FIRST RESPONDERS AND CRISIS MAP SYMBOLS: MAKING COMMUNICATION CLEARER

A Thesis in

Geography

by

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ABSTRACT

During the initial hours of a disaster, first responders enter chaotic, devastated areas to assess the situation and report multiple events to their command stations. After the tragedies of 9/11 in New York City, the Federal Geographic Data Committee (FGDC) Homeland Security Working Group (HSWG) proposed universal map symbols for use by all levels of emergency personnel. In 2006, the symbol set became an American National Standards Institute (ANSI) standard. For map use in a crisis situation, map elements have to be easily understood and interpreted at a glance. Therefore, universal symbol sets, especially ones that are meant to assist first responders in rescue efforts, should go through rigorous testing and evaluation methods.

This study explores how human factors research and testing methods can be used by cartographers to improve the design and comprehension of pictorial map symbols. Using the ANSI recommended open-ended testing method; this study examines the comprehension level of the proposed FGDC HSWG Emergency and Hazard Management Mapping Standards point symbology. Open-ended testing was conducted with 50 firefighters in California using 15 symbols from the Incidents category and 13 symbols from the Operations category. The results of this research show that 22 of the 28 symbols tested did not achieve the 85% comprehension level necessary. This research also shows that the greater the ambiguity inherent in a symbolic representation of some real world event, the greater the variation in responses, the lower the comprehension score, and the greater the likelihood that decision making processes will be affected during emergency situations.
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Chapter 1

INTRODUCTION

Fires, floods, hurricanes, tsunamis, landslides, earthquakes, terrorism, shootings, bombings…the list goes on and on. These extreme episodes have become memorable events in our lives and seem to be the top news headlines with increasing frequency. Consider the responsibilities of emergency response personnel in these situations and the tasks with which they are faced. Thrown into uncertain and often unimaginable conditions, emergency responders confront many challenges in rescue efforts.

Spatial information during these events is a critical component of rescue efforts. First responders are called in from locations near and far to collaborate with local emergency personnel during such disasters and common means of map symbol communication do not exist. This was especially evident during the events in New York City on September 11, 2001. The Emergency Operations Center which housed GIS systems was in a building that collapsed and lost all capabilities for several hours until a back-up location was established at Hunter College (Cutter, 2003; Kevany, 2003). During this time, first responders began creating their own map symbols to communicate to their command stations the events that were taking place at their locations (Galloway, 2003). It was at this time that the emergency management community realized there was great need for universal emergency symbols that could be used by federal, state and local agencies to mitigate the problems associated with symbol misinterpretation on maps (Dymon, 2003).
The need for a universal emergency symbol standard is apparent when considering mapping practices during an emergency situation. When an event occurs, federal, state and local units of emergency responders gather spatial data about the situation and display the information on maps (Symbology Subgroup, 2005). These maps are known as crisis maps and are “…often generated during an event and need to be interpreted quickly under pressure” (Dymon, 2003, p. 228). Recognizing the importance of spatial information during emergency situations, the Federal Geographic Data Committee (FGDC) Homeland Security Working Group (HSWG) was asked to develop a set of standard symbols to be used by emergency personnel during a disaster event (Dymon, 2004). The Emergency and Hazard Management Mapping Standard – Point Symbology was submitted to and accepted by the American National Standards Institute (ANSI) in 2006.

In the proposal submitted to ANSI by FGDC HSWG, the following rationale is given in relation to the need for such a standard and the impact on existing or potential markets:

3.2. Existing Practice and Need for a Standard
Frequently maps of the same situation produced by different agencies depict the information using different symbols. The loss in time and possible error involved when comparing and using differently symbolized information can and has hampered emergency response and placed lives and property in jeopardy. Establishment of Emergency and Hazard Management Mapping Standard – Point Symbology will significantly improve emergency response and facilitate providing critical government services among 87,000 government entities in the United States.

3.3.2. Impact on Existing or Potential Markets:
This standard will have a positive impact on the overall GIS community by promoting smoother emergency response among federal, state, local, and tribal entities. The private sector (software developers and vendors) will benefit by developing tools that provide the display functionality required to implement this Standard (Symbology Subgroup, 2005).
**Research Purpose**

The main goal of the cartographer is to design effective representations of spatial information using graphic symbols. Ideally, the symbols created by the cartographer are interpreted with ease by the map user, but this is not always the case. Problems arise when the information encoded by the cartographer is not accurately decoded by the user (Blok, 1987). Further problems arise when the map user is unable to spend time referring to a legend during the map reading process, especially when the map is being used in an emergency situation where events are unpredictable and response time is critical.

To date, research has not been conducted to assess the comprehension and usability of the proposed FGDC HSWG Emergency and Hazard Management Mapping Standard – Point Symbology. One of the work plan items outlined by the FGDC HSWG Symbology Subgroup is to standardize criteria for evaluating the current symbol set (Pers. Comm. Bob Phillips, May 2008). With that goal in mind, this research explores how human factors testing methods can be used by cartographers to improve the design, effectiveness and comprehension of pictorial symbol sets. In particular, this study examines the comprehension level of the proposed FGDC HSWG Emergency and Hazard Management Mapping Standard – Point Symbology for use by emergency personnel and first responders using the American National Standards Institute (ANSI) recommended open-ended testing method (Wolff and Wolgalter, 1998).

In order to test the comprehension level of a subset of the FGDC HSWG symbols from the Incidents and Operations categories, an open-ended test was designed and administered to 50 firefighters in California and the responses were judged by two firefighters in Pennsylvania. The major goals of this study were to evaluate the
comprehension level for a subset of the FGDC HSWG symbols as well as to assess
whether or not the open-ended testing method can be used to measure the comprehension
of pictorial map symbols.

Background

FGDC HSWG Symbology Subgroup Design Methodology

The methodology for creating the FGDC HSWG point symbol standard was a three
step process conducted by Dr. Ute Dymon of Kent State University over the period of 12
months. The initial work was funded by the Federal Emergency Management Agency
(FEMA) through the Michael J. Baker Corporation. The first step in creating the symbol
standard was to identify existing point emergency and hazard map symbols used by
international organizations, federal, state and local agencies (Dymon, 2003). The second
step of the process included developing a matrix to:

1. identify the hazards and emergency information for which symbology was used
2. to identify the agencies that currently use hazard and emergency symbology
3. to identify hazard and emergency symbology embedded in commercial software
   (Dymon, 2003, p. 229).

Once the matrix had been developed to identify the range of symbology used by
various organizations and commercial software packages, the third step was to identify
“symbology schemes and groupings” (Dymon, 2003, p. 229). Based on the results, the
Symbology Subgroup then decided on the four most common categories. The symbols
from the matrix were then redrawn and categorized under one of the categories.

The Hazard Management Mapping Standard – Point Symbology was developed for
use by emergency management and first responder communities at all levels of need
including national, state, local and incident (Dymon, 2004). Symbols were created for
Incidents, Natural Events, Operations and Infrastructure. The following definitions are given for each category:

- **Incidents**: cause of action or source of disaster (49 total symbols)
- **Natural Events**: phenomenon created by naturally occurring conditions (25 total symbols)
- **Infrastructure**: the basic facilities, services and installations needed for the functioning of a community (85 total symbols)
- **Operations**: capabilities or resources available during or implemented due to an emergency (44 total symbols)

In addition, symbols include a graphical category structure (symbols of different categories are delineated by shape and/or fill) to visually distinguish symbols between the four categories as well as within categories. Symbols within the Infrastructure and Operations categories also contain a damage/operational status hierarchy (delineated by frame type and/or color) (Figures 1a and 1b). The symbols utilize True Type Fonts, have been designed for use on large and medium map scales, and are reproducible in black and white.
Incident Command System (ICS) Symbology

