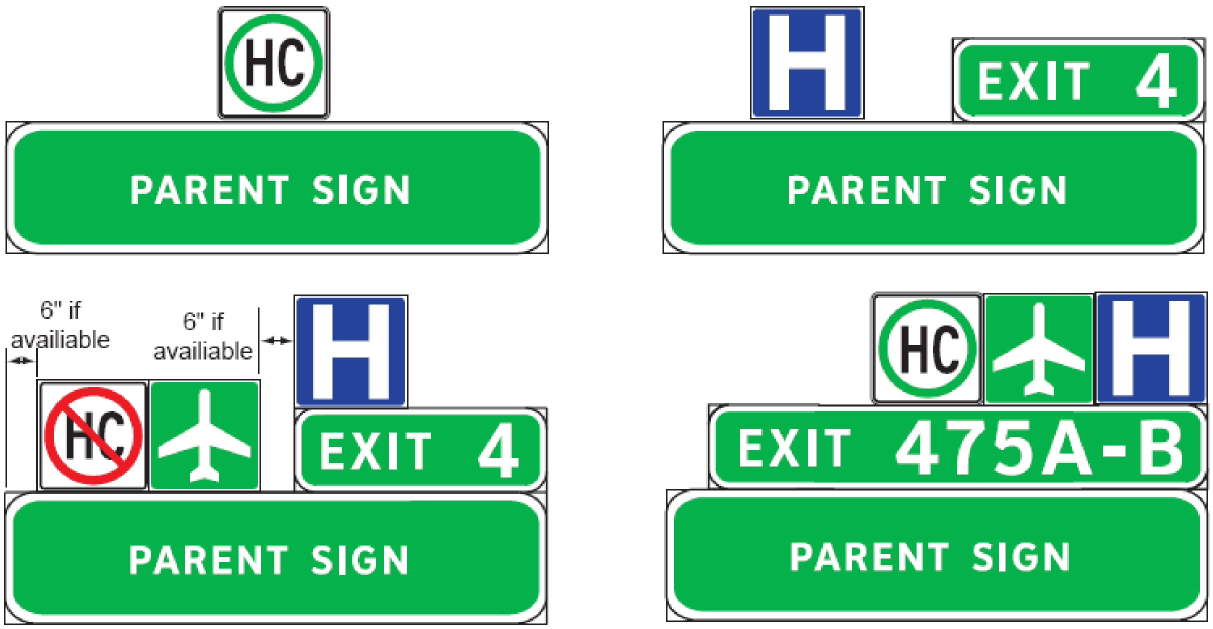


Figure 16 Overhead Freeway Guide Sign and Routing Plaque Typical Assemblies

The *Freeway Signing Handbook* further illustrates that plaques should be horizontally centered at the top of the parent guide sign. If the parent guide sign includes an exit number panel, the plaque (or plaques) should be centered between the exit number panel and the opposite sign edge. A spacing of 6 inches between the edge of the sign and the exit number panel is desired. If there is not enough space to place a routing plaque between the exit number panel and the sign edge, the plaque may be placed above the exit number panel.

The size of symbols is mainly described in Chapter 2H of the TMUTCD. Recreational and cultural interest area symbol signs should be 24×24 inches. Where greater visibility or emphasis is needed, larger sizes should be used. Symbol sign enlargements should be in 6-inch increments. Recreational and cultural interest area symbol signs should be 30×30 inches when used on freeways or expressways, as guided in Section 2H.05, Symbol Sign Sizes.

Word messages in the legend of freeway and expressway guide signs shall be in letters at least 8 inches high. Larger lettering shall be used for major guide signs at or in advance of interchanges and for all overhead signs, as guided in Section 2E.13 of the TMUTCD.

5.2.2 Preliminary Identification of Location and Size of Symbols/Signs

Since there is standard guidance for the location and size of supplemental guide signs, this section focuses only on the symbol sign plaques, which are a substitute for the supplemental guide signs.

In the engineer survey regarding the location of symbol sign plaques, most engineers (71 percent) agree to place the MTG symbol sign on the top of the parent guide sign, like the airport and hospital guide sign routing plaques. Advance guide and exit direction signs are selected by most engineers (82 and 49 percent, respectively) to place the MTG symbol signs on. Only a Nevada engineer suggests also placing the MTG sign on exit gore signs. One Minnesota engineer prefers to install the MTG sign on a supplemental guide sign; he/she also would like to place the MTG signs on advance guide and exit direction signs. Based on the responses of the management sections of potential MTGs, the Toyota Center would like to install its guide signs at the nearest freeway exit only in each direction. The other three MTGs wanted to install their guide signs not only at the nearest freeway exit but also in other places, such as on other highways and on mile markers. This means these three MTGs preferred trailblazing signs.

Most surveyed engineers (71 percent) believe that the trailblazing sign is necessary for MTGs. Of the 12 engineers who think the trailblazing sign is necessary, 42 percent of the engineers think the maximum number of trailblazing signs provided for each MTG along one approach should depend on the location, distance, and how many turns to the MTG. Engineers have different opinions on the maximum radius of an MTG that trailblazing signs should be provided for. Four of them prefer 5 miles, and three prefer 10 miles.

Regarding the legend of MTG signs, 47 percent of surveyed engineers think that the most effective legend of MTG symbol plaques should contain the symbol and the associated text at the bottom, 29 percent prefer the symbol only, and 24 percent prefer a symbol with text on top. No one considers text alone to be an effective legend. If taking symbol and text into consideration as a legend for MTG signs, seven engineers think either the MTG category or the name of each MTG is the most effective text for MTG plaques. The MTG survey indicates that all MTG management sectors wanted to show the names of their facilities and the messages of their events. In addition, Schlitterbahn Waterpark in New Braunfels would like to display distance information and its logo. The Toyota Center preferred to display a symbol. In the motorist survey on MTG signing, the name of the destination (36.12 percent), the action information such as “exit” (26.18 percent), and the distance (13.22 percent) are most preferred by motorists to be display on the specific signs for MTGs.

Regarding symbol and text sizes in symbol sign plaques, 59 percent of the engineers believe that 6 inches is the minimum text size for an MTG symbol sign plaque. Most engineers (94 percent) agree that the size of the MTG symbol plaque is the same as that for airports and hospitals. Forty-one percent of the engineers prefer the 30×30-inch size, and 41 percent prefer the 36×36-inch size as the minimum dimensions of a symbol sign plaque for MTGs on the freeway. Figure 17 illustrates these two types of dimensions for symbol sign plaques.

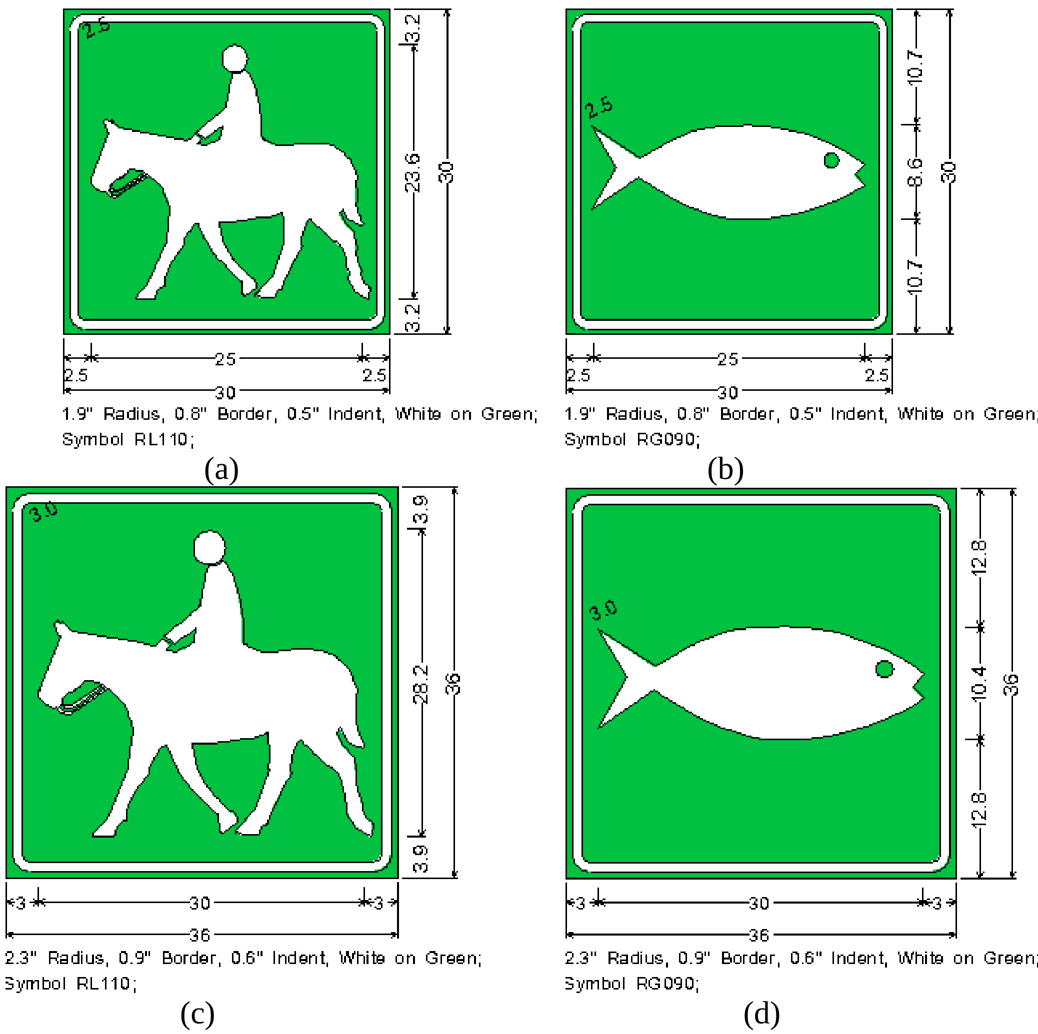


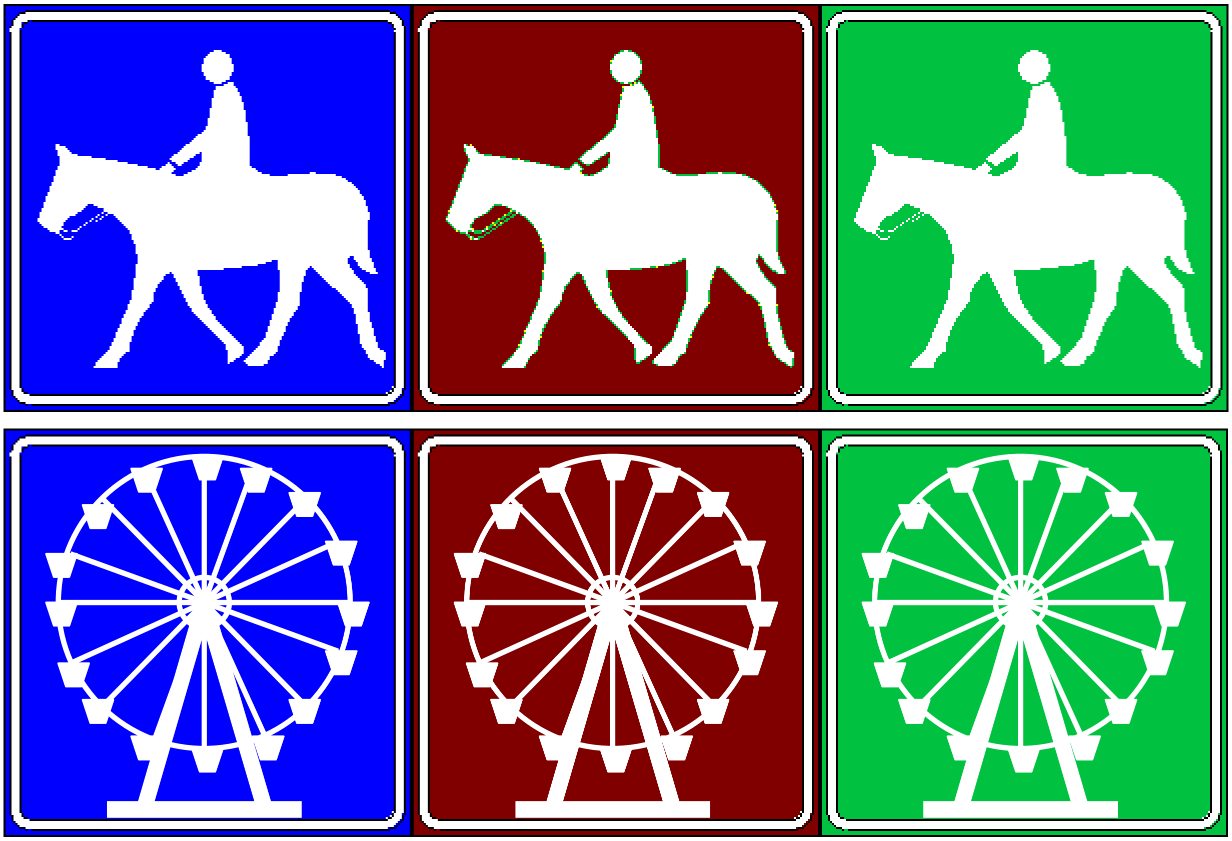
Figure 17 Dimensions of Symbol Sign Plaques for MTGs on Freeways—Size 30×30 Inches in (a) and (b), and Size 36×36 Inches in (c) and (d)—Plotted Using SignCAD

Regarding the number of symbol plaques, most engineers (65 percent) agree that a maximum of three plaques could be attached to an overhead freeway guide sign without overloading the motorists' comprehension level. If a parent sign includes an exit number panel, 53 percent of the engineers still think three is the maximum number. One engineer from Minnesota and one from Massachusetts suggest no plaques on top of an overhead freeway guide sign. When the parent guide sign includes an exit number panel, two engineers from Texas do not agree to put any plaque on it.