The symbology that is most familiar to and currently used by a majority of firefighters is the Incident Command System (ICS) symbology. This symbology was developed by the National Wildland Fire Coordinating Group (NWCG). The NWCG is made up of the USDA Forest Service, Bureau of Land Management (BLM), National Park Service (NPS), Bureau of Indian Affairs (BIA), the Fish and Wildlife Services (FWS), and state forestry agencies through the National Association of State Foresters (NWCG, 2008). The purpose of NWCG is “to coordinate programs of the participating wildfire management agencies so as to avoid wasteful duplication and to provide a means of constructively working together” (NWCG). ICS has a standardized, color-coded symbol set with which firefighters and other agency personnel are familiar. Figure 2 shows the ICS symbology and their associated
colors and definitions. If one had to classify the ICS symbology into one of the three point symbol categories (geometric, associative and pictorial) (Dent, 1999), it is clear that the ICS symbology is primarily geometric with a few exceptions. For example, the symbol for First Aid Station can be considered associative as it uses a cross-like symbol to represent the location of this facility. While speaking with Chief Tom O’Keefe at CalFire (March, 2008) as well as Chief Jeff Zolfarelli at Livermore-Pleasanton Fire (December, 2007), it became apparent why the ICS point symbols are geometric. Many times, firefighters responding to incidents hand draw the events that are taking place on paper maps. For example, CalFire uses United States Geologic Survey (USGS) 1:24,000 topographic sheets for mapping incidents. While interviewing Chief O’Keefe, he showed me how he uses the map to show what resources are allocated, which direction the fire is spreading and where potential evacuations should take place. This was all done with a pencil and a USGS topographic sheet. One of the main advantages of the ICS symbol set is that they are easily memorized and can be reproduced with little effort by hand. Figure 3 compares eight ICS symbol representations with the same FGDC HSWG representations. It is highly unlikely that even a skilled artist would be able to easily replicate the pictorial symbols that are available in the FGDC HSWG symbol set, let alone a firefighter who has been fighting a fire or responding to some other incident and who has had little sleep for over a 24 hour period.
Figure 2: Incident Command System (ICS) symbology. Source: NWCG.gov.

Figure 3: A comparison of eight ICS and FGDC HSWG symbols.
**Overview**

In order for the FGDC HSWG symbol set to be considered effective from the map reader’s perspective, individual symbols must go through some type of comprehension testing on maps with the end user group. The detailed FGDC HSWG symbols must have excellent performance on maps to warrant adoption in place of symbology that is currently used by and familiar to firefighters. The detailed symbols must also be able to be comprehended without the use of an extensive legend. The initial assumption of this study is that all symbols that are pictorial and bear a strong resemblance to their referent will be the symbols that pass the comprehension test.

This thesis describes the process behind testing and evaluating a subset of the FGDC HSWG symbols. Chapter 2 begins with a general overview of cartographic design, previous studies carried out on point symbol design and evaluation, how the FGDC HSWG symbols were initially tested and why using the ANSI open-ended comprehension test is a good choice for this symbol set. Chapter 3 gives an overview of the experiment design and methodology, followed by results and discussion in Chapters 4 and 5 respectively. The thesis wraps up with conclusions and future work.
Chapter 2

LITERATURE REVIEW AND BACKGROUND

The first section of this chapter outlines the general rules and guidelines that cartographers follow while designing maps and symbols as well as the factors that influence those design decisions. I then evaluate previous research carried out on pictorial symbol design and comprehension testing, followed by a description and evaluation of the initial FGDC HSWG Symbology Subgroup testing method. Finally, the ANSI Z535.3 Standard for Safety Signs and Symbols is introduced with a description of how this testing method can be modified to fit a mapping context.

General Guidelines

Cartographic Design

Cartographic design has two fundamental goals: 1) “to serve the purpose of the map based on its intended audience and use, and 2) to communicate the map’s information in the most efficient manner, with simplicity and clarity” (Slocum et al., 2005, p. 226). Map symbols are the vehicle by which effective communication of geographic information is conveyed to the end user and it is important to understand the processes that inform map symbol design decisions.

Map Reading

Semiologist Jacques Bertin (1983) makes an important distinction between the map-viewing and map-reading processes. He states that cartographers create some maps to be seen and some maps to be read. A map that is seen gives the viewer an intuitive understanding of the overall spatial arrangement of the elements portrayed in the map
(MacEachren, 1995). For example, a map placed in a phone book next to a restaurant’s advertisement is meant to show the location of the restaurant and does not involve a complex, map-reading process. In contrast, a map to be read, for example a road map or a topographic map requires the viewer to consciously extract data in order to gain an understanding of the individual map features and their relationships to one another (MacEachren). Maps use different symbols to create a generalized representation of the real world. In order for map reading and ultimately map use to be successful, each symbol must be designed in such a way that it is distinguishable from the others.

As Arthur Robinson et al. (1995) describe, map design is similar to textual written communication. When a person attempts to communicate through written language there are guidelines that should be followed in order to make the communication process successful, such as word and letter ordering, spelling, and grammar. Similarly, a cartographer must pay close attention to design guidelines in order to produce a map that is an effective communication tool (Robinson et al.). Map and textual communication are similar in that they need to be presented in a clear manner in order to facilitate communication, but the way graphical and textual information are received by humans differs. Textual information is received “in a serial fashion: words follow each other in sequence in a definite order. But with graphics, people receive visual information synoptically: all at once, instead of a sequence. “This means that every map symbol is affected by its location and appearance relative to all the other symbols” (Nivala et al., 2005, p. 2).

One of the central questions in map reading has always been how the map is perceived and understood by the reader. A map user may not understand the content of
the map, the symbols that are used, nor the overall purpose of the map (Nivala et al., 2005). When this communication barrier exists, there is an interruption in the map reading process.

The interruption in map reading that is especially relevant to this current study is when a map user is not able to easily understand, what symbols mean on the map they are using. Cartographers usually incorporate legends in their map displays describing what the symbols are represent. When a map user has to search for the legend, and repeatedly read the definition and then relocate the original place they were looking on the map, reading is interrupted and often times this can hinder information sharing, especially during time critical situations. In such situations the use of symbology that can be interpreted intuitively, without the need of a legend, would be very beneficial.

**Choosing Appropriate Map Symbols**

There are certain processes that cartographers follow when choosing appropriate symbol types for their maps. The symbolization process relies on the ability to communicate knowledge with graphic marks. Not only to communicate it but to do it effectively, logically and coherently.

Depending on the purpose of the map, the data type and scale, different combinations of visual variables are used. Bertin (1983) identified six visual variables that ease the reading and understanding of map symbols: size, value, texture, color, orientation and shape. The variables best suited for quantitative mapping (how much of something is present at a given location) are: size, color value, color saturation and texture (Dent, 1999). The variables best suited for qualitative mapping (categorical
characteristics of geographic phenomenon) are: shape, color hue, orientation and arrangement (Dent).

Scale is a central issue in cartographic design. Scale is important because it affects the amount of detail that can be shown on a map, it has an impact on symbolization of map features, and it drives the amount of generalization that takes place. A large scale map is less generalized and shows greater detail while a small scale map is more generalized and shows less detail. Point symbols are used to represent locations such as cities (on small scale maps), line symbols are used to represent linear features such as roads, and area symbols are used to represent areal features such as lakes (Dent, 1999). Again, it is important to note that this can change with the scale of the map. For example, a river on a large scale map will most likely be represented as an areal feature whereas the same river on a small scale map will be represented as a line feature.

The final step in the symbolization process is matching symbol types to the data being mapped. The questions that arise in this phase of the design process are the spatial dimension of the data (point, line, area or volume), whether or not the data are discrete (phenomenon that occur in isolated locations) or continuous (phenomenon that occur everywhere) as well as whether the data are smooth (phenomenon that change gradually over space) or stepped (phenomenon that change abruptly or unevenly over space). Once the data have been classified into an appropriate data types, the next step is to determine the level of measurement (nominal, ordinal, interval or ratio) of the data. It is the job of the cartographer to choose the appropriate sign vehicles to communicate a clear representation of reality (Slocum et. al., 2005; Dent, 1999).
**Point Symbols**

**Point Symbol Types**

The symbols used in the FGDC HSWG symbol set are nominal discrete point symbols, and typically, three types of point symbols are used on maps for nominally encoded data: geometric, associative and pictorial. Geometric (or abstract) symbols are circles, triangles, diamonds, etc. and, due to their abstract nature, often require the use of a legend (MacEachren, 1995). Associative symbols can be considered “emblems” that are universally understood. For example, a cross symbol used to represent the location of a church or other religious facility in a Christian culture (MacEachren). Pictorial symbols are designed to look like their real-world counterpart. An example is a symbol designed to look like a gas pump on a National Park Service map. When a map user sees this symbol, they will most likely assume that this is the location of a gas station. Which symbol a cartographer chooses to use largely depends on scale (Dent, 1999). Geometric symbols are typically used on small scale maps while pictorial symbols are used more frequently on large scale maps as seen in Figures 4 and 5.

![Figure 4: A large scale National Park Service (NPS) map that uses pictorial point symbols to show the location information of areas of interest.](image-url)
Figure 5: A small scale map from Lonely Planet that uses geometric point symbols to show the location of cities.

Often times, “symbol design is fairly ad hoc -- as maps are drawn new point symbol sets are designed or existing ones are altered or copied. Unfortunately, this is often done without reference to the symbols’ suitability for the potential uses of the map or their effectiveness in use” (Morrison et al., 1995, p. 126). In order to design effective pictorial map symbols, the cartographer should determine what attributes are most representative of the phenomenon being mapped (Forrest et al., 1985). This is directly related to how well the symbol will be interpreted by the map user. The greater the symbol resembles its real world referent, the greater the likelihood that it will be quickly and easily interpreted by the map user. The iconicity of a symbol is said to be high if it is pictorial and low if it is geometric (MacEachren, 1995). If a symbol is pictorial and has high iconicity, it is likely that a legend will not be needed to aid the map user in
interpretation. But a complication does arise when a symbol’s position varies from high to low iconicity. Forrest et al. (1985) present the example of a triangle used to represent a duck versus a triangle used to represent an Egyptian pyramid. While a triangle representing a duck is considered to be a geometric symbol with low iconicity, a triangle representing a pyramid can be considered pictorial as it is directly related to its referent. As such, careful consideration should be taken by the cartographer to ensure that the point symbols designed for a particular map are closely aligned with the map purpose.

**Previous Studies on the Comprehension of Pictorial Map Symbols**

There have been many studies conducted on how map design and/or human cognitive processes affect the reading, comprehension, and usability of maps, but little research has focused on how pictorial symbol design affects these processes. Previous research on point symbol design has typically focused on the perceptual qualities of symbols (i.e., color, size, and shape) in relation to participant recognition in visual search processes.

Kilkoyne (1973; as cited in Forrest and Castner 1985), performed a series of tests evaluating pictorial and geometric map symbols. The study required introductory geography students to “count, verify or, compare the number of times individual symbols appeared on a particular map” (Forrest and Castner, p. 14). The whole test consisted of nine (count, verify or compare) tasks and the time to complete the entire test was recorded. The results of this test showed that both search times for geometric and pictorial symbols are slower when placed on a dark gray background compared to search times for the same symbols placed on a white background. It was also concluded that pictorial symbols are more accurately counted, verified or compared than geometric symbols. Similar research done by Phillips (1973; as cited in Forrest and Castner 1985)
tested visual search times for pictorial, semi-pictorial, and geometric symbols with elementary school children. The conclusions of this study also supported the idea that pictorial and semi-pictorial (or associative) point symbols perform better than geometric (or abstract) symbols in visual search tasks.

Forrest et al. (1985) claim that there are two requirements in the design of a pictorial map symbol. First, “its color or some other quality which can be processed peripherally, must contribute to its detection” and second, “it must in some way remind the reader of the object or information which it represents so as to lessen the reader’s dependence upon the legend or memory” (Forrest et al., p. 11). In this study, the authors tested point symbols used on tourist maps. Four symbol sets were tested that varied from abstract to pictorial. Three sets were pictorial, two with frame shapes and one without, and the fourth set was abstract with frame shapes. The mean search times for the three framed sets were found to be faster than the unframed set, showing statistically significant differences. Other conclusions of this study were that abstract symbols were identified fastest while unframed pictorial symbols slowest and abstract symbols cause more identification errors than pictorial symbols.

Blok (1987) measured the comprehension of point, area and line symbols used on Dutch tourist maps. The emphasis of this study was not on the perceptual qualities of the tourist symbols; instead it was focused on the meaning attached to symbols by the user. The author wanted to evaluate whether or not the meaning that was encoded by the cartographer could be decoded by the map user.

This study used a comprehension test to measure the efficiency of symbols. Thirty-seven Dutch tourist symbols were tested. Each symbol was first tested
independently on a white background. The symbols that achieved a comprehension score of 50% were considered efficient. The symbols that did not achieve this score on the first test (independently on a white background) were tested again in a map context. Answers given by participants were judged by three people and “classified into one of the following nine categories: (1) certain, (2) almost certain, (3) likely, (4) marginally likely, (5) unlikely, (6) opposite meaning, (7) wrong, (8) don’t know, (9) no response” (Blok, 1987, p. 69). Scores were based on categories 1 to 3 outlined above. Of the 37 symbols tested in this study, 14 achieved a comprehension rating of 50%. The author concluded that the meaning of symbols is clearer when placed on a map background as opposed to a white background, that pictorial symbols are clearer than abstract symbols, and that the use of signs that are familiar or use convention help the user better attach meaning to a symbol.

Clarke (1989) conducted a study to analyze the efficiency of a set of British Tourist Authority (B.T.A) symbols that were being developed to achieve standardization and uniformity for tourist maps. A symbol’s effectiveness was measured based on how well it was understood by the participants. The study used 40 participants that were tourists. Participants were first asked to fill out a questionnaire with biographical information including their age, sex, occupation, frequency of map use and education in map reading. A total of 90 symbols, placed on two different map treatments (33 symbols placed on one map and 57 placed on the second map) were tested. All of the symbols being tested were either pictorial or associative with the exception of three symbols that were geometric. This study employed ‘The Comprehension Method’ (Blok, 1987) where each participant is asked to offer meaning to each of the symbols being tested. The
method used by Blok was slightly modified with the ‘free choice’ of answers given by participants categorized into only one of the following four (as opposed to nine) categories:

1. Correct response
2. Correct associative response, although not entirely accurate
3. Incorrect response
4. No response
(Clarke, p. 107)

This modified method counted an answer correct if it falls into one of the first two categories outlined above. The author also believed that a more strict measure of 80% comprehension should be used as the criteria to determine whether a symbol is efficient in conveying its intended meaning, although this study used the same comprehension rating (50%) as the study conducted by Blok. Similar to the conclusions drawn by Blok, Clarke also concluded that symbols that are familiar (i.e. conventional signs) and symbols that hold a strong relationship to their referent are the ones that achieved higher comprehension scores. Blok and Clarke both argue that if symbol sets are to be standardized, they should first go through comprehension testing.

A more recent study was conducted by Nivala and Sarjakoski (2005) related to point of interest (PoI) pictogram symbols for mobile topographic map users. They show that one set of PoI symbols designed by Finnish and Danish cartographers were not easily interpreted by all when tested with a sample of both males and females from different age groups and nationalities through an intuitivity test. According to their study, an intuitivity test such as this one can answer some initial questions of usability including:

- Do users understand what symbols mean?
- Are they intuitive, can users understand them without explanation or legend?
(Nivala and Sarjakoski, p. 6)
The results of their intuitivity test strongly indicated that, “more consideration and research is needed in relation to the map symbol design” (Nivala and Sarjakoski, p. 8).

While the studies outlined above offer valuable insight into what perceptual qualities of pictorial symbols aid in visual search time and what characteristics make pictorial symbols easier or harder to comprehend, insight on how these effect decision making processes by the map user is limited. It is also important to note that these studies focus on tourist map symbols or symbols that can be used and interpreted at a leisurely pace. The immediate comprehension of these symbols is not a critical factor in their use situation because tourists always have the option to refer to a map legend or can stop and ask a person exactly where the feature they are looking for is located. Typically tourist symbols also represent points of interest that are static (concrete things) whereas emergency situations are always changing.

The comprehension studies done by Blok and Clarke also allow uncertain interpretations and all of the symbols were not tested in a mapping context. In Blok’s study, a symbol received a correct answer if it was certain, almost certain or likely. Clarke’s study was stricter by only considering a response correct if it was totally correct or a correct associative response. An overall comprehension score of 50% also seems to be a low threshold of acceptability when testing symbols for emergency responders because the decisions that are made based on a symbol are extremely important in this context.
Background

FGDC HSWG Symbology Subgroup Testing Method

The evaluation process for the existing FGDC HSWG symbol set, although not fully documented or published, is briefly outlined on the HSWG Symbology Reference homepage. Evaluation of the symbol set was voluntary, and several emergency personnel from various public and private agencies were contacted and invited to participate. This was an online survey that was open to public response from December 8, 2003 through January 31, 2004. Participants were asked to accept, reject or give a vote of no preference for each symbol based on its appearance and definition.