The surveyed engineers evaluated the priority on placing each type of routing plaque on top of overhead freeway guide signs, when considering the space availability and the workload of drivers. One engineer did not complete this question, and one engineer selected no priority by making decisions simply based on the application order. After averaging the scores of each plaque, the exit number panel receives the first priority, while the MTG symbol plaque receives the lowest.

Regarding the color of the symbol plaques, the surveyed engineers have no obvious preference for blue, brown, or green. Representatives of symbol plaques with these three types of background colors are illustrated in Figure 18.

The majority (41 percent) agrees that the color of the background of a symbol and text plaque should be dependent on the category of MTG and should match the service. One Colorado engineer suggests that blue should be used on highways while green can be used on interstate highways. Schlitterbahn Waterparks in New Braunfels and South Padre Island like the blue and white color, while Sam Houston Race Park and the Toyota Center prefer green. The motorist survey shows that nearly half (49 percent) of responders prefer blue as the background color for specific signs for MTGs; 35 percent prefer green, and 5 percent prefer brown.



(a) Blue (b) Brown (c) Green

Figure 18 Illustration of Colors of Symbol Plaques Plotted in SignCAD

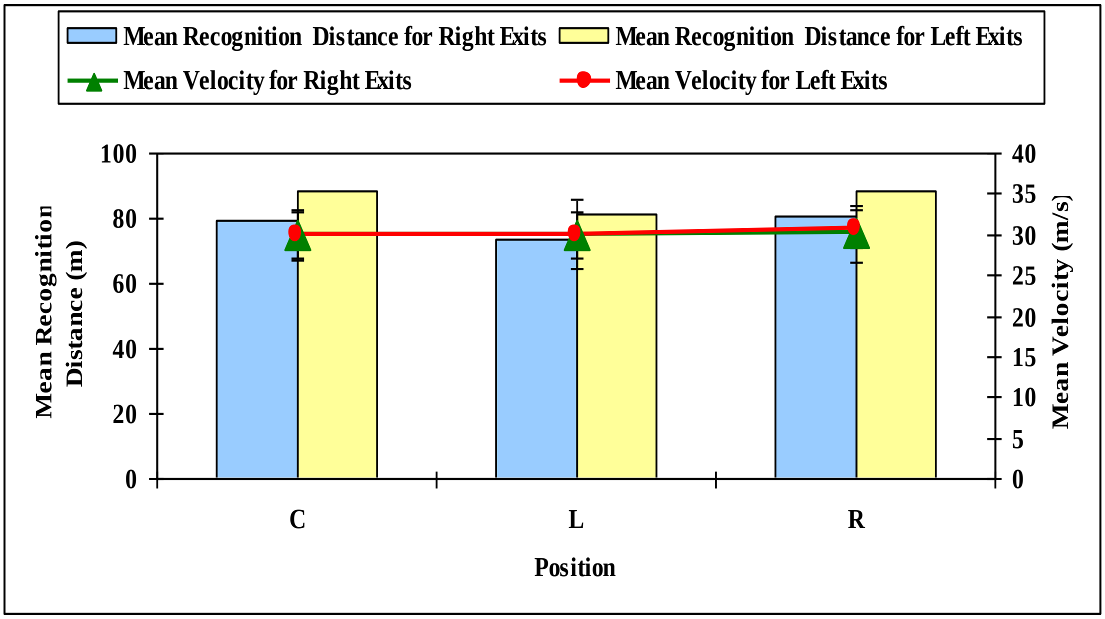
5.2.3 Simulator Tests on Location and Size of Symbol Signs

5.2.3.1 Experiment Process

The location and size of symbol signs were examined in the same test as the types of symbols, including right, center, and left position on top of the corresponding guide signs, and regular, large, and extra large sizes of symbols.

5.2.3.2 Results and Analysis

The Effect of Position in Simulation Experiment. The *Freeway Signing Handbook* advises to horizontally center symbols at the top of the parent guide sign. However, the position of symbols could be at the right, center, and left on top of the parent guide signs in some real cases. In the driving simulation experiment, the impacts of symbol position on recognition distances were investigated. Figure 19 summarizes the mean recognition distance with three symbol positions under right-lane exits and left-lane exits.



Note: C = center position; L = left position; R = right position.

Figure 19 Mean Recognition Distance and Velocity at Different Positions

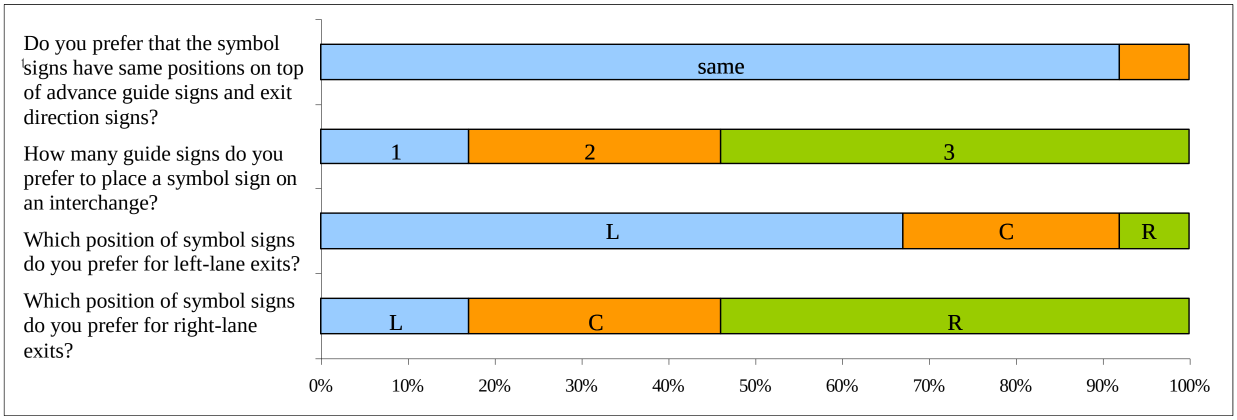
Figure 19 shows that, for right-lane exits, symbol signs with center and right positions maintained a similar recognition distance (79.45 m or 260.66 ft, and 80.37 m or 263.68 ft, respectively), both greater than that of the left position (73.55 m or 241.31 ft). For left-lane exits, symbol signs with center and right positions also maintained a similar recognition distance (88.56 m or 290.55 ft, and 88.28 m or 289.63 ft, respectively), both greater than that of the left position (80.99 m or 265.72 ft).

Using position as a between-subjects variable, the one-way analysis of variance (ANOVA) test indicated no effect on the position of the recognition distance under both right-lane and left-lane exits ($F_{2, 257} = 0.884$, $p = 0.414$ and $F_{2, 46} = 0.236$, $p = 0.79$).

An ANOVA test was conducted to determine whether the mean recognition distances in different position conditions were obtained from different speeds that subjects drove. The test results showed that there was no difference in speed for three position groups for right- and left-exit interchanges ($F_{2, 257} = 0.095$, $p = 0.909$ and $F_{2, 46} = 0.225$, $p = 0.799$).

In terms of the installation method of guide signs, the overhead symbol signs had a relatively greater recognition distance (92.06 m, or 295.47 ft) compared to the recognition distance of ground-mounted symbol signs (76.78 m or 251.90 ft). ANOVA tests showed that there was no impact from position on recognition distance for overhead guide signs ($F_{2, 78} = 2.48$, $p = 0.09$) and ground-mounted guide signs ($F_{2, 114} = 0.475$, $p = 0.623$).

Subject Preference for the Position of Symbol Signs. Participants' preference for the position of MTG symbol signs was investigated in the posterior questionnaire and is illustrated in Figure 20.



Note: C = center position; L = left position; R = right position.

Figure 20 Results of Survey Questions about the Position of Symbol Signs

From Figure 20, it is obvious that for tested symbol signs, most subjects (54 percent) preferred the right position to the center (29 percent) or left (17 percent) position for right-lane exits. For the left-lane exit, however, most (67 percent) preferred the left position to the center (25 percent) or right (8 percent) position. Few subjects (17 percent) desired a symbol sign to be placed only on the exit direction sign, 29 percent preferred a symbol sign placed on one advance guide sign, and 54 percent preferred the symbol sign on two advance guide signs. Almost all participants (92 percent) chose the same positions for symbol signs for both advance guide signs and exit direction signs.

Only two persons suggested that symbol signs on advance guide signs be positioned at the center in order to attract the drivers' attention, while symbol signs on exit direction signs should be positioned on the same side as that of lane exits, i.e., choosing the right position for right-lane exits and the left position for left-lane exits, while at the exits.

Symbol Sizes and Recognition Performance. The relationship between the symbol sizes and their recognition performance was examined. An ANOVA test found that there were insignificant differences among all driving speeds ($F_{2,\ 125} = 0.185$, $p = 0.83$). Therefore, the recognition distances were comparable.

In Table 49, the larger the symbol size, the greater the recognition distance is. A one-way ANOVA test showed that there were significant differences in means of recognition distance among small, medium, and large symbol sizes ($F = 26.98$, $p < 0.01$).

Table 49 Recognition Distance for Three Symbol Sizes

Size	Descriptive Statistics	Grand Total
L (extra large)	Average of RD (m)	114.60
	Std. dev. of RD (m)	48.28
M (large)	Average of RD (m)	74.82
	Std. dev. of RD (m)	24.94
S (regular)	Average of RD (m)	62.53
	Std. dev. of RD (m)	24.61

Note: L = large size; M = middle size; S = small size.

5.2.3.3 Primary Findings

The positions of symbol signs on top of parent guide signs had no significant effect on recognition distance. However, symbol signs positioned at the center and right obtained greater recognition distance for both right-lane exits and left-lane exits. Subjects preferred the right position for right-lane exits and left position for left-lane exits. They also suggested that symbol signs should be placed on advance guide signs, exit direction signs, and even exit ramps. Symbol sizes significantly affected the recognition distance of symbols. The larger the size, the greater the recognition distance is.

5.3 An Alternative to Supplemental Guide Signs for Texas MTGs

Texas MTG signs could be supplemental guide signs on freeways supported by federal and state guidance. Supplemental guide (SG) signs should be installed as an independent guide sign assembly but are constrained by available space. In order to deliver MTG information within the limited space, one of the feasible solutions is to position the dependent supplemental plaques (SP) on top of other interchange guide signs when symbol sign plaques are not required. Dependent supplemental plaques will also not be limited to the longitudinal space along freeways. With proper placement, MTG messages can be displayed two or three times, accompanied by advance guide signs and exit direction signs at freeway interchanges.

5.3.1 Study Objective

The goal of this section is to determine whether the proposed dependent supplemental plaques could substitute for independent supplemental guide signs when sufficient space is not available.

In order to achieve the goal, a slide show test was conducted to evaluate the relative effectiveness of the dependent supplemental plaques and independent supplemental guide signs. The research objectives are therefore (1) to test drivers' capability to read and comprehend the MTG messages on dependent supplemental plaques in a limited time, while comparing the results with those of independent supplemental guide signs; and (2) to test their relative impacts on standard important interchange signs, such as advance guide and exit direction signs.

5.3.2 Study Method

A slide-based experiment simulated a situation where drivers approach a freeway interchange. The slide show presentation method is a compact, inexpensive, and portable testing methodology. The subjects view a series of signs containing standard interchange signs, such as advance guide, exit direction, and destination signs. The drivers' recollection of messages for each interchange is used as a measure of effectiveness. This provides an evaluation of the difference in a driver's ability to perceive the messages on independent supplemental guide signs and dependent supplemental plaques. A posterior questionnaire follows to determine the subjects' preference and comprehension.

5.3.2.1 Experiment Preparation

Sign Design. All signs to be tested were plotted using the professional sign design software SignCAD^{TM} with the standard font and size recommended in the Texas *Freeway Signing Handbook.* The font Clearview 5WR was used for the 16-inch letters in advance guide and exit direction signs. This font was also used for the 13.3-inch letters in independent supplemental guide signs and dependent supplemental plaques. Other sign elements, such as numerals, shields, and letters, were in compliance with minimum heights and letter styles for freeway guide signs. All plotted signs were saved as bitmap files and then deployed in Microsoft PowerPoint slides.

The destinations shown on independent supplemental guide signs or dependent supplemental plaques were all major attractions or potential MTGs in Texas. Street names shown on advance guide and exit direction signs were the corresponding road names for each destination. These signs direct the drivers to their destinations.

Explore Time. Explore time is the time it takes drivers to read and recognize the sign while driving. Since drivers may have a very limited time span to read and recognize signs, the explore time of each sign was one of the main issues in experiment preparation. Bhise and Rockwell (1973) indicated that the length of time for a driver to look at a sign on the freeway was related to the driver’s workload. Drivers spend an average of 2.6 seconds fixating on each guide sign in low-density traffic and only 0.9 seconds per sign in high-density traffic. In this research, the guide sign was displayed 2.5 seconds to simulate a driver’s single glance at a sign in a lighter-traffic environment, and 1.0 second in a heavy-traffic environment. This setting of explore time was successfully used in the human factors effects test of nine-panel logo signs by Hummer and Maripalli (2008).