There were a total of 394 participants. Of the total, 343 people identified their occupation and are grouped within the following three categories: 45% emergency managers, 39% GIS technicians and 16% fire fighters. Of the total, 55% identify themselves as managers and the other 45% identify themselves as technical specialists. According to the FGDC HSWG website, “the data suggests that the majority of survey participants were First Responders, the target community for this project.”

Participants were also given the opportunity to comment on the overall design of the symbols, and according to the website, many of the comments received were, “critical of the design and functionality of particular symbols.” The majority of the comments suggested improving particular symbol designs to make them more useful.

Analysis was done with a Mann-Whitney statistical comparison using the results of a previously conducted (and non-documented) pilot study and the aforementioned online evaluation. It was determined that any symbol that received below a 75% overall approval rating would be reconsidered and either deleted or redesigned. Of the 214
symbols evaluated by the public, 22 symbols received less than a 75% approval rating. The symbols that did not receive an overall approval rating of more than 75% were either modified or deleted from the standard.

As previously outlined, there have been cartographic studies conducted on pictorial symbol comprehension, but these studies have typically focused on user groups that can read and interpret maps at a leisurely pace. In order to determine how effective the symbols developed by the FGDC HSWG are, the open-ended comprehension test used in human factors research is a good choice because it focuses on the comprehension of hazard warning signs and symbols.

Because there is no required comprehension testing method available for cartographers to use that has been as thoroughly researched and tested as the open-ended method in the ANSI Z535.3 standard, I recommend that we use this existing method and modify it to suit map reading. There are many advantages to using this method, especially when cartographers are designing symbol sets where the use of an extensive legend is not a feasible option as is the case with the FGDC HSWG set. First, the definitions that are given in the ANSI Z535.3 standard can be applied to cartographic symbols. Second, the open-ended testing method has been used by many researchers in both the academic and non-academic human factors community. Third, the hazard warning signs and symbols that we encounter in our everyday lives have most likely gone through this comprehension testing.

**ANSI Standard Z535.3 – Criteria for Safety Symbols**

Human factors is similar to cartography in that both areas focus on design of generalized visual representations of real world phenomenon for a particular end user
community to communicate information. Hazard related pictorial symbols that are placed on consumer products, warning signs and other materials are similar to hazard related pictorial symbols used on crisis maps. On a basic level, both categories of graphic symbols are typically pictorial in nature and need to communicate information about the hazard clearly and efficiently because misinterpretation could lead to injury or loss. These two categories of symbols also have the potential to be encountered by the end user in high pressure, high stress situations where decision making should happen instantaneously. In the context of national map symbol standardization, cartographers should adopt standards of experimental testing that are as rigorous as those used by the human factors community. Figure 6 shows three hazard alerting symbols that have gone through and passed the ANSI open-ended comprehension testing.

Figure 6: Three hazard alerting symbols that have passed open-ended comprehension testing.

In 1979, the ANSI Z53 Committee on Safety Colors and the ANSI Z35 Committee on Safety Signs and Colors (ANSI, 2002). The primary responsibility of the committee is “to develop standards for the design, application, and use of signs, colors, and symbols intended to identify and warn against specific hazards and for other accident prevention purposes” (ANSI, 2002, p. v). ANSI standard Z535.3 Criteria for Safety Symbols was a new standard created by this committee in 1991 and it has gone through revisions in 1998 and 2001.
The purpose of ANSI Standard Z535.3 is to “provide general criteria for the design, evaluation and use of safety symbols to identify and warn against specific hazards and to provide information to avoid personal injury” (ANSI, 2002, p. 1). The standard provides guidance for various stages within the design process including symbol types and colors, graphic design considerations, symbol selection criteria and suggested comprehension testing methods. All of the information contained in the standard has gone through multiple revisions through experimental research and testing. A list of references is available within the standard. For example, the “Symbol Testing Research, Procedures and Results” section of the standard is informed by 16 studies that are all targeted at empirically testing and evaluating both the open-ended comprehension and multiple choice tests that are outlined in Annex B “General Procedures for Evaluating Candidate Symbols” of the standard. There are also several hazard warning symbols recommended for use that are available in the standard and are accompanied by the references documenting who completed the comprehension testing and when. The common symbols available in this standard have passed comprehension testing by various researchers and are therefore acceptable to use.

In order to determine if the open-ended comprehension testing method is suitable in a cartographic context, it seems reasonable to compare some of the definitions in the ANSI Z535.3 standard to the intended meaning of pictorial map symbols and more specifically to the FGDC HSWG symbology standard. In the beginning pages of the standard, there are definitions given for terms used in the standard. Of those definitions the following four are especially relevant to pictorial map symbols and the FGDS HSWG symbol set.
**Image:** that portion of the safety symbol which is a graphic rendering, either abstract or representational, of the safety message

**Referent:** the message intended to be associated with the safety symbol

**Safety Symbol:** a configuration, consisting of an image, with or without a surround shape, which conveys a message without the use of words. As used in this standard, the word safety symbol includes graphic art, such as pictograms, pictorials and glyphs

**Surround Shape:** a geometric configuration around the image, which can convey additional safety information  
(ANSI, 2002, p. 1-2)

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**Open-Ended Testing**

This research study uses an open-ended testing method often used in human factors research to test the comprehensibility of pictorial hazard symbols (Wolff and Wogalter, 1998). This method has been used in several studies related to hazard warning symbols including Mayhorn et al. (2004) on homeland security safety symbols, Wolff and Wogalter (1998) on multiple common-day warning signs, and Liu et al. (2005) on intensive care unit (ICU) warning signs and symbols.

The open-ended testing method more closely recreates the cognitive processes of people when they encounter a warning sign or symbol and is also the method most recommended by ANSI (Mayhorn et al., 2004; ANSI, 2002; Wolff and Wogalter, 1998). Another form of testing that is outlined by ANSI for use in measuring symbol comprehension is the multiple choice test. A study conducted by Wolff and Wolgalter, comparing the multiple choice to open-ended testing, shows that the multiple choice lacks ‘ecological validity.’ In short, when a person encounters a hazard warning sign or symbol in a real world situation, they do not have a set of choices available to them to
determine the intended meaning. Rather, the warning sign or symbol needs to be interpreted quickly in context and convey the intended meaning to the user.

Context is an important part of the open-ended testing method. Wolff and Wogalter (1998) define context as, “information relating to the probable environments in which the symbol would appear” (p. 175). In their study, context was given in the form of photographs depicting real world environments where the hazard symbol being tested would most likely appear. In Mayhorn et al. (2004), context was given in the form of a text description to convey the situational context in which the symbol would be. In Liu et al. (2005) context was given in two forms: global and fine. In the global context, ICU symbols were shown in the general environment they could be found. In the fine context the direct application of the symbol was shown in a context “in which possibly other symbols could appear together with the symbol being tested” (p. 83). Without context, the real-world understandability of representative symbols will be hard to determine (Wolff and Wogalter).

**Summary**

The test of a good set of emergency map symbols used in a crisis situation is that they are easily understood by first responders, can help solve problems, enable responders to communicate the risk at hand clearly in either map, written and/or verbal form and ultimately aid in saving lives and resources. The evaluation method carried out by the FGDC HSWG Symbology Subgroup does not answer any of these questions. This symbol set should therefore go through a comprehension test to evaluate whether or not the symbols can be interpreted and used for decision making processes by their intended
audience. This chapter discusses comprehension tests that might serve as possibilities and why the open-ended testing method as used from ANSI standard Z535.3 is suitable.
Chapter 3

Methodology and Experiment Design

In order to test the comprehension of a subset of the FGDC HSWG symbol set, the open-ended testing method was modified to fit a map symbol context. This section describes how this was done, who the participants of the study are, and how the results of the test were judged and analyzed.

Maps Used for Testing

The first step in designing the test booklet was to define context for emergency map symbols and firefighters. A map is a logical choice for context in this testing situation. It is the environment where the symbols will appear and is where participants would encounter them in real-life rescue situations. The best way to incorporate context into this study was to use maps with which firefighters are already familiar the maps used in this testing procedure are ones that are currently used by Livermore-Pleasanton Fire Department (LPFD) and The California Department of Forestry and Fire (CalFire). In doing so, a dual purpose is served. First, the respondent did not need additional time for interpreting the map in the test booklet. Secondly, being familiar with the basemap may also help in interpreting the symbols.