Another concerned time was the gap between viewing two sequential signs when approaching an exit. This gap should mimic the time while a vehicle is driving between two sets of traffic signs, which was calculated in this research through dividing the distance between two sets of signs by 60 mph, a typical driving speed on freeways in Houston. In order to save total testing time, all gaps were compressed to one third of the calculated values. For example, if the space between an advance guide sign and independent supplemental guide sign is 800 ft (245 m), the duration between them should be 800(ft)/5280(ft/mile)/60(mile/hr)×3600(seconds/hr)/3 = 3 seconds.

Test Scenarios. In this slide show test, various sign scenes on freeway interchanges were considered:

- **Two sign combinations**. Standard interchange signs (advance guide and exit direction signs) were combined with independent supplemental guide signs or dependent supplemental plaques at a freeway interchange.
- **Two sign series**. One advance guide sign and one exit direction sign are used at minor interchanges. Two or more advance guide signs and one exit direction sign are used at major and intermediate interchanges.
- **Two sign arrays**. A sign array refers to a set of individual sign panels that are installed together at a given point on the roadway, typically on the same sign-mounting structure or assembly. A single sign array includes a standard interchange sign with or without a dependent supplemental guide sign that represents less information workload in a driver scan. Another is a multiple sign array including three sign panels installed together on the same sign support and containing a standard interchange sign, which represents more information workload.

Four different types (a, b, c, and d) of sign groups, comprised of sign combinations and sign series, are illustrated in Figure 21, showing the duration and distance between sequential sign appearances.

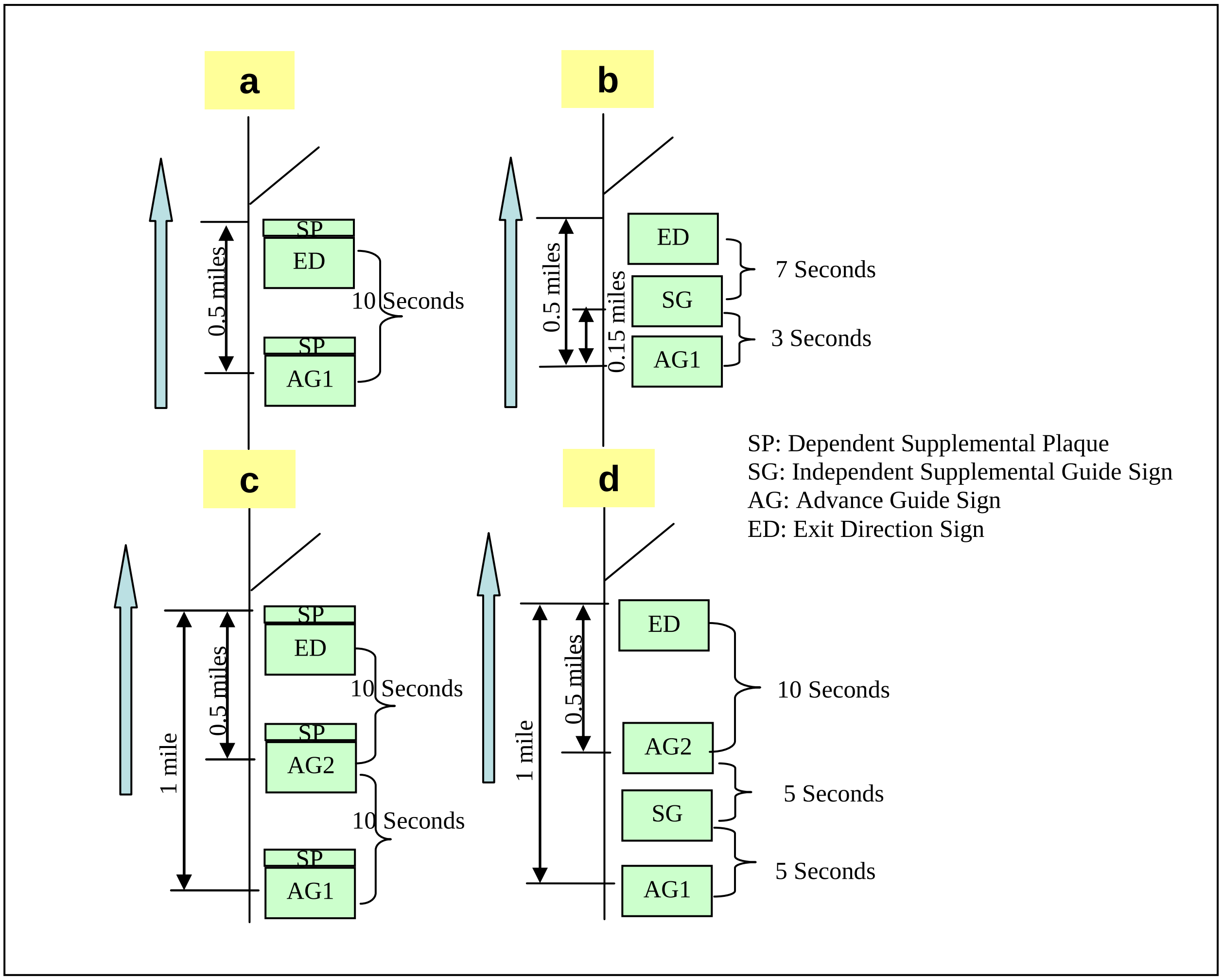


Figure 21 Distances and Gaps between Tested Signs in Four Types of Sign Groups

There were 12 scenarios or, in other words, 12 interchanges. Letters A to L (representing different road names to be tested) were assigned to these interchanges randomly, as shown in Table 50.

In Table 50, 12 participants (P1 to P12) engage in one round of testing, so the total number of test participants could be a multiple of 12. At interchanges 1-8, four types of sign groups were displayed in the case of single sign arrays for 1.0 or 2.5 seconds. At interchanges 9-12, three sign panels on the same sign support showed 1.0 or 2.5 seconds together. Only a and b sign groups were involved in the last four scenarios. The units of information on each structure were 12 on average. This complies with the regulation in Section 2E.07A of the TMUTCD, in which the guidance says, “The maximum amount of information provided by freeway signing on any sign structure should not exceed 20 units.”

Table 50 Test Scenarios

Scenario (Interchange) No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Sign Arrays	**Single**								**Multiple**			
Display	**1 Second**				**2.5 Seconds**				**1 Second**		**2.5 Seconds**	
Type	a	b	c	d	a	b	c	d	a	b	a	b
P1	A	B	C	D	E	F	G	H	I	J	K	L
P2	L	A	B	C	D	E	F	G	H	I	J	K
P3	K	L	A	B	C	D	E	F	G	H	I	J
P4	J	K	L	A	B	C	D	E	F	G	H	I
P5	I	J	K	L	A	B	C	D	E	F	G	H
P6	H	I	J	K	L	A	B	C	D	E	F	G
P7	G	H	I	J	K	L	A	B	C	D	E	F
P8	F	G	H	I	J	K	L	A	B	C	D	E
P9	E	F	G	H	I	J	K	L	A	B	C	D
P10	D	E	F	G	H	I	J	K	L	A	B	C
P11	C	D	E	F	G	H	I	J	K	L	A	B
P12	B	C	D	E	F	G	H	I	J	K	L	A

5.3.2.2 Experiment Procedure

Test Participants. A total of 48 subjects (26 female and 22 male) with valid driver licenses were recruited to evaluate the supplemental guide signs and their alternative. Participants' ages fell into four ranges. No subject was under 16 years old.

- 16 to 25 years old: 17 subjects,
- 26 to 45 years old: 16 subjects,
- 46 to 65 years old: 10 subjects, and
- over 65 years old: 5 subjects.

Participants' driving experience fell into three categories:

- 1 to 5 years: 23 subjects,
- 5 to 20 years: 16 subjects, and
- over 20 years: 9 subjects.

Slide Show Test Procedure. The slide show was displayed on a portable laptop screen. The size of the slides remained the same for all the test scenarios. Moreover, the size of letters on independent supplemental guide signs and dependent supplemental plaques was kept the same. The letter heights of advance guide and exit direction signs did not vary in the experiment. A minimum specific ratio for legibility distance of the 1-inch (25 mm) lettering is 40 ft (12 m). In the experiment, the minimum letter height of tested messages was about 0.2 inches in the slide show; the minimum required legibility distance was 8 ft (2.4 m). Subjects sat in front of the screen within 1 m. This assured that the legibility and size of the sign messages did not interfere with the reading ability of drivers.

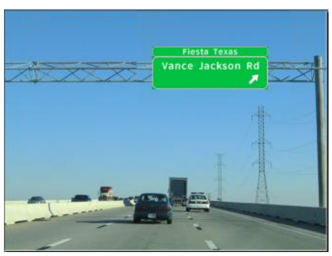
Before going through the test scenarios, a test demonstration was used to educate the subjects on the topics of advance guide signs, exit direction signs, and supplemental signs, and which messages might be displayed on the signs in the test, such as the pool of destination names, road names, and action information. At the same time, their familiar destination names were checked for further analysis. After the participants were accustomed to the testing environment and had no questions, the stimulus presentation started. Each participant was asked to recall the text on the signs for 12 interchanges. The subjects controlled the onset of each interchange when they were ready.

At each interchange, the slide with the first sign array was shown for 1.0 second or 2.5 seconds, and then the sign array disappeared per customized animation. The remaining time of the slide mimicked the view gap when a driver is moving from an upstream sign to a downstream sign. After the gap, the presentation automatically proceeded to the next slide with a second sign array. After a delay of 1.0 second or 2.5 seconds, the second sign array in this slide also disappeared. The slide show automatically advanced to the next slide, which remained at a standstill. At that time, the participants could recall and record sign messages on an answer sheet. After recording the messages, subjects could click on the mouse to proceed to the next interchange. The experiment procedure for interchange signs in scenario 1 is exemplified in Figure 22, and the assumption stated to the subjects was as follows: “You are driving along a freeway. You will see a series of guide signs at assumed freeway interchanges. Read the messages displayed on the guide signs. After each interchange, please recall the messages you had previously read, such as destination names, street names, and highway names.”

Approaching interchange 1

The single sign array (an advance guide sign and a dependent supplemental plaque) was shown for 1 second and then disappeared.

The slide with no sign was continuously showing for 10 seconds, simulating the view gap when driving from an upstream sign to a downstream sign.



The single sign array (an exit direction sign and a dependent supplemental plaque) was shown for 1 second and then disappeared.

The subject wrote down messages that she/he could recall. Afterwards, the slide went to interchange 2.

Figure 22 An Experimental Example for One Interchange Sign

Posterior Questionnaire. After the slide stimulus presentation, each participant was asked to complete a questionnaire on his/her preference of sign groups and comprehension on dependent supplemental plaques. The questionnaire results were compared with the experimental results.

5.3.3 Study Results

The primary measurement of effectiveness for the experiment was correct message recall. Accurate rates of reading messages on dependent supplemental plaques were compared to those on independent supplemental guide signs. Correct responses to advance guide and exit direction signs were also analyzed in the two sign combinations to indicate the impacts from dependent supplemental plaques and independent supplemental guide signs. The Z-test is used to analyze the test results at a 95 percent confidence level, and its value beyond the interval (–1.96, 1.96) indicates that the difference between the two proportions is statistically significant.

5.3.3.1 Response to Destination Signs

Table 51 summarizes the overall and detailed correct responses to MTG messages on dependent supplemental plaques and independent supplemental guide signs under different explore times and sign arrays.

Table 51 Correct Responses for MTG Messages

Sign Type	Explore Time	Sign Array	MTG Messages			
			Correct Recall	Total Number	Correct Percentage	Z-Statistic
Dependent SP	All	All	193	288	67%	–5.52
Independent SG			249	288	86%	
Dependent SP	All	Single	162	192	84%	–0.29
Independent SG			164	192	85%	
Dependent SP	All	Multiple	31	96	32%	–7.97
Independent SG			85	96	89%	
Dependent SP	1.0 Second	All	81	144	56%	–4.58
Independent SG			117	144	81%	
Dependent SP		Single	69	96	72%	–1.35
Independent SG			77	96	80%	
Dependent SP		Multiple	12	48	25%	–5.74
Independent SG			40	48	83%	
Dependent SP	2.5 Seconds	All	112	144	78%	–3.28
Independent SG			132	144	92%	
Dependent SP		Single	93	96	97%	1.79
Independent SG			87	96	91%	
Dependent SP		Multiple	19	48	40%	–5.63
Independent SG			45	48	94%	

In Table 51, the overall result indicated that the percentage of correct recall for both sign types was high, while dependent SP signs received less accurate responses than independent SG signs (67 percent versus 86 percent in Table 3). In the case of single arrays, dependent SP signs performed as well as independent SG signs (84 percent versus 85 percent). In the case of multiple sign arrays, dependent SP signs had a significantly lower correct percentage than independent SG signs (32 percent versus 89 percent). Therefore, the difference in correct message recall between dependent SP and independent SG signs was mainly attributed to the case of the multiple sign arrays.