Maps Used by Livermore Pleasanton Fire Department (LPFD)

‘Stick-maps,’ as LPFD firefighters call them, are simple representations of streets and residential and commercial areas with building footprints; cultural features such as fire stations, parks and hospitals; as well as property identification numbers. The entire set of maps cover the cities of Livermore and Pleasanton and are categorized and
numbered by using a map grid. For example, the map sheet that was used in this experiment is number N4155 (see Figure 7). Each edge of the map sheet has an adjacent map sheet identification number.

The map used in this study was chosen because it has commercial and residential areas, a hospital, helipad and fire station locations (Figure 7). The hospital is clearly labeled VALLEY CARE MEDICAL CENTER and within the same medical complex is a helipad that is symbolized using the Incident Command System (ICS) representation which is an upper case H with a circle frame shape. Across the street from the hospital, on the corner of West Las Positas Boulevard and Santa Rita Road is a fire station that is symbolized by a Maltese cross (which is known around the world as a symbol of fire service) with a number 3 inside referring to the fire house number.

Maps Used by California Department of Forestry and Fire (CalFire)

CalFire uses United States Geological Survey (USGS) topographic maps. The features typically represented on 1:24,000 scale topographic maps are: boundaries, buildings and related structures, contours, land survey systems, transportation (railroads, roads, highways), hydrography and vegetation. The USGS has 7.5 minute 1:24,000 topographic sheets that cover the entire United States.

The map used for testing with respondents from CalFire was a section of a 1:24,000 topographic sheet from the City of Loma Linda, in San Bernardino County, California (see Figure 8). In order to be consistent with the experiment conducted with LPFD, an area of Loma Linda was selected that had a hospital, residential area, fire station and wooded area. Unlike the larger scale ‘stick-maps’ used by LPFD, USGS topographic sheets do not have specialized fire symbology (Maltese cross, helipad, etc.)
or property numbers. Selected building locations are represented using a building footprint polygon with a black fill. In the portion of the topographic map used for this test, there are two hospitals, Loma Linda University, a civic center and a public library. In order to get higher contrast between the symbols and the basemap in the test booklet, the basemap was set to a 20% transparency level.

Figure 7: Map used for Livermore-Pleasanton Fire Department testing.
Symbols Used in Testing

Of the four categories of symbols defined in the FGDC HSWG standard, selected symbols from the Incidents and Operations categories (see Table 1) were tested. Fifteen of the 44 symbols from the Incidents category and 13 of the 48 symbols from the Operations category were selected for testing based on high relevance to fire incidents and response. In order to help firefighters’ who were not familiar with the symbol set distinguish the difference between the two categories and frame shapes, the test booklet was divided into two sections. At the beginning of each section, a page was inserted with the section number heading and a definition of the frame shape. For example, Section 1 which tested Incidents, stated, “The symbols in this section of the test are used to represent Incidents. They symbolize a cause of action or source of disaster.”
The same map was used for both sections of the test but within each section the map only displayed the subset of symbols from the category being tested. Section 1 tested the comprehension of the Incidents category and Section 2 tested the comprehension of the Operations category.

In the Incidents category, there are eight themes. Symbols that were defined in the standard as features related to the fire incidents theme, hazardous incidents theme and vehicle incidents theme were selected. Not all symbols from each theme were selected, especially from the hazardous and vehicle incident themes, but nearly all symbols were selected from the fire incidents theme. Within the Operations category, symbols were selected from the emergency medical operation theme, emergency operations theme and fire suppression operations theme. A complete list of symbols used with their accompanying definitions can be seen in Table 1 for Incidents and Table 2 for Operations.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>✷</td>
<td><strong>Flammable Solid</strong> - uncontrolled or potentially dangerous presence of desensitized explosives that when dry are explosives of Class 1 which are wetted with sufficient water, alcohol, or plasticizer to suppress explosive properties</td>
</tr>
<tr>
<td>✷</td>
<td><strong>Origin</strong> - location where the fire started</td>
</tr>
<tr>
<td>✷</td>
<td><strong>Vehicle Incident</strong> - an event involving a wheeled or tracked vehicle resulting in damage, bodily injury, death, or the disruption of transportation services</td>
</tr>
<tr>
<td>✷</td>
<td><strong>Hot Spot</strong> - an area of intensified fire activity and increased heat or a particularly active part of a fire</td>
</tr>
<tr>
<td>✷</td>
<td><strong>Smoke</strong> - the visible products of combustion rising above the fire</td>
</tr>
<tr>
<td>✷</td>
<td><strong>Civil Displaced Population</strong> - persons or groups of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, violations of human rights, or natural or human-made disasters</td>
</tr>
</tbody>
</table>
Oxidizers - uncontrolled or potentially dangerous presence of a material that may, generally by yielding oxygen, cause or enhance the combustion of other materials

Flammable Liquid - uncontrolled or potentially dangerous presence of a liquid having a flash point of not more than 60.5°C (141°F)

Flammable Gas - uncontrolled or potentially dangerous presence of any material which is a gas at 20°C or less and 101.3 kPa of pressure (14.7 psia) of pressure (a material which has a boiling point of 20°C or less at 101.3 kPa which is ignitable at 101.3 kPa (14.7 psia) when in a mixture of 13 percent or less by volume with air; or has a flammable range at 101.3 kPa (14.7 psia) with air of at least 12 percent regardless of the lower limit.

Vehicle Accident - a sudden, unexpected event involving a vehicle resulting in damage, bodily injury, death and/or the disruption of transportation services

Fire Incident - the destructive act of something burning; caused either by electrical or technological malfunction, lightning, arson, human error or human negligence

Explosive - uncontrolled or potentially dangerous presence of any substance or article, including a device, which is designed to function by explosion (i.e., an extremely rapid release of gas and heat) or which, by chemical reaction within itself, is able to function in a similar manner even if not designed to function by explosion

Wild Fire - an uncontrolled fire in a wooded area

Special Needs Fire - a fire that affects special treatment facilities, such as nursing homes or assisted living centers, resulting in partial or total destruction of the structure and/or bodily injury, smoke inhalation or death

Non-Residential Fire - a fire that originates at or affects a non-residential or commercial facility, resulting in partial damage or total destruction of the structure and/or bodily injury, smoke inhalation or death

Table 1: A complete list of the symbols and definitions for symbols tested in the Incidents category

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Emergency Teams</strong> - The locus of an emergency management team</td>
</tr>
<tr>
<td></td>
<td><strong>Emergency Operations Center</strong> - the physical location where an organization comes together during an emergency to coordinate response and recovery actions and resources and make management decisions</td>
</tr>
<tr>
<td></td>
<td><strong>Fire Suppression Operation</strong> - the extinguishing of a burning (and flaming) object by means of applying an agent, such as water</td>
</tr>
<tr>
<td></td>
<td><strong>Emergency Operation</strong> - those actions taken during the emergency period to protect life and property, care for the people affected, and temporarily restore essential community services</td>
</tr>
</tbody>
</table>
Other Water Supply Location - any source of water other than a fire hydrant that is sufficient for the purpose of fire fighting

Emergency Collection Evacuation Point - a designated place where displaced persons or victims of war or disaster are assembled and/or evacuated from

Emergency Incident Command Center - the physical location from which an incident commander manages an incident

Emergency Staging Areas - a designated place where emergency management forces, equipment, and supplies are assembled prior to engagement in operations

Fire Station - a facility housing firefighting equipment and/or personnel

Hospital - the locus of an institution where the sick or injured are given medical or surgical care

Medical Evacuation Helicopter Station - the locus of an emergency helicopter landing pad, utilized to transport severely injured persons

Emergency Medical Operation - urgent and unexpected medicinal treatment and/or transport during serious situations which require demands of immediate action

Fire Hydrant - A discharge pipe with a valve and spout from which water may be drawn from a water main in sufficient volume and at sufficient pressure for firefighting purposes

Table 2: A complete list of symbols and definitions for symbols tested in the Operations category

Symbol Size

According to the ANSI Z535.3 standard, symbol size is also an important factor in the test design. It states, “Typical size or sizes of the final symbol should be determined and those sizes used in testing” (ANSI, 2002, p. 31). In the FGDC HSWG standard, they recommend that the symbols should not be below 12 points in order to retain detail and clarity. If a user does require a smaller symbol size, the frame shape for that particular symbol category should be used.