In both 1.0-second and 2.5-second explore times, dependent SP signs performed worse than independent SG signs (56 percent versus 81 percent and 78 percent versus 92 percent, respectively). In the 1.0-second explore time, dependent SP and independent SG signs had similar correct response percentages (72 percent versus 80 percent) in the case of single sign arrays, and the difference between them was not significant. For multiple sign arrays, subjects could correctly read significantly fewer messages on dependent SP signs than they could on independent SG signs (25 percent versus 83 percent). Since dependent SP signs were placed with other multiple signs, they were easy to ignore within the limited scan time. In contrast to dependent SP signs, independent SG signs displayed a unique sign, which appeared for 1 second in the test.

In the 2.5-second explore time, dependent SP signs performed better than independent SG signs in the case of single sign arrays (97 percent versus 91 percent), although the difference was not very significant. In the case of multiple sign arrays, dependent SP signs had a significantly lower correct message recall than independent SG signs (40 percent versus 94 percent), which is similar to the case for the 1.0-second explore time.

By extending the explore time from 1.0 second to 2.5 seconds, the percentages of correct responses for both dependent SP signs (from 56 percent to 78 percent) and independent SG signs (from 81 percent to 92 percent) increased. The MTG messages on dependent SP signs received more correct answers in the 2.5-second explore time than in the 1.0-second explore time for both single sign arrays (97 percent versus 72 percent) and multiple sign arrays (40 percent versus 25 percent). More correct recalls of MTG messages on independent SG signs in the 2.5-second explore time were recorded than in the 1.0-second explore time for both single sign arrays

(91 percent versus 80 percent) and multiple sign arrays (94 percent versus 83 percent). All these imply that the increased scan time (such as from 1.0 second to 2.5 seconds) will increase the correct recall numbers.

5.3.3.2 Response to Standard Interchange Signs

Since supplemental guide signing can reduce the effectiveness of other important interchange guide signing, the correct message recalls on advance guide and exit direction signs in the test were examined to summarize the impacts of independent SG and dependent SP signs. Table 52 lists the overall and specific correct responses sorted by explore time and sign arrays for AG and ED signs.

Table 52 Correct Responses for AG and ED Messages

Sign Type	Explore Time	Sign Array	AG & ED Messages			
			Correct Recall	Total Number	Correct Percentage	Z-Statistic
Dependent SP	All	All	220	288	76%	–3.12
Independent SG			249	288	86%	
Dependent SP	All	Single	178	192	93%	–3.06
Independent SG			190	192	99%	
Dependent SP	All	Multiple	42	96	44%	–2.46
Independent SG			59	96	61%	
Dependent SP	1.0 Second	All	100	144	69%	–2.47
Independent SG			118	144	82%	
Dependent SP		Single	86	96	90%	–2.79
Independent SG			95	96	99%	
Dependent SP		Multiple	14	48	29%	–1.89
Independent SG			23	48	48%	
Dependent SP	2.5 Seconds	All	120	144	83%	–1.94
Independent SG			131	144	91%	
Dependent SP		Single	92	96	96%	–1.36
Independent SG			95	96	99%	
Dependent SP		Multiple	28	48	58%	–1.73
Independent SG			36	48	75%	

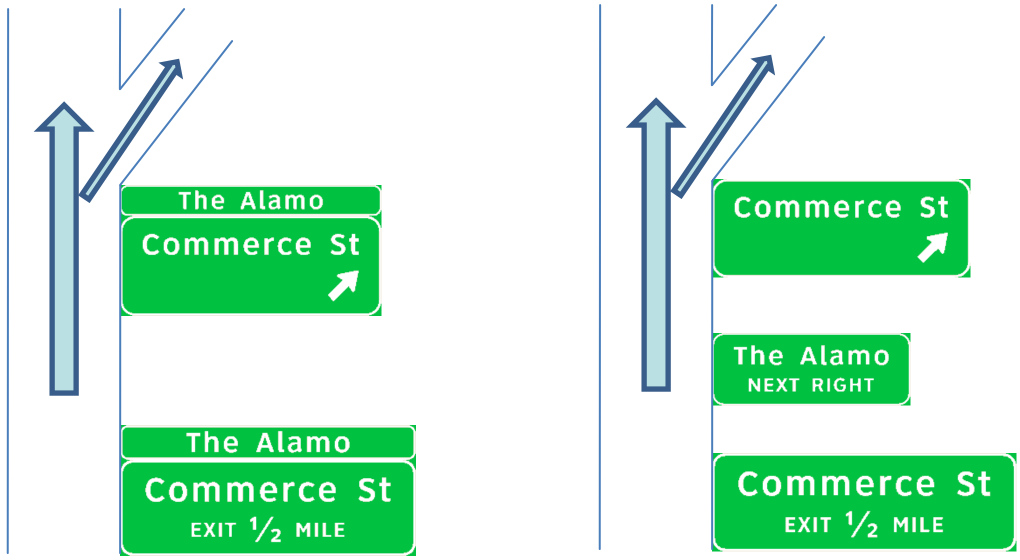
As is shown in Table 52, the overall correct recall percentage for AG and ED signs in the sign type of dependent SP signs was lower than that of independent SG signs (76 percent versus 86 percent). In other words, dependent SP signs attached on the top of AG and ED signs had more negative impacts on those AG and ED signs than independent SG signs did. This negative impact is attributed to the placement of dependent SP signs.

In the case of single sign arrays, the AG and ED signs were correctly recalled at fairly high levels for both SP and SG sign types (93 percent versus 99 percent). In the 1.0-second explore time, the AG and ED signs in single sign arrays received significantly lower correct responses for the sign type with dependent SP signs than that with independent SG signs (90 percent versus 99 percent). In the 2.5-second explore time, the difference in correct responses to the AG and ED messages in single sign arrays was not significant between dependent SP and independent SG sign types (96 percent versus 99 percent).

In the case of multiple sign arrays, the correct percentage for AG and ED messages was significantly lower in the sign type with dependent SP signs than that with independent SG signs (44 percent versus 61 percent, $z = -2.46$), but the difference was not significant in the two types of explore times ($z = -1.89$ and $z = -1.73$ for 1.0 second and 2.5 seconds, respectively). AG and ED signs in Table 52 only refer to the guide signs directly on the bottom of dependent SP signs. In addition to AG and ED signs, multiple sign arrays contained other guide signs on the same sign support. Taking the other information units on multiple signs, rather than the message on dependent SP signs, into consideration, the correct percentages of information recall on sign types with dependent SP and independent SG signs were 21 percent and 24 percent in the 1.0-second explore time, respectively; and 32 percent and 30 percent in the 2.5-second explore time, respectively. The difference between them was not significant ($z = -0.93$ and 0.7, respectively). Table 52 also indicates the tendency that a longer explore time would result in more correct messages recalls, the same conclusion as in Table 51.

5.3.3.3 Subjects' Preference and Comprehension

In the posterior questionnaire, the participants were asked to select between dependent SP and independent SG signs. Examples were provided and explained regarding the difference between these two sign groups. The subjects' preferences on single and multiple sign arrays are described in Figures 23 and 24.



a b

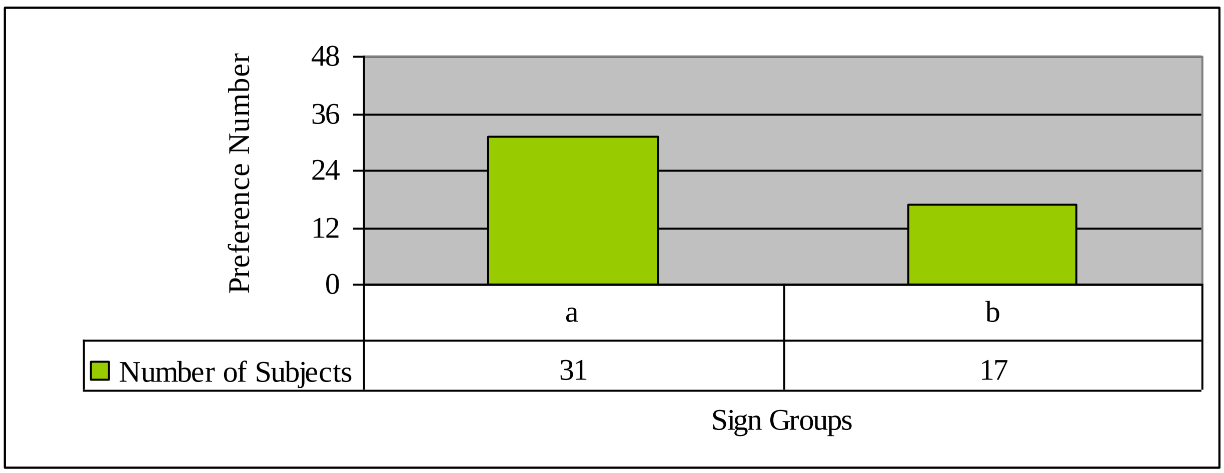


Figure 23 Subjects' Preference for Single Sign Arrays

As shown in Figure 23, 31 subjects preferred dependent SP signs (case a), and 17 subjects preferred independent SG signs (case *b*). One of the reasons more people chose case *a* is that it connects or associates the destination names with road names. This type of sign placement will not only save sign materials and cost, but also will minimize the number of times that the subjects need to see the signs.

The reason why some subjects chose case *b* is that the signs in this situation are clearer and cause less confusion. The subjects were further asked in the test about their comprehension of dependent SP signs on top of AG and ED signs. Thirty-nine participants understood that they could reach both the destination and the road displayed on the single sign arrays from the freeway exit, while only nine subjects were not clear about this relationship.

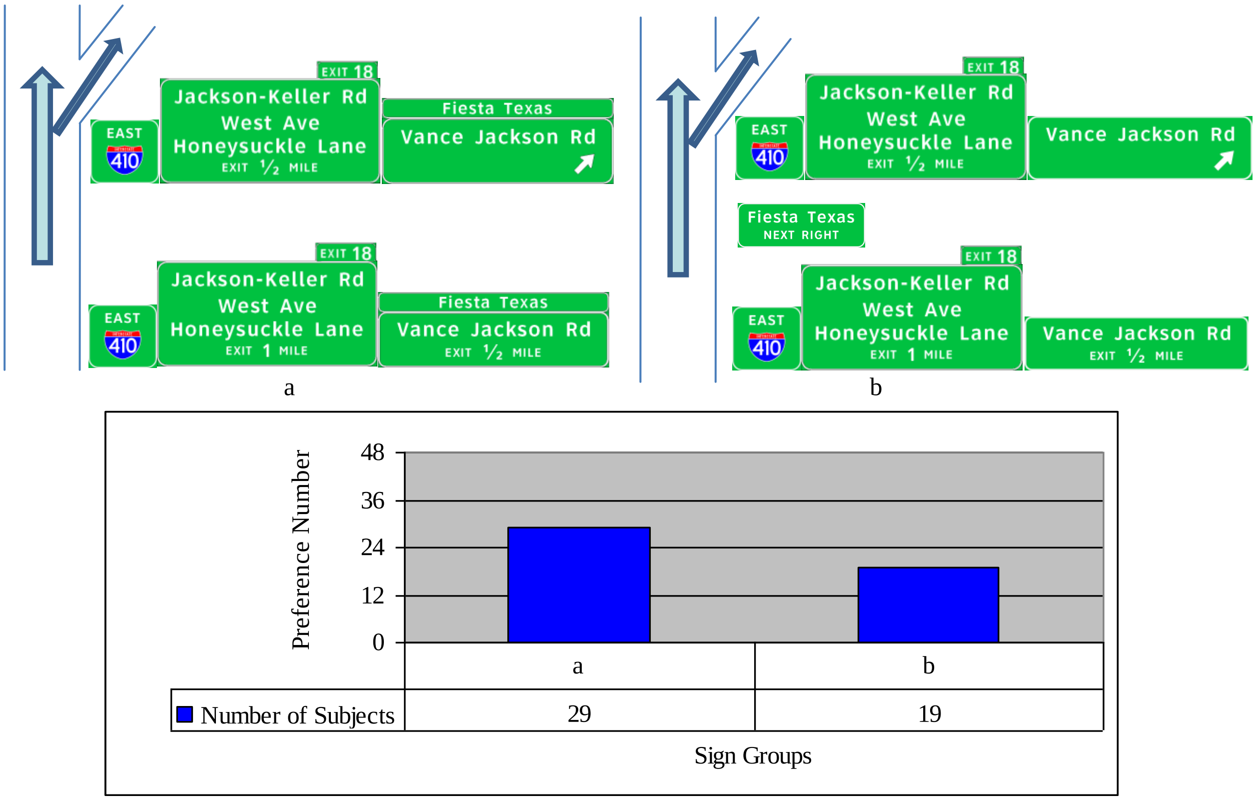


Figure 24 Subjects' Preference for Multiple Sign Arrays

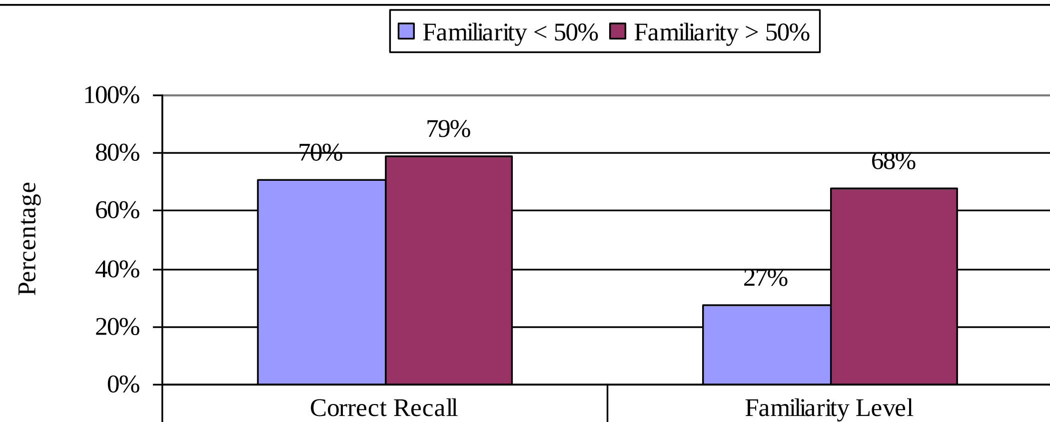
Figure 24 shows the test results on subjects' preference for multiple sign arrays, where 29 subjects preferred dependent SP signs and 19 subjects preferred independent SG signs. While compared with single sign arrays, the number of subjects who preferred dependent SP signs in multiple sign arrays slightly decreased (31 versus 29). This is a result of information overload from multiple sign panels.

5.3.3.4 Subjects' Familiarity with Destinations

In the test, each tested destination name randomly appeared in 1 of 12 test scenarios displayed in the form of either dependent SP or independent SG signs. The correct recalls on the 12 destinations were not significantly different using a chi-square test (Df = 11, p = 0.902). The participants were asked to check familiar destination names in the posterior survey. It was found that there is a relationship between the subjects' correct responses and their familiarity with the destinations.

Based on survey responses, 6 of the 12 destinations were claimed to be familiar by more than 50 percent of subjects. These destinations are named "familiar destinations." Similarly, the other six destinations are "unfamiliar destinations."

Through analyses as in shown in Figure 25, the familiar destinations are related to a higher correct response percentage in the test, while the unfamiliar destinations are related to a lower percentage (79 percent versus 70 percent, $z = 2.4 > 1.96$). The higher familiarity level (68 percent for the group of familiar destinations) relates to a higher correct percentage (79 percent for the same group). This implies drivers would have better comprehension and recall for messages that they are familiar with.



	Correct Recall	Familiarity Level
Familiarity < 50%	70%	27%
Familiarity > 50%	79%	68%

Figure 25 Correct Percent and Familiarity Level of Tested Destinations

5.3.3.5 Respondents' Gender, Age, and Driving Experience

Table 53 summarizes the statistics of the subjects' gender, age, and driving experience.

Table 53 Correct Responses by Gender, Age, and Driving Experience

Subject Groups (Gender, Age, Experience)		Sign Type	MTG Messages in All Sign Arrays			
			Correct Recall Number	Total Number	Correct Percentage	Z-Statistic
Gender	Female	All	243	312	0.78	0.71
	Male		199	264	0.75	
	Female	Dependent SP	107	156	0.69	–3.96
		Independent SG	136	156	0.87	
	Male	Dependent SP	86	132	0.65	–3.86
		Independent SG	113	132	0.86	
Age	16-25	All	155	204	0.76	NA
	26-45		146	192	0.76	
	46-65		90	120	0.75	
	Over 65		51	60	0.85	
	16-25	Dependent SP	61	102	0.60	–5.41
		Independent SG	94	102	0.92	
	26-45	Dependent SP	67	96	0.70	–2.03
		Independent SG	79	96	0.82	
	46-65	Dependent SP	39	60	0.65	–2.53
		Independent SG	51	60	0.85	
	Over 65	Dependent SP	26	30	0.87	0.36
		Independent SG	25	30	0.83	
Driving Experience	1-5 years	All	213	276	0.77	NA
	5-20 years		150	192	0.78	
	Over 20 years		79	108	0.73	
	1-5 years	Dependent SP	87	138	0.63	–5.59
		Independent SG	126	138	0.91	
	5-20 years	Dependent SP	68	96	0.71	–2.44
		Independent SG	82	96	0.85	
	Over 20 years	Dependent SP	38	54	0.70	–0.65
		Independent SG	41	54	0.76	

Table 53 Correct Responses by Gender, Age, and Driving Experience (Continued)

Subject Groups (Gender, Age, Experience)		Sign Type	MTG Messages in Single Sign Arrays			
			Correct Recall Number	Total Number	Correct Percentage	Z-statistic
Gender	Female	All	243	312	0.78	0.71
	Male		199	264	0.75	
	Female	Dependent SP	89	104	0.86	–0.41
		Independent SG	91	104	0.88	
	Male	Dependent SP	73	88	0.83	0.00
		Independent SG	73	88	0.83	
Age	16-25	All	155	204	0.76	NA
	26-45		146	192	0.76	
	46-65		90	120	0.75	
	Over 65		51	60	0.85	
	16-25	Dependent SP	56	68	0.82	–0.96
		Independent SG	62	68	0.91	
	26-45	Dependent SP	54	64	0.84	0.00
		Independent SG	54	64	0.84	
	46-65	Dependent SP	34	40	0.85	0.30
		Independent SG	33	40	0.83	
	Over 65	Dependent SP	18	20	0.90	1.25
		Independent SG	15	20	0.75	
Driving Experience	1-5 years	All	213	276	0.77	NA
	5-20 years		150	192	0.78	
	Over 20 years		79	108	0.73	
	1-5 years	Dependent SP	77	92	0.84	–1.56
		Independent SG	84	92	0.91	
	5-20 years	Dependent SP	55	64	0.86	0.25
		Independent SG	54	64	0.84	
	Over 20 years	Dependent SP	30	36	0.83	1.13
		Independent SG	26	36	0.72	

As is shown in the first part of Table 53, if the single sign arrays and multiple sign arrays were combined for analyzing dependent SP and independent SG signs, dependent SP signs would receive significantly lower correct responses in all subject groups except for the "over 65 years old" age group (z = 0.36) and for "over 20 years driving experience" group (z = –0.65). As analyzed in Table 51, the difference in correct message recall between dependent SP and independent SG signs was mainly attributed to multiple sign arrays.

Therefore, in the second part of Table 53, the comparison of correct responses between dependent SP and independent SG signs was focused on single sign arrays. There is no significant difference for each subject group. Regarding gender groups, females performed relatively better than males for both dependent SP (86 percent versus 83 percent) and independent SG signs (88 percent versus 83 percent).

For age groups, the percentages of correct responses for dependent SP signs were slightly higher with age (from 82 percent to 84 percent, 0.85 percent, and 90 percent, respectively), while the percentages of correct recalls for independent SG signs were slightly lower with age (from 91 percent to 84 percent, 83 percent, and 75 percent, respectively). For the driving experience groups, the correct percentages did not vary greatly for dependent SP signs in the three groups (84 percent, 86 percent, and 83 percent), while driving experience was inversely related to the correct responses of independent SG signs (91 percent, 84 percent, and 72 percent, respectively). Inexperienced drivers had the highest correct responses.

5.3.4 Study Findings

In this study, the dependent supplemental plaques placed on top of advance guide and exit direction signs are proposed as an alternative to independent supplemental guide signing on urban freeways. This is an alternative to current practice. A slide show test was conducted, and the findings are highlighted as follows:

- Overall results indicated that independent SG signs received more correct message recalls than dependent SP signs, which was mainly attributed to the conditions of multiple sign arrays. However, in the case of single sign arrays, the correct responses for dependent SP signs were as high as for independent SG signs in both heavy (1.0-second explore time) and light (2.5-second explore time) traffic environments. What is more, the correct percentage for dependent SP signs was higher than that for independent SG signs in low-density traffic conditions. In the case of multiple sign arrays, due to the abundant information units with dependent SP signs in the same sign structure, the correct rate for dependent SP signs was significantly lower than for independent SG signs. The study also illustrated that correct responses increased with an extended explore time in that respondents had a longer time to perceive the sign messages.
- Correct responses to the messages of AG and ED signs demonstrated the impacts of dependent SP and independent SG signs. In the condition of single sign arrays,

dependent SP signs were related to a relatively lower correct percentage (90 percent compared with 99 percent) of AG and ED sign messages' recall, respectively, in the 1.0-second explore time. It was more likely that drivers had to select the right messages to read between dependent SP and AG/ED signs in the short period of time. A longer explore time could reduce this negative effect of dependent SP signs on AG and ED signs. In the 2.5-second explore time, the difference in correct responses to AG and ED signs was insignificant between dependent SP and independent SG sign types. In the case of multiple sign arrays, the difference was not significant as well.

- Subjects preferred dependent SP over independent SG signs in either single sign arrays or multiple sign arrays. Most responders (39 out of 48) can interpret that they would approach both the destinations on dependent SP signs and roads on AG/ED signs when exiting the freeway. The association of destination names and road names could assist drivers in comprehending the guide signs.
- The examination of subjects' familiarity with destinations indicated that the familiar destinations are related to higher correct response percentages. In terms of subjects' gender, age, and driving experience, the use of dependent SP signs would not introduce any significant change to the correct message recall while compared to independent SG signs.

The proposed alternative to independent SG signs, dependent SP signs, indeed performed well in the case of single sign arrays. Proposed dependent SP signs are comprehensible and will save not only space on freeways but also the cost of installation, management, and materials. It is recommended that dependent SP signs be installed on top of AG and ED signs for critical MTGs when freeway sign space is limited and there is single array signing. However, if AG and ED signs are installed with multiple signs on the same sign support, dependent SP signs may not be the optimal selection.

5.4 MTG Symbols on Supplemental Guide Signs and Symbol Sign Plaques

5.4.1 Study Objective

Supplemental guide signs and symbol sign plaques on top of a parent guide sign are recommended as the types of Texas MTG signs to be used on freeways. When freeway space is limited, symbol sign plaques are proposed to display MTG symbols; dependent supplemental plaques, as an alternative to supplemental guide signs, are considered to display MTG word messages in single sign arrays. In this section, the MTG symbols in these two recommended MTG sign types (supplemental guide signs and symbol sign plaques) are examined. The objective of this study is to identify whether symbols are helpful in locating MTG destinations and which type of MTG sign is better for supplemental guide signs and symbol sign plaques.

5.4.2 Study Method

In this study, four scenarios for MTG signs were examined through a simulation experiment based on drivers' responses. The experiment was conducted in the driving simulator, followed by a posterior questionnaire survey of subjects. Tested MTG signs were placed at the standard-oriented positions on the sections of freeway interchanges. Four MTGs were proposed in the test. The participants' recognition and comprehension of MTG signs and symbols were evaluated.

5.4.2.1 Experiment Preparation

Four Types of MTG Symbols and Signs. The four tested MTG symbol signs are: (1) the Alamo (A), (2) Fiesta Texas (F), (3) Sam Houston Race Park (R), and (4) Sea World (S). These symbols were obtained in the following ways:

- The symbol for the Alamo was provided by the project panel, which is actually used on one of the freeways in San Antonio.
- The symbol for Fiesta Texas is self-designed by the research team and represents the category of amusement parks.
- The symbol for Sam Houston Race Park is from the symbol pools of the MUTCD.

- The symbol for Sea World is also self-defined by the research team and originates in the MUTCD.

Figure 26 lists these four MTG symbol signs.

The Alamo Sam Houston Race Park Fiesta Texas Sea World

Figure 26 Four Types of MTG Symbols

In Figure 26, the sign type in the first row is for symbol sign plaque symbols only, the second row is for symbol sign plaque symbols and text, the third row is for supplemental guide sign text and symbols, and the bottom row is for supplemental guide sign text only. All signs were sketched by using the professional sign design software SignCAD™. The plotted sign images were imported into the driving simulator for various scenario tests. All symbols were kept the same sizes, and text sizes in symbol sign plaques were equal. The text sizes in supplemental guide signs were also equal.

Test Scenarios. There are four scenarios based on the four types of MTG signs. In each scenario, the tested MTG signs have the same type, which is a symbol sign plaque (symbol), symbol sign plaque (symbol and text), supplemental guide sign (text and symbol), or supplemental guide sign (text only). A scenario example is shown in Figure 27 with start points and tested MTGs.