Symbol sizes should be viewed by participants as they would be viewed in a real world situation. For the purpose of this experiment, each symbol was scaled to the size of 33 points. Any size below or above 33 points appeared either too small or too big for the test maps. Figure 9 shows some example symbols at variable sizes. You can see that
the best range to get the full detail of symbols is between 30-33 point sizes (the two largest sizes shown), especially for the more detailed representations. For each test section, symbols were placed on the map to create a fictitious scenario. Since respondents are familiar with the mapped area, ‘hypothetical situation’ was placed in small text on the bottom right hand side of the map (See Appendix A).

Figure 9: Variation in symbol sizes for both the Operations and Incident categories. From left to right point sizes are: 12, 20, 24, 30 and 33.

**Comprehension Questions**

“Collect short definitions of the meaning of each symbol from the appropriate target audience. Respondents should be asked what the symbol means and what action they would take in response to seeing the symbol. Both questions need to be asked in order to reduce the likelihood that answers are vague or difficult to interpret” (ANSI, 2002, p. 32).

Once the map, symbols and symbol size had been determined, the next step was to consider the proper wording for the two comprehension questions. The first ANSI question, “Exactly what do you think this symbol means?” was appropriate and worked well for both the incident and operations sections of the test booklet. The second question from the ANSI standard relating to the actions that would be taken in response to the symbol needed to be rephrased in order to be suitable in a firefighter, map and symbol context. Instead of asking, “What action would you take in response to this symbol?” the question was rephrased to specifically target the firefighting community and was reworded to, “What action would firefighters take in response to this symbol?”
In Section 2 of the test booklet, using the second ANSI comprehension question did not fit the symbol category. For example, if a firefighter was responding to what he/she believed to be the symbol representing the staging area for an emergency situation, the question, “What action would you/firefighters take in response to the symbol?” would not be well suited and therefore, not very useful when measuring symbol comprehension. On the other hand, if he/she were asked, “What role would this site play in firefighters’ activities?” there is a greater likelihood of getting a better understanding of what the participant thinks the symbol means. This phrasing was used in the second test section.

**Test Booklet Instructions**

The initial page of the test booklet (Appendix A) presents instructions meant to give the participants a clear understanding of what the test is and how they should take it. The instructions from the standard are typically given in verbal, not written form. Because the principle investigator was not able to administer the test in person, written instructions were attached to the front of each test booklet. The wording for the instructions page was taken directly from the model available in the ANSI standard but modified to suit a firefighter map and symbol context. Other modifications to the wording of the instructions were related to the way the information was presented in the test booklet, as described earlier in this section.

The test booklet instructions describe the contents of the test booklet, the reason for administering such a test, where the symbols are likely to be encountered, what respondents should do if they are stuck on a particular symbol, and, most importantly, that it is not the participants being tested but the symbols being tested. The instructions also stated that before beginning the test booklet respondents should first read and sign
the informed consent and retain one copy for their records and return the second signed copy with the completed test booklet.

The instructions also included directions to turn to the first and second pages of the test booklet. In order to give participants a more realistic idea of what kind of answers the test was looking for, an example of a poor and good answer were given. These two pages were titled ‘Example of a poor answer’ and ‘Example of a good answer’ and were designed to look like a standard test booklet page. The symbol representing emergency shelter was used as the example symbol and was not one of the symbols selected for testing. Participants were told in the instructions page that the good example describes the exact meaning of the symbol and what actions should be taken in response to the symbol in a clear and precise way. They were asked to do the same when answering the test booklet questions.

Participants

Participants in this study are firefighters from the Livermore-Pleasanton Fire Department (LPFD) in Alameda County, California and The California Department of Forestry and Fire in California. These choices satisfy the ANSI recommendations:

The population(s) of potential users of a symbol must be carefully determined. Any testing should use a smaller, target audience representative of the population(s). Particular attention should be given to subgroups that are anticipated to have greater comprehension problems or information needs, such as the elderly, children, illiterate, non-English speaking or disabled (ANSI, 2002, p. 31).

Participants LPFD

In order to find research participants, LPFD Deputy Fire Chief Zolfarelli was contacted. Chief Zolfarelli gave written approval for the testing to be carried out with his
firefighters during two training sessions in December 2007. LPFD is comprised of two one-hundred-year-old fire departments. The individual departments, Livermore and Pleasanton started out as volunteer departments and consolidated into one department eleven years ago that now serves both cities (Pers. Comm. Chief Zolfarelli, December 2007).

The test booklet was randomly given to fire captains, engineers, firefighters and firefighter paramedics. According to Chief Zolfarelli, the Captain is the working supervisor of the crew, the engineer drives the fire apparatus and the firefighter and firefighter paramedic are the third and fourth component of the fire crew (Pers. Comm. Chief Zolfarelli, December 2007). Although permission was given for the research test, the principle investigator was not granted permission to administer the test in person. Given these constraints, the test booklet was designed to be self explanatory.

Currently, the Livermore-Pleasanton Fire Department uses the Vigilys Tactical Operations software system for mapping fire incidents and planning related response activities. This system enables field personnel and operations centers to dynamically update situation information using a map interface and share the information through the World Wide Web in real time (http://www.systechnologies.com). The symbol set used in the Vigilys system is a blend of the ICS and FGDC HSWG sets. Because LPFD uses this technology, it is very relevant to test this symbol set with this group since they are likely to encounter the FGDC HSWG emergency symbols during response activities. It should be noted that LPFD is one of the first to pilot the Vigilys software and in the initial pilot test, only ICS symbology is used. Current and future releases of the software will have both symbol sets (Pers. Comm, Mike St. John, March 2008).
Participants – CalFire

In order to gain participation from The California Department of Forestry and Fire, Chief Tom O’Keefe of San Bernardino County, California was contacted. Meeting with and interviewing Chief O’Keefe on current mapping practices and response activities was informative. According to Chief O’Keefe, CalFire is contracts with local cities and counties. CalFire San Bernardino County for example is responsible for 25 cities, three counties, four national forests and two national parks. During peak fire season this department has six hundred firefighters. This unit is responsible for the largest geographic area in all of California. CalFire regularly works with other agencies including Forest Service, Bureau of Land Management, National Park Service, and the US Coast Guard. CalFire primarily responds to wildland fires but also respond to events such as earthquakes, floods, hazardous materials incidents, riots, events like Hurricane Katrina as well as the events of 9/11.

Seventy test booklets were created for this group and given to Chief O’Keefe. He sent the booklets to CalFire firefighters throughout the state of California. Specifically, the test booklets were mailed to members of Incident Management Teams. The participants were Incident Commanders, Deputy Incident Commanders, Operations Section Chiefs, Planning Section Chiefs, Situation Unit Leaders and Field Observers. All of the aforementioned members of an Incident Management Team are responsible for mapping incidents in some capacity. Therefore, Chief O’Keefe felt that these were the best groups to target.
Participant Biographical Information

According to the ANSI Z535.3 standard, participant biographical information should be collected in order to determine that participants meet testing criteria. Prior to test administration, it was determined that this research study would focus on the target audience of firefighters who are representative of the user population of the emergency symbol set. Therefore, biographical information was not collected. It was also determined that a participants gender, age, first language or ethnicity information would not be collected because the sample size used in this study (a total of 50 participants) is relatively small and breaking out participant groups by biographical characteristics would not show sufficient evidence. If the symbols were to be used by the general public, biographical information would be very useful, but the purpose of this study is to see if a specific user community, firefighters, can comprehend the symbol set.

Testing Procedure

The test booklet design for this experiment was in accordance with the ANSI Z535.3 standard with slight modifications for an emergency mapping, firefighter community context. After the test booklet was designed, five randomized versions of the test were made. Each section of the test was randomized separately. Random numbers were generated using the website www.random.org.

A total of fifty test booklets were prepared and delivered to LPFD on December 26, 2007 and picked up on January 2, 2008. Of the 50 test booklets, 33 were returned. Testing was administered by Chief Zolfarelli. He distributed the test booklet in his training sessions and those who wished to participate did, and those who did not wish to participate did not return the test booklets. A total of 70 test booklets were prepared and
delivered to CalFire on March 14, 2008 and were returned via the postal service the week of April 7, 2008. Chief O’Keefe prepared a letter and sent the test booklets to members of CalFire throughout the state. As with LPFD, those who wished to participate did and returned the test booklets to Chief O’Keefe.

Of the 33 test booklets returned from LPFD, only twenty-seven were used for scoring purposes. Any test booklet that was less than 75% complete was omitted from the study. Of the 70 test booklets given to Chief O’Keefe, 32 were returned and 23 were used in this study (the remaining ten were late in arriving and therefore equal numbers of test booklets were not used among the two groups).

Once all of the test booklets had been collected, each test booklet was assigned a test booklet number and each page was de-randomized. Once the sorting had been done, a spreadsheet was created for each symbol that was tested. Four pieces of information were recorded from each of the test booklet pages on the spreadsheet: the symbol being tested and its definition, the test booklet number, the participant’s response to the first comprehension question and the participant’s response to the second comprehension question.

**Judging**

Prior to administering the test and judging the results, the possible range of acceptable answers for symbol meaning must be identified (ANSI, 2002). The standard recommends having two judges who will look through participant answers and code a ‘1’ for correct responses and a ‘0’ for incorrect responses. Incorrect responses include answers that are wrong, no answer or answers that are critical confusions (when the opposite action is conveyed) (ANSI, 2002). If there is a discrepancy between judgments,
the average of the two scores (0.5) should be taken. The definitions for each of the symbols used in this experiment were taken from the FGDC HSWG website.

**Judges**

Two firefighters from Alpha Fire Company in State College, Pennsylvania were the judges for this study. One of the requirements for selecting judges (in the ANSI Z535.3 standard) is that they should not have seen the symbols prior to judging the responses. After a short introductory interview, it was clear that neither of the two judges had ever encountered the FGDC HSWG symbol set. The reason that I solicited firefighters to judge the answers of the open-ended test is because I felt that they were better suited to judge the responses properly in contrast to having judges that have no experience with firefighting activities. For example, in many of the participant’s responses, there are firefighter-specific acronyms or firefighter specific ‘lingo’ used. I also believe that having firefighters judge the responses to the open-ended test makes this study well-rounded. Two groups of firefighters took the open-ended test and firefighters evaluated their answers based on their firefighting experience and knowledge.

The two judges were given spreadsheets that had each symbol and its proper definition printed at the top of the page and each of the 50 participants’ answers to the two comprehension questions. The judges were instructed to first read the proper definition of the symbol and then carefully examine participants’ responses to the two comprehension questions to determine if the answer is correct or incorrect.
**Analysis and Criteria for Acceptance**

In order for a symbol to be accepted using the ANSI recommended open-ended testing method, it must have an 85% overall comprehension rate. The overall comprehension rate is calculated by dividing the number of correct answers by the total number of respondents. This score assumes that there are 50 participants. If another number of participants are used, the acceptance rate can be adapted to statistically equivalent levels (ANSI, 2002). Depending on the severity of the hazard and the importance of symbol comprehension, higher criteria for acceptance may be established (ANSI, 2002).

Once the judging was complete and the spreadsheets were collected, I went through the spreadsheets and coded a ‘1’ if both judges said the participant had answered correctly, ‘0’ if both judges agreed that the correct definition had not been given, and ‘0.5’ where there was disagreement between the judges’ scores (for example if one judge thought the answer was correct and the other judge thought it was incorrect). It is important to note that the second comprehension question was important in the judges’ scores. If the participant did not give the exact definition of the symbol but their actions in response to the symbol were correct, the judges considered that a correct response.

**Summary**

This section has described the open-ended testing method as outlined in the ANSI Z535.3 standard and explained how it was modified to fit a mapping context, who the test participants are, as well as how the test was administered and judged. The next section reports the results of the open-ended comprehension test.
Chapter 4

RESULTS

The results of this study show that of the 28 symbols tested, six achieved a comprehension level of 85% or greater; three symbols from the Incidents category and three symbols from the Operations category. The following section will describe the results of the open-ended testing method by reporting the range of answers given by the 50 test participants for each of the 28 symbols tested.

Incidents Symbol Category

Of the 48 symbols available in the Incidents category, 15 were tested in this study. Table 3 lists the number of correct responses and percentage correct responses per Incident symbol in ascending order. Based on the ANSI Z535.3 85% correct criterion, results based on the firefighters that participated in this study indicate that three of the symbols are effective in communicating emergency related information. The three symbols with the highest rate of comprehension that achieve the ANSI level are: “Wild Fire” (85%), “Special Needs Fire” (88%), and “Non-Residential Fire” (90%). Seven incident symbols received below 50% comprehension. The symbols that fall in this category are: “Flammable Solid” (10%), “Origin” (14%), “Vehicle Incident” (14%), “Hot Spot” (20%), “Smoke” (37%), “Civil Displaced Population” (45%), and “Oxidizers” (47%). The five symbols that achieved over 50% comprehension but less than 85% are: “Flammable Liquid” (54%), “Flammable Gas” (70%), “Vehicle Accident” (70%), “Fire Incident” (71%), and “Explosive” (72%).
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Number Correct Responses</th>
<th>Percent Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>♦</td>
<td>Flammable Solid</td>
<td>5</td>
<td>10%</td>
</tr>
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<td>♦</td>
<td>Origin</td>
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<td>14%</td>
</tr>
<tr>
<td>♦</td>
<td>Vehicle Incident</td>
<td>7</td>
<td>14%</td>
</tr>
<tr>
<td>♦</td>
<td>Hot Spot</td>
<td>10</td>
<td>20%</td>
</tr>
<tr>
<td>♦</td>
<td>Smoke</td>
<td>18.5</td>
<td>37%</td>
</tr>
<tr>
<td>♦</td>
<td>Civil Displaced Population</td>
<td>22.5</td>
<td>45%</td>
</tr>
<tr>
<td>♦</td>
<td>Oxidizers</td>
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<td>47%</td>
</tr>
<tr>
<td>♦</td>
<td>Flammable Liquid</td>
<td>27</td>
<td>54%</td>
</tr>
<tr>
<td>♦</td>
<td>Flammable Gas</td>
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<td>70%</td>
</tr>
<tr>
<td>♦</td>
<td>Vehicle Accident</td>
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<td>70%</td>
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<td>Fire Incident</td>
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<td>71%</td>
</tr>
<tr>
<td>♦</td>
<td>Explosive</td>
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<td>72%</td>
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<td>♦</td>
<td>Wild Fire</td>
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<td>85%</td>
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<tr>
<td>♦</td>
<td>Special Needs Fire</td>
<td>44</td>
<td>88%</td>
</tr>
<tr>
<td>♦</td>
<td>Non-Residential Fire</td>
<td>45</td>
<td>90%</td>
</tr>
</tbody>
</table>

Table 3: Number of correct responses and percent comprehension for each symbol tested in the Incidents category.
Participant Responses – Incidents

flammable solid

Five firefighters answered this correctly and received a score of 1 by both judges. The remaining 45 responses received a score of 0 by judges and fall into the following categories:
- 22 firefighters interpreted this symbol as flammable storage, storage on fire, warehouse on fire or a flammable box
- 4 firefighters interpreted this symbol as a structure fire
- 2 firefighters interpreted this symbol as high fuel load
- 10 firefighters responded with other definitions such as: cardboard recycling, flammable metal fire, miscellaneous fire, canyon fire, fire department storage, etc.
- 7 firefighters answered with no response or unknown

origin

Seven firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5 (where there was a discrepancy between judges scoring). The remaining 41 responses received a score of 0 by judges and fall into the following categories:
- 19 firefighters interpreted this symbol as a fire that is out or extinguished
- 6 firefighters interpreted this symbol as hazardous materials or chemical fire
- 6 firefighters interpreted this symbol as an unknown type fire
- 1 firefighter interpreted this symbol as a fire that should be allowed to burn
- 9 firefighters answered with no response or unknown
Vehicle Incident

Six firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5. The remaining 42 responses received a score of 0 by judges and fall into the following categories:

- 11 firefighters interpreted this symbol as a safe route for cars to travel
- 11 firefighters interpreted this symbol as a car or vehicle
- 7 firefighters interpreted this symbol as vehicle parking
- 7 firefighters interpreted this symbol as a traffic incident
- 5 firefighters responded with other definitions such as: police department unit, abandoned vehicle, unknown vehicle type incident but not an accident, motor pool, etc.
- 1 firefighter answered unknown

Hot Spot

Six firefighters answered this correctly and received a score of 1 by both judges. Eight firefighters received a score of 0.5. The remaining 36 responses received a score of 0 by both judges and fall into the following categories:

- 12 firefighters interpreted this symbol as a fire involving oxidizers, combustibles or chemicals
- 4 firefighters interpreted this symbol as a flammable liquid or solid
- 3 firefighters interpreted this symbol as flammable
- 4 firefighters responded with other definitions such as: a fire with a hole in it, flammable pipeline, a burnt area, etc.
- 13 firefighters responded with no response or unknown
Smoke

15 firefighters answered this correctly and received a score of 1 by both judges. Seven firefighters received a score of 0.5. The remaining 28 responses received a score of 0 by both judges and fall into the following categories:

- 23 firefighters interpreted this symbol as a fire that is producing a toxic chemical cloud
- 5 firefighters responded with other definitions such as: campfires OK, flammable gas fire, uncontrolled fire, flammable placard, etc.