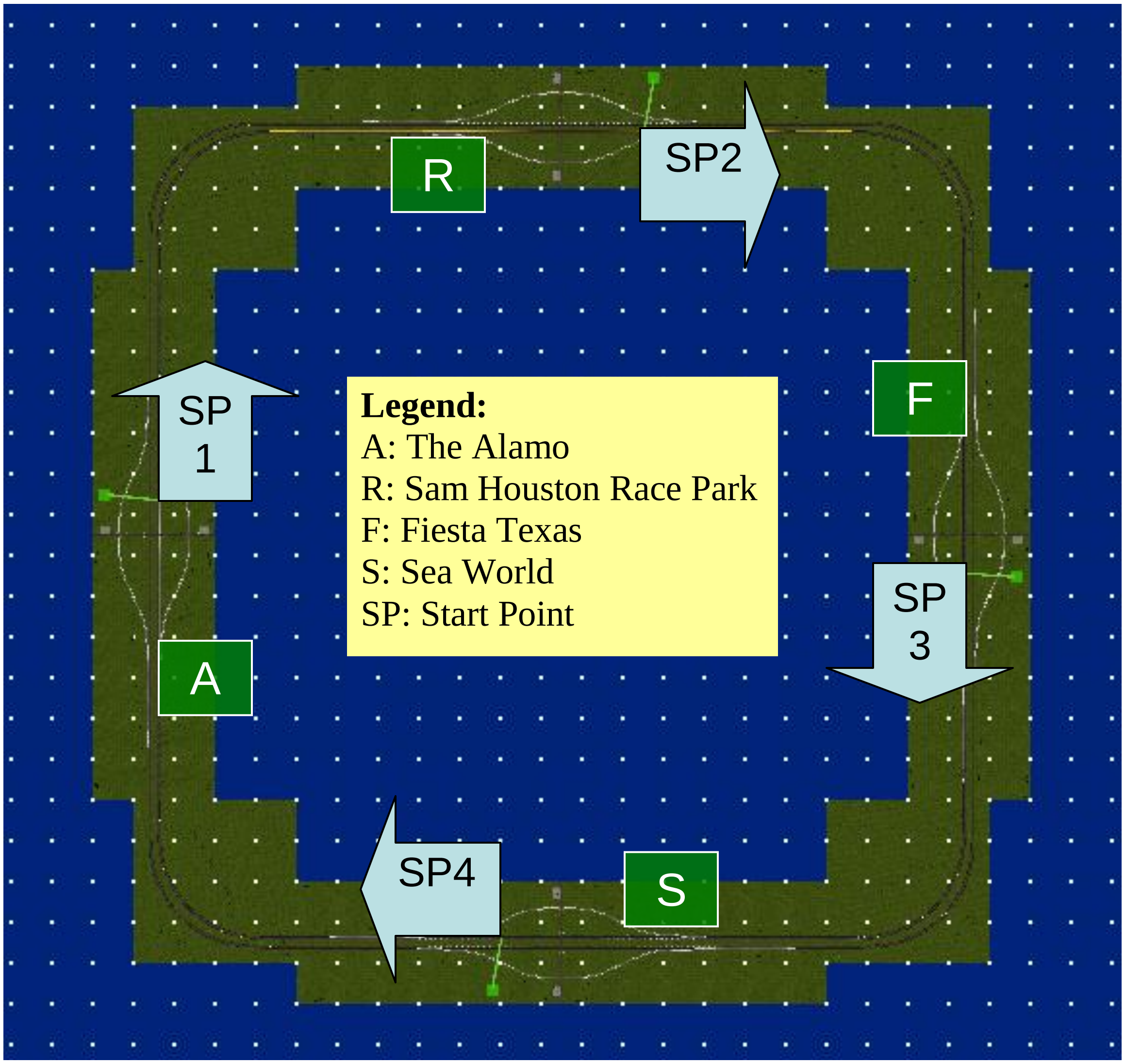


Figure 27 Test Scenario Example

In each scenario, a closed freeway was established with a total length of 8 miles (12.8 km) with four interchanges designated to correspond to four MTG destinations (the Alamo, Sam Houston Race Park, Fiesta Texas, and Sea World). Four start points (SP1, SP2, SP3, and SP4) were defined in order to randomize the sequence of the assigned destinations during the driving test. Each MTG sign had its corresponding placement of advance guide signs and exit direction signs.

According to the guidance in Section 2E 32 of the MUTCD, “If only one Advance Guide sign is used, the Supplemental Guide sign should follow it by at least 245 m (800 feet),” so the supplemental guide signs of the MTG sign type were installed following the advance guide sign by 0.15 miles (245 m). However, symbol sign plaques of MTG sign types were placed on top of advance guide signs and exit direction signs. Detailed locations of various signs are illustrated in Figure 28.

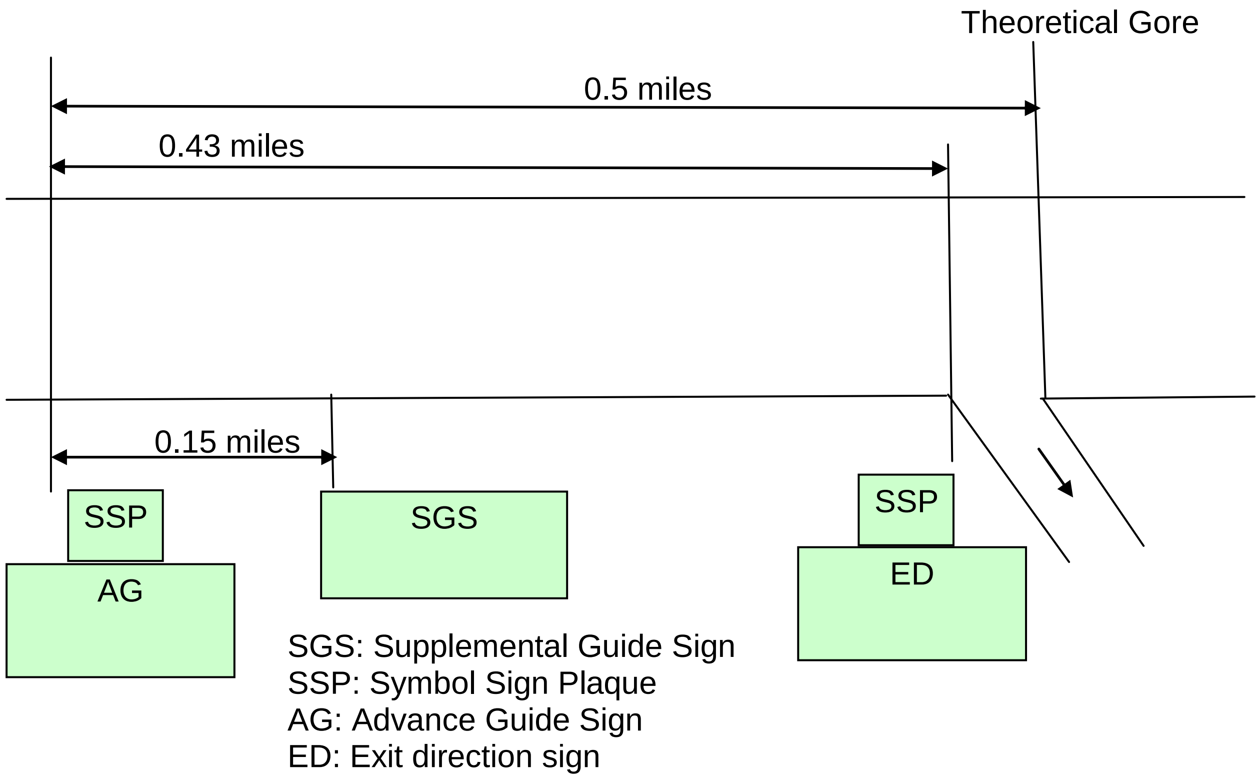


Figure 28 Placement of Different Types of Signs

5.4.2.2 Experiment Procedure

Test Participants. A total of 24 subjects with valid driver licenses were recruited to evaluate the symbol signs for MTGs. Four MTGs (A, F, R, and S) and four start points (1, 2, 3, and 4) were randomized in the following sequence:

1. S A R F 3 4 1 2
2. F A S R 4 3 1 2
3. R F S A 1 3 2 4
4. S R F A 3 1 4 2
5. R F A S 1 2 3 4
6. R A F S 1 2 4 3
7. R A S F 4 2 1 3
8. A S R F 4 1 2 3
9. F S A R 2 3 4 1

10. S F A R 1 4 3 2
11. S A F R 1 4 2 3
12. A R S F 3 4 2 1
13. A F S R 4 2 3 1
14. R S F A 2 4 3 1
15. A F R S 2 1 3 4
16. F R S A 2 1 4 3
17. R S A F 3 2 4 1
18. A S F R 1 3 4 2
19. S R A F 3 1 2 4
20. S F R A 2 4 1 3
21. A R F S 2 3 1 4
22. F A R S 4 1 3 2
23. F S R A 3 2 1 4
24. F R A S 4 3 2 1

Participants followed this order to test the scenarios. Each subject was exposed to four scenarios and took approximately 30 minutes to complete the test. In each scenario, one of four MTGs was assigned as their destination. The tested symbols were explored and explained to the subjects before the formal test started. After the participants became accustomed to the testing environment, they were instructed to drive on the designed freeways in the scenario. Subjects were asked to maintain their lane positions and follow the speed limit (65 mph) to locate their assigned MTG destinations. Participants were asked to press the programmable buttons beside the steering wheel when clearly identifying the target symbols or text, which were related to the assigned MTG. The subjects followed guide signs and/or symbols and, based on their responses to presented signs, decided where to exit.

Questionnaire Survey. After the simulator test, each participant was asked to complete a questionnaire to acquire: (1) their preference between two types of possible MTG signs based on their experience in the simulation test, (2) proper messages for each sign type, (3) the background color of symbol sign plaques, and (4) their habits for reading a sign assembly. The questionnaire results were further compared with the experimental results.

5.4.3 Study Results

The results were analyzed in two parts, based on the data obtained from the simulation experiment and posterior questionnaire.

Driving Simulation Results. The primary measurements of effectiveness for the experiment were recognition distance, maneuver distance, and correct exits. Recognition distance is the distance between the recognition point, where the participant correctly identifies the assigned destination on the MTG sign, and the position of the MTG sign. The recognition distances were calculated based on the coordinates of the subject vehicle and MTG signs in the simulator. Maneuver distance is the distance between the recognition point and the theoretical gore. Within the maneuver distance, participants could make a decision whether they should exit the freeway interchange to the assigned destination through a safe maneuver. The maneuver distances were calculated based on the coordinates of the subject vehicle and theoretical gore location in the simulator. Correct exits were recorded when the subject correctly made an exit at the freeway interchange where the sign of the assigned MTG was installed according to the MTG destination assignment. These three MOEs are summarized in Tables 54 and 55.

Table 54 Recognition Distance and Maneuver Distance According to MTG Sign Types

MTG Sign Type	LT	LTS	SS	SST
Avg. Recognition Distance (m/ft)	61/200.13	72/236.22	80/262.47	86/282.15
Avg. Maneuver Distance (m/ft)	598/1961.94	628/2060.37	8762874.02	762/2500.00

Note: LT: supplemental guide sign text only; SS: symbol sign plaque symbol only; SST: symbol sign plaque symbol and text.

Table 55 Correct Exits According to MTG Sign Types

MTG Sign Types	LT	LTS	SS	SST
Correct Exit	11	17	21	20
Correct Exit Percentage	46%	71%	88%	83%

Using sign type as a between-subjects variable, the one-way ANOVA test indicated that the difference in the mean recognition distances for the four MTG sign types are not significant ($F_{3,\ 80}$ = 1.862, p = 0.143). However, there is significant difference in the mean maneuver distance between all the supplemental guide signs and symbol sign plaques (612.79 m or 2010.47 ft versus 820.14 m or 2690.75 ft) via a nonparametric test (p = 0.00) regardless of symbol and text. In the large supplemental guide signs, the mean maneuver distance between text-only signs and text-plus-symbol signs is not significantly different (p = 0.121). In the symbol sign plaques, the difference of mean maneuver distance between symbol-only signs and text-plus-symbol signs is not significant as well (p = 0.686).

Posterior Questionnaire Results. Through the posterior questionnaire survey, 11 of the 24 participants preferred symbol sign plaques as an MTG sign, and 13 participants preferred the supplemental guide signs. There was an almost identical preference between these two types of MTG signs. In the type of symbol sign plaque, 20 of 24 responders wanted to display the symbol and name of the MTG on it. The other two preferred the MTG symbol only. Three responders suggested adding action information on the symbol sign plaques. In the type of supplemental guide sign, 20 of the 24 responders wanted to display the symbol and name of the MTG on it. The other two preferred the MTG text only. All responders believed that the supplemental guide signs had provided enough information.

Regarding the background color of the symbol sign plaque, 19 subjects liked green, 4 liked blue, and 1 liked brown. Through inquiring about their habits when reading a sign assembly, it is found that 14 of the 24 subjects (58 percent) liked to read the sign information from left to right, 6 (25 percent) liked to read from up to down, and 4 (17 percent) liked to read from down to up.

5.4.4 Study Findings

According to the results from the driving simulator tests and the associated posterior questionnaire survey, the symbol sign plaques performed as well as, or even better than, the supplemental guide signs. For the type of symbol sign plaque, the subjects preferred to display the information of MTG symbol and name. For the type of supplemental guide sign, the subjects liked to display the information of MTG symbol and name, too. Supplemental guide signs with symbols and text performed better than signs with only text in all MOEs, including the recognition distance, the maneuver distance, and the correct exits.

CHAPTER 6
WARRANTS AND DESIGN FOR MAJOR TRAFFIC GENERATOR GUIDE SIGNING

Based on the surveyed opinions of engineers and needs of MTGs in Chapter 3, the identified MTG eligibility criteria for Texas in Chapter 4, and the types of symbols, location, and size of symbols/signs tested and identified in Chapter 5, the warrants and design for MTG guide signing in Texas are established and summarized in two parts: the eligibility criteria and the symbols for MTGs in Texas.

6.1 Eligibility Criteria for Major Traffic Generators

The MTG eligibility criteria in Texas are identified in Chapter 4 and are summarized here. A traffic generator can be considered a major traffic generator if the following criteria are met:

1. parking for a minimum of 1,000 vehicles in metropolitan and urban areas, 700 vehicles in suburban areas, and 400 vehicles in rural areas;
2. a location along either the interchange crossroad or the freeway and within 8 miles of the major traffic generator in rural areas, within 3 miles in suburban areas, or within 2 miles in metropolitan areas and urban areas;
3. at least 325,000 visitors per year in metropolitan areas, at least 300,000 visitors per year in urban areas, at least 200,000 visitors per year in suburban areas, and at least 80,000 visitors per year in rural areas; and

4. a minimum of 15 events per year in metropolitan areas, 10 events in urban areas, 8 events in suburban areas, and 6 events in rural areas.

6.2 Symbols for MTG Guide Signing

For the qualified MTGs, the type of guide signing could be a *supplemental guide sign* if there is sufficient space or a *symbol sign plaque* if available space is limited.

The types of symbols for Texas MTGs could be category-oriented symbols according to the MTG classification. Symbol designs shall be essentially like those shown in the TMUTCD and in *Standard Highway Sign Designs for Texas*. New symbol designs shall be adopted by the Texas Department of Transportation (TxDOT) based on research evaluations to determine road user comprehension, sign conspicuity, and sign legibility.

In MTG supplemental guide signs, the legend and size shall be the same as in the guidelines prescribed for other supplemental guide signs. Accepted MTG symbols may be included. The sign color shall be a white legend on a green or brown background in accordance with the TMUTCD. Only one supplemental guide sign for an MTG may be used on each interchange approach. If used, it is normally installed as an independent guide assembly. A supplemental guide sign should not list more than two MTGs. When more than two MTGs meet the signing criteria, the MTG with the greatest need for signing should be shown. If necessary, MTG trailblazing signs can be used depending on the location, distance, and how many turns to the MTG.

Where the freeway space is not available for installing independent supplemental guide signs, dependent supplemental plaques may be installed on top of interchange signs to display the word MTG message when not overloading the driving information.

In MTG symbol sign plaques, the legend should contain the MTG symbol and associated word message at the bottom. The message should be either the MTG category or the name of the MTG. The size of the MTG symbol should be 30×30 inches when used on freeways or expressways. Where greater visibility or emphasis is needed, larger sizes should be used. Symbol sign enlargements should be in 6-inch increments. The word messages should be in letters at least 6 inches high. Where greater visibility or emphasis is needed, larger lettering shall be used, such as 8-inch letters. The color of the MTG symbol sign plaques shall be a white legend on a green, blue, or brown background, depending on the type of MTG service.

MTG symbol sign plaques may be placed on the top of advance guide and exit direction signs at freeway interchanges. Where necessary, MTG symbol sign plaques can be installed on freeway ramps, such as exit gore signs. The position of MTG symbol sign plaques on parent guide signs follows the guidelines in the Guide Sign Routing Plaque in *Freeway Signing Handbook*. Where necessary, trailblazing MTG symbol sign plaques shall be used, like airport symbol signs. At most three symbol sign plaques could be placed at the top of a parent guide sign, whether or not there is an exit number panel. When there is a need for other guide sign routing plaques, the priority for other routing plaques should be higher than MTG symbol sign plaques.

Not all facilities that meet the MTG criteria should automatically display their informational signing. TxDOT shall retain the authority to deny requests for signing where other non-technical standards cannot be met. TxDOT should also retain the authority to specify the appropriate MTG sign types, message content, size of sign, sign location, color, etc., in accordance with standards for acceptable signing practice.

CHAPTER 7 CONCLUSION AND RECOMMENDATIONS

In this report, the eligibility criteria of Texas MTGs are identified based on a fuzzy logic–based algorithm from the review of practices and manuals of other states, and from the engineer survey. The types of symbols, location, and size of symbols/signs are identified based on the literature review of practices of other states, engineer survey, MTG survey, and simulator and slide show tests. The recommended warrants and symbol design are submitted to TxDOT as a reference for MTG guide signing in Texas.

The achievements of this report do not end the study of MTG guide signing. Future work is recommended in the following areas:

- Taking some unexpected situations during driving into consideration would help the driving experience in driving simulator tests have a truer feel, such as a truck blocking drivers' sight when reading MTG guide signs, lane changing, distracting factors, etc.
- Driving workload should be evaluated when MTG signs supplement the information on multiple sign arrays or more information is added to MTG signs, which might lead to safety issues. Besides the driving information load model, the NASA (National Aeronautics and Space Administration) Task Load Index might be beneficial in conducting the workload assessment.
- In addition to laboratory experiments, selecting a typical MTG for a field test is possible with the support of TxDOT. For example, researchers install Toyota

Center signs on adjacent freeways in downtown Houston, use video cameras to record traffic data, and carry out a before-after analysis.

- The efforts of this research and future work should contribute to guidelines for MTG guide signs, as a supplement to the TMUTCD. The guidelines should contain the MTG criteria for judging the application of MTG signing, sign standards for designing, installing, and maintaining appropriate signs to direct drivers efficiently, etc.
- Therefore, further testing is recommended using more symbols and scenarios on selected MTGs as pilot studies, together with a more comprehensive evaluation of the impacts on drivers' workload, travel time, and safety. The research efforts in this project, together with the corresponding future work, will yield guidelines for MTG guide signing for Texas as a supplement to the TMUTCD.

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APPENDIX A
ENGINEER SURVEY FORM

SURVEY ON SYMBOLS AND WARRANTS FOR MAJOR TRAFFIC GENERATOR GUIDE SIGNING

Department of Transportation Studies at Texas Southern University

QUESTIONNAIRE

Background: Texas Southern University (TSU) is conducting Research Project 0-5800 for the Texas Department of Transportation on engineering practices in identifying symbols and warrants for major traffic generators (MTGs). The objective of this survey is to collect information on sign design and the eligibility criteria for MTGs.

Please respond to all of the following questions for your opinion and assume you are providing the information for a standard maker. This survey is for research purposes only. The results of this research could possibly provide a reference for the guidance on MTG guide signs in Texas. It will take you about 30 minutes to finish all of the questions. Your response is highly appreciated.

Your background information

First Name ☐ Last Name ☐

Title ☐

Organization ☐

Nature of work ○ Researcher ○ Engineer ○ Executive

○ Other(s) (Please specify) ☐

Address Line 1 ☐

Address Line 2

City State Zip

Telephone Fax

Email

PART 1 On Sign Design

1. Have you ever used symbol signs for traffic generators in your district?

Yes No

If yes, the symbols are: (multiple choice)

Standard symbols found in the MUTCD

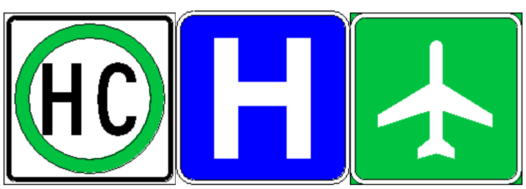
Standard symbols found in

(Please specify)

Designed by yourself

2. Symbol sign plaques

Guide Sign Routing Plaque Examples



ER14-1 FD 9-2 F 1-5

(Source: Freeway Signing Handbook 3-20, TxDOT, 02/2008)

2-1. Can symbol signs effectively help unfamiliar motorists navigate a regional freeway system to its major traffic generators (MTGs) if these MTG signs are installed as guide sign routing plaques?

Yes No

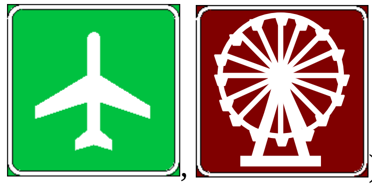
2-2. Which forms of symbol can be designed for MTG symbol plaques?

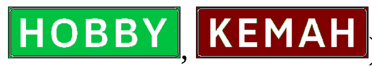
A uniform symbol for all MTGs

Category-oriented symbols according to the classification of MTG

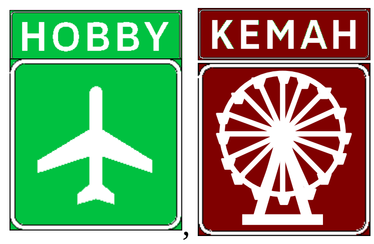
Specific symbols for each MTG

2-3. Which would be the most effective legend design of MTG symbol plaques?

Symbol only (e.g., )

Text only (e.g., 

)

Symbol and top text (e.g., 

)

Symbol and bottom text (e.g., 

)

2-4. Which would be the most effective text for MTG plaques?

Letters "MTG" Letters "Attractions" MTG category

Name of each MTG Abbreviation of each MTG Other(s)

2-5. Which would be the most effective text form?

UPPERCASE LETTERS (e.g., 

)

lowercase letters (e.g., 

)

Title Case Letters (e.g., 

)

2-6. Which would be the most effective text style in your area?

Clearview 4W   Clearview 5WR   Series E (Modified)   Other(s)

2-7. What is the minimum text size (inches) of this type of sign?

4   6   8   10   12   15   16   Other(s)

2-8. Do you agree the size of MTG symbol plaques should be the same as that for airports, hospital, etc.?

Yes   No

2-9. MUTCD Section 2H.05 guides that recreation and cultural interest area symbol signs should be 30×30 inches when used on freeways and should be enlarged in 6-inch increments. What are the minimum dimensions of the symbol sign plaques for major traffic generators (MTGs) on freeways you prefer? (Height × Width)

Minimum: inches × inches

2-10. Do you agree the placement for MTG symbol signs is at the top of parent guide signs, like airport and hospital guide sign routing plaques?

Yes   No

2-11. Which of the following signs at freeway interchanges should the MTG symbol sign be placed on? (multiple choice)

Advance guide signs   Exit directional signs   Exit gore signs   Other(s)

2-12. Which color do you prefer as the background of symbol plaques for MTGs at the top of a parent guide sign?

Green   Brown   Blue   Other(s)

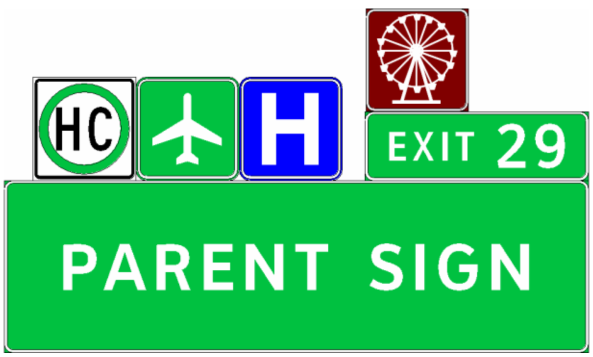
2-13. Which color do you prefer as the background of text plaques for MTGs at the top of a parent guide sign?

Green   Brown   Blue   Other(s)

2-14. How many plaques could be attached to an overhead freeway guide sign without overloading the motorists' comprehension level?

0 1 2 3 4 More than 5 (specify ______)

2-15. If a parent sign includes an exit number panel and other types of routing plaques, how many plaques could be attached to an overhead freeway guide sign without overloading the motorists' comprehension level?



0 1 2 3 4 More than 5 (specify ______)

2-16. If space is limited or drivers' workload is too high, please evaluate the priority for placing each type of routing plaque on top of overhead freeway guide signs, 1 representing the lowest priority and 4 representing the highest priority.

______ Hazardous cargo (e.g., 

)

______ General service signs (e.g., 

)

______ Exit number panels (e.g., 

)

MTG symbol plaques (e.g., )

No priority, based on application order

3. Trailblazing signs

3-1. Is a trailblazing sign necessary for MTGs?

Yes No

(If your answer is yes, please answer the following questions; if your answer is no, please skip to question 4.)

3-2. What is the maximum number of trailblazing signs provided for each MTG along one approach?

0 1 2 3 4 More than 5 (specify)

3-3. What is the maximum radius of an MTG the trailblazing signs may be provided within?

5 miles 10 miles 15miles 20miles Other(s)

4. Which type of sign should be used on freeways for major traffic generators? (multiple choice)

Symbol sign plaques

Supplemental guide signs

Specific service (logo) signs

Tourist-oriented directional signs

Recreational and cultural interest area signs

5. Please specify any manuals, guidelines, reports, etc. on MTG symbol signing.

I have additional information. Please contact me via email later.

6. Please specify any suggestions or comments about MTG signing.

PART 2 On Major Traffic Generators (MTGs)

1. Does your agency have criteria or guidance for MTGs?

Yes No

(If you answer "Yes," please answer the following sub-questions. Otherwise, please skip to question 2.)

1-1. What is the definition of an MTG in your area?

1-2. What are the criteria of MTGs in your area?

1-3. Which of the following parts could be potential major traffic generators in Texas? (multiple choice)

Arena Auditorium Stadium

☐ State and national parks ☐ Fairgrounds ☐ Amusement park
☐ Zoo ☐ Convention hall ☐ Civic center
☐ Amphitheater ☐ Other(s) ____

2. Have you ever been involved in developing the criteria for MTGs?

○ Yes ○ No

(If not, please suggest a person or persons who may have this type of experience, and then skip to question 3.)

Name(s) ____ **Contact(s)** ____

2-1. Which methods did you use to develop the criteria for MTGs? (multiple choice)

☐ Discussion and meeting with experts
☐ Based on the existing MTG criteria of other states
☐ Based on survey of other states
☐ Others. Please list the method.
____

○ I have additional information. Please contact me via email later.

2-2. What is the design procedure for developing MTG criteria you have used?

3. Please list any manual(s) about MTG criteria that you know of.

4. Is it necessary to allocate a quota of MTGs for each city?

○ Yes ○ No

5. Some of the following factors may be considered for identifying the criteria of MTGs. Please evaluate the importance of each one, with 0 representing unimportant, 1 the least important impact, and 10 the most important impact.

Factors	Population division	Trip generation per event	Parking space	Distance from highway	Minimum annual attendance	Number of events per year	Road type (freeways or conventional highways)	Other(s) please specify
Importance (0-10)								

5-1. Population division

The TMUTCD defines city population into four ranges (TMUTCD Table 2H-2):

(1) over 250,000 (2) 50,000~250,000 (3)15,000~50,000 (4) under 15,000.

Which kind of population division do you prefer in order to synthesize the eligibility criteria of MTGs for Texas? (If you choose the second option, please click "1 category.")

4 category **1 category**

5-2. Parking space

The TMUTCD defines the minimum parking space for different types of generators as follows:

TMUTCD Table 2H-2

Population	>250,000	50,000~250,000	15,000~50,000	<15,000
College	500	400	200	100
Parking, Park and Ride Terminal, and Rail Terminal Facilities	200	100	100	100

Please choose the minimum parking space as potential MTG criteria for Texas, and fill in Table 5-2.

Minimum parking space for identifying MTG criteria for four population ranges

	Major Metropolitan	Urban	Suburban	Rural
Major Traffic Generator	○ 1000 ○ 1100 ○ 1200 ○ 1300 ○ Other ☐	○ 800 ○ 900 ○ 1000 ○ 1100 ○ Other ☐	○ 600 ○ 700 ○ 800 ○ 900 ○ Other ☐	○ 400 ○ 500 ○ 600 ○ 700 ○ Other ☐

5-3. Distance from highway

The TMUTCD defines the distance (miles) from highway based on different generators and population ranges:

TMUTCD Table 2H-2

	Major Metropolitan	Urban	Suburban	Rural
College	3	4	5	5
Airport	5	8	10	10
Recreational area	5	5	5	5
Government facilities	0.5	1	1	2

Please choose the minimum distance from the highway as potential MTG criteria for Texas, and fill in Table 5-3.

Minimum distance from the highway for identifying MTG criteria for four population ranges

	Major Metropolitan	Urban	Suburban	Rural
Major Traffic Generators	○ 8 ○ 5 ○ 3 ○ 2 ○ Other ☐	○ 10 ○ 8 ○ 5 ○ 2 ○ Other ☐	○ 10 ○ 8 ○ 5 ○ 3 ○ Other ☐	○ 10 ○ 8 ○ 5 ○ 3 ○ Other ☐

5-4. Minimum annual attendance

The TMUTCD defines the minimum annual attendance based on different generators, road types, and population:

	Major	Urban	Suburban	Rural

	Metropolitan			
Recreational area on conventional highway	100,000	50,000	25,000	10,000
Recreational area on freeway	300,000	250,000	100,000	50,000

Please choose the minimum annual attendance as potential MTG criteria for Texas, and fill in Table 5-4.

Minimum annual attendance for identifying MTG criteria for four population ranges

	Major Metropolitan	Urban	Suburban	Rural
Major Traffic Generators	200,000 300,000 400,000 450,000 Other	150,000 200,000 250,000 300,000 Other	100,000 150,000 200,000 250,000 Other	50,000 100,000 135,000 150,000 Other

5-5. Number of events per year

Please choose the minimum events per year as potential MTG criteria for Texas.

Major Metropolitan	Urban	Suburban	Rural
20	15	12	Over 10
15	12	10	Over 8
12	10	8	Over 5
10	8	5	Over 3
Other	Other	Other	Other

6. Please evaluate the importance of the following indices on their impact on transportation systems, with 0 representing no impact, 1 the least important impact, and 10 the most important impact.

Index	V/C Ratio	Travel Time	Average Speed	Average Stop	Total Delay	Stop Delay	Fuel	HC	CO	NOx	Crash
Importance											

7. Any additional comments and suggestions.

APPENDIX B
LIST OF ENGINEER RESPONDENTS

No.	Responder's Name	Title	Organization
1	Aaron Weatherholt	Engineer of Traffic Operations	Illinois DOT
2	Charlie Wicker	Engineer Technician	TxDOT
3	Christopher Freeman, P.E.	Director of Transportation Operations	TxDOT Amarillo District
4	David Barol	Transportation Engineer	TxDOT
5	David Partee	Principal Traffic Engineer	Nevada DOT
6	Donald Howe	Senior Transportation Engineer	California DOT
7	Jesus Leal	Director of Transportation Operations	TxDOT
8	Kelli Williams	District Traffic Engineer	TxDOT
9	Ken Nakao	Professional Engineer I	Colorado DOT
10	Larry Colclasure	Director of Transportation Operations	TxDOT
11	Mark Bott	Operation Engineer	Michigan DOT
12	Michael Tugwell	State Traffic Engineer	Tennessee DOT
13	Michael Weiss	Signing Engineer	Minnesota DOT
14	Robert Fay	Asst. State Traffic Engineer	Massachusetts Highway Department
15	Tim Crouch	State Traffic Engineer	Iowa DOT
16	Tony Sullivan	Asst. State Maintenance Engineer	Arkansas Highway and Transportation Department
17	Wes Dean	State Traffic Engineer	Mississippi DOT

APPENDIC C
MTG SURVEY FORM

Texas Southern University
Department of Transportation Studies

You have been selected to be one of the potential candidates for major traffic generators (MTGs), which attract a significant volume of motorists. We are interested in your opinion about the need for setting up your guide signs on freeways. The survey is a part of Research Project 0-5800 for the Texas Department of Transportation (TxDOT) to identify symbols and warrants for major traffic generators. It is for research purposes only. The results of this survey could help better communicate with motorists going to your facility and guide customers to your site efficiently.

It would be highly appreciated if you could finish the survey by Tuesday, June 24, 2008. If anyone else is interested in this topic, please forward it to them. The following survey will take you about 5 minutes to complete. (Please type "A" next to your choice.)

Major Traffic Generator (MTG) Survey

1. Would you like to install guide signs for your facility to inform motorists along freeways?
______Yes
______ No

2. Would you like to pay all the costs of your guide signs?
______Yes
______ No

3. If classifying MTGs, which category does your facility fall into?
______ Amusement park
______ National or state park
______ Stadium
______ Zoo
______ Other, please specify:___________________

4. Which background color for guide signs do you like?
______ Green
______ Blue
______ Brown

5. Would you like to display a symbol on your guide sign?
______Yes
______ No

6. Which form of symbol would you like to display?
______A uniform symbol for all MTGs
______A category-oriented symbol according to the classification of MTG
______A specific symbol for your facility

7. Do you think the symbol will be helpful to direct motorists to your site?
______Yes
______ No

8. Which elements should be displayed on your guide signs?
______The name of your facility
______Distance information
______Action information (e.g., “EXIT 133A,” “NEXT RIGHT,” etc.)
______A symbol
______An arrow
______Other, please specify:__________________

9. Which kind of guide sign would you want to use at the freeway interchange approaching your site?
______Two or three small guide signs
______One large guide sign

10. Where would you like to install your guide signs in each direction along freeways?
______At the nearest freeway exit only
______At the nearest freeway exit and other places, please specify:__________________

11. Do you have any comments on the guide signs for MTGs that you would like to make?
____

12. Please tell us the basic information on your facility.
1) Parking space (vehicles):
_____<1000, ______1000-1100, _____1100-1200, _____1200-1300, _____>1300
2) Number of events per year:
______<10, ______10-12, ______12-15, ______15-20, _____>20

3) Event attendance (persons):
______<200,000, ______200,000-300,000, ______300,000-400,000,
______400,000-450,000, ______>450,000
4) Distance from the nearest freeway exit (miles):
______ <2, ______2-3, ______3-5, ______5-8, ______>8

We value your opinion and invite you to complete and email this survey to wangh@tsu.edu. Your response is highly appreciated.

If you have any problem, please feel free to contact:

Fengxiang Qiao, Ph.D.
Assistant Professor
Department of Transportation Studies
Texas Southern University
3100 Cleburne Street
Houston, TX 77004
Tel: (713) 313-1915
Fax: (713) 313-1856

APPENDIX D
LIST OF MTG RESPONDENTS

No.	Responder's Name	Title	Organization
1	Cris Garthe	Manager	Toyota Center
2	Darren Hill		Schlitterbahn, New Braunfels
3	Eric Heacock	Vice President Business Development	Sam Houston Race Park
4	Mike Bigelow		Schlitterbahn Waterpark, South Padre Island

APPENDIX E
MOTORIST SURVEY

Motorists Survey Instrument for Robertson Stadium at the University of Houston

FREEWAY GUIDE SIGN QUESTIONNAIRE

<u>Background:</u> Texas Southern University (TSU) is conducting Research Project 0-5800 for the Texas Department of Transportation to identify symbols and warrants for major traffic generators (MTGs). This survey is for research purposes only. It will take you about 2 minutes to finish all of the questions. Your response is highly appreciated.

Gender: A. Male B. Female
Age: A. Under 18 B. 18-25 C. 26-35 D. 36-45 E. 46-65 F. Over 65
Years of driving experience: ______ Year(s)
Level of education: A. Middle school B. High school C. College D. Other __________
Zip code: __________

1. **How many times have you ever been to the University of Houston (UH) Robertson Stadium?**
   A. 1 B. 2-5 C. More than 5

2. **It is easy to find UH Robertson Stadium based on existing freeway guide signs.**
   A. Strongly Agree B. Agree C. Neutral D. Disagree E. Strongly Disagree

3. **You find Robertson Stadium basically based on the information provided by: (multiple choice)**
   A. GPS B. Online map C. Experience D. Guide signs
   E. Others____________

4. **The guide signs for UH are well designed and easy to understand.**
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

5. **The guide signs for UH are well placed and easy to follow.**
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

6. **The quantity of guide signs for UH is not enough**.
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

7. Do you think it is necessary to place specific signs on freeways for major traffic generators such as UH Robertson Stadium, the Toyota Center, etc.?
A. Yes B. No

7.1. If yes, what information would you want these specific signs to provide? (multiple choice)
A. The name of destinations
B. A symbol
C. Distance information
D. Action information (such as "Exit")
E. An arrow
F. Other(s) ___________________________

7.2. Which background color for guide signs do you prefer?
A. Green B. Blue C. Brown

8. Based on your experience in Texas, which major traffic generators have the <u>best</u> guide signs? Please specify (such as the Toyota Center, Sea World, etc.).

____

9. For "the best" you mean:
A. Best sign design B. Best sign position
C. Adequate number of signs D. Others_____

10. Have you ever gotten lost in Texas on freeways when you tried to reach a major traffic generator? A. Yes B. No

10.1. If yes, where was your destination? Please specify.

10.2. If yes, what was the reason(s)? (multiple choice)
A. There was no specific guide sign.
B. Not enough guide signs.
C. The guide signs could not be seen clearly.
D. The signs were confusing and difficult to understand.
E. Not enough time to make lane change.
F. Too many signs.
G. Other(s), please specify:_______________

Motorists Survey Instrument for Toyota Center

QUESTIONNAIRE

Background: Texas Southern University (TSU) is conducting a research project for the Texas Department of Transportation to identify symbols and warrants for major traffic generators (MTGs). This survey is for research purposes only. It will take you about 2 minutes to finish.

Gender: A. Male B. Female
Age: A. Under 18 B. 18-25 C. 26-35 D. 36-45 E. 46-65 F. Over 65
Years of driving experience: ______ Year(s)
Level of education: A. Middle school B. High school C. College D. Other __________
Zip code: __________

1. **How many times have you ever been to the Toyota Center?**
   A. 1 B. 2-5 C. More than 5

2. **It is easy to find the Toyota Center based on existing freeway guide signs.**
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

3. **You find the Toyota Center basically based on the information provided by: (multiple choice)**
   A. GPS B. Online map C. Experience D. Guide signs
   E. Others__________________

4. **The guide signs for the Toyota Center are well designed and easy to understand.**
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

5. **The guide signs for the Toyota Center are well placed and easy to follow.**
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

6. **The quantity of guide signs for the Toyota Center is not enough**.
   A. Strongly agree B. Agree C. Neutral D. Disagree E. Strongly disagree

7. **Do you think it is necessary to place specific signs on freeways for major traffic generators such as the Toyota Center?**
   A. Yes B. No

   7.1. If yes, what information do you want these specific signs to provide? (multiple choice)
   a. The name of destinations
   b. A symbol
   c. Distance information
   d. Action information (such as "Exit")
   e. An arrow
   f. Other(s) __________________

7.2. Which background color of guide signs do you prefer?
A. Green B. Blue C. Brown

8. What's the best factor about the guide signs of the Toyota Center?
A. Design B. Position C. Adequate number of signs D. Others_______

9. Have you ever gotten lost when trying to reach the Toyota Center?
A. Yes B. No

9.1. If yes, what was the reason(s)? (multiple choice)
A. There was no specific guide sign.
B. Not enough guide signs.
C. The guide signs could not be seen clearly.
D. The signs were confusing and difficult to understand.
E. Not enough time to make lane change.
F. Too many signs.
G. Other(s), please specify_________________

Thanks!