Civil Displaced Population

13 firefighters answered this correctly and received a score of 1 by both judges. 19 firefighters received a score of 0.5. The remaining 18 responses received a score of 0 by both judges and fall into the following categories:

- 5 firefighters interpreted this symbol as an incident involving children
- 13 firefighters responded with other definitions such as: campground, occupants have left the building, evacuate to the west, two bodies/victims, a cabin, casualty collection area, residential area, triage area, etc.

Oxidizers

19 firefighters answered this correctly and received a score of 1 by both judges. Nine firefighters received a score of 0.5. The remaining 22 responses received a score of 0 by both judges and fall into the following categories:

- 5 firefighters interpreted this symbol as something flammable or a fire
- 3 firefighters interpreted this symbol as a tank fire
- 4 firefighters responded with other definitions such as: flammable container, hazard of unknown origin, explosive, flammable solid, etc.
- 10 firefighters answered with no response or unknown

**Flammable Liquid**

26 firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5. The remaining 22 responses received a score of 0 by both judges and fall into the following categories:

- 5 firefighters interpreted this symbol as flames that are reactive to water
- 2 firefighters interpreted this symbol as sprinklers
- 2 firefighters interpreted this symbol as a water source for firefighting
- 5 firefighters responded with other definitions such as: fire area, water infrastructure threatened by fire, natural gas fire, oil fire, tear drop, etc.
- 8 firefighters answered with no response or unknown

**Flammable Gas**

26 firefighters answered this correctly and received a score of 1 by both judges. 18 firefighters received a score of 0.5. The remaining 16 responses received a score of 0 by both judges and fall into the following categories:

- 2 firefighters interpreted this symbol as oxygen tank storage
- 1 firefighter interpreted this symbol as a fire extinguisher
- 1 firefighter interpreted this symbol as a high rise fire
- 3 firefighters answered with no response or unknown
Vehicle Accident

34 firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5. The remaining 14 responses received a score of 0 by both judges and fall into the following categories:

- 4 firefighters interpreted this symbol as a junkyard, wrecking yard or repair shop
- 4 firefighters interpreted this symbol as a broken down vehicle
- 4 firefighters responded with other definitions such as: area where car accidents occur frequently, route not safe for passenger vehicles, no vehicle accident etc.
- 2 firefighters answered with no response or unknown

Fire Incident

33 firefighters answered this correctly and received a score of 1 by both judges. Five firefighters received a score of 0.5. The remaining 12 responses received a score of 0 by both judges and fall into the following categories:

- 9 firefighters interpreted this symbol as flammable
- 2 firefighters interpreted this symbol as a high hazard area
- 1 firefighter answered with no response or unknown

Explosive

27 firefighters answered this correctly and received a score of 1 by both judges. 18 firefighters received a score of 0.5. The remaining five responses received a score of 0 by both judges and fall into the following categories:

- 4 firefighters interpreted this symbol as an explosion
- 1 firefighter interpreted this symbol as an energized electrical
Wild Fire

36 firefighters answered this correctly and received a score of 1 by both judges. 13 firefighters received a score of 0.5. One firefighter took this symbol to represent a burning Christmas tree.

Special Needs Fire

43 firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5. The remaining 5 responses received a score of 0 by both judges and fall into the following categories:

- 3 firefighters responded with other definitions such as: handicapped fire shelter, shelter in place, station with ADA compliant restrooms
- 2 firefighters answered with no response or unknown

Non-Residential Fire

42 firefighters answered this correctly and received a score of 1 by both judges. Four firefighters received a score of 0.5. The remaining 4 responses received a score of 0 by both judges and fall into the following category:

- 4 firefighters responded with other definitions such as: nuclear plant or factory, refinery fire, fabrication of flammables, multi-story complex, etc.

Operations Symbol Category

Of the 43 symbols available in the Operations category, 13 were tested in this study. Table 4 illustrates the number of correct responses and percentage correct responses per operation symbol in ascending order. Based on the ANSI Z535.3 85% correct criterion the firefighters that participated in this study believe that three of the
symbols are effective in communicating emergency related information. The three symbols with the highest rate of comprehension that achieve the ANSI level are: “Medical Evacuation Helicopter Station” (87%), “Emergency Medical Operation” (91%), and “Fire Hydrant” (100%). Seven operations symbols received below 50% comprehension. The symbols that fall in this category are: “Emergency Teams” (2%), “Emergency Operations Center” (6%), “Fire Suppression Operation” (6%), “Emergency Operation” (11%), “Other Water Supply Location” (22%), “Emergency Collection Evacuation Point” (27%), and “Emergency Incident Command Center” (36%). The three symbols that achieved over 50% comprehension but less than 85% are: “Emergency Staging Areas” (57%), “Fire Station” (71%), and “Hospital” (76%).

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Number Correct Responses</th>
<th>Percent Correct</th>
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</thead>
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<td>Emergency Teams</td>
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</tr>
<tr>
<td>🚁</td>
<td>Emergency Operations Center</td>
<td>3</td>
<td>6%</td>
</tr>
<tr>
<td>🔥</td>
<td>Fire Suppression Operation</td>
<td>3</td>
<td>6%</td>
</tr>
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<td>🚔</td>
<td>Emergency Operation</td>
<td>5.5</td>
<td>11%</td>
</tr>
<tr>
<td>🚖</td>
<td>Other Water Supply Location</td>
<td>11</td>
<td>22%</td>
</tr>
<tr>
<td>🌦️</td>
<td>Emergency Collection Evacuation Point</td>
<td>13.5</td>
<td>27%</td>
</tr>
<tr>
<td>⚠️</td>
<td>Emergency Incident Command Center</td>
<td>18</td>
<td>36%</td>
</tr>
<tr>
<td>🏥</td>
<td>Emergency Staging Areas</td>
<td>28.5</td>
<td>57%</td>
</tr>
<tr>
<td>🚔</td>
<td>Fire Station</td>
<td>35.5</td>
<td>71%</td>
</tr>
<tr>
<td>🏥</td>
<td>Hospital</td>
<td>38</td>
<td>76%</td>
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</table>
## Participant Responses – Operations

### Medical Evacuation Helicopter Station

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Correct</th>
<th>Comprehension</th>
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</thead>
<tbody>
<tr>
<td>🧵</td>
<td>Medical Evacuation Helicopter Station</td>
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<td>87%</td>
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</table>

### Emergency Medical Operation

<table>
<thead>
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<th>Symbol</th>
<th>Description</th>
<th>Correct</th>
<th>Comprehension</th>
</tr>
</thead>
<tbody>
<tr>
<td>🧵</td>
<td>Emergency Medical Operation</td>
<td>45.5</td>
<td>91%</td>
</tr>
</tbody>
</table>

### Fire Hydrant

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Correct</th>
<th>Comprehension</th>
</tr>
</thead>
<tbody>
<tr>
<td>🧵</td>
<td>Fire Hydrant</td>
<td>50</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 4: Number of correct responses and percent comprehension for each symbol tested in the Operations category.

### Emergency Teams

One firefighter answered this correctly and received a score of 1 by both judges. The remaining 49 responses received a score of 0 by the judges and fall into the following categories:

- 11 firefighters interpreted this symbol as some type of shelter facility
- 9 firefighters interpreted this symbol as restrooms for either civilians or firefighters
- 7 firefighters interpreted this symbol as an evacuation center
- 5 firefighters responded with other definitions such as: housing, staging area, caution, etc.
- 12 firefighters responded either unknown or had no response

### Emergency Operations Center

Two firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5 (where there was a discrepancy between judges scoring). The remaining 46 responses received a score of 0 by the judges and fall into the following categories:

- 15 firefighters interpreted this symbol as some type of shelter facility
- 7 firefighters interpreted this symbol as some type of house or building
- 3 firefighters interpreted this symbol as an incident base
- 21 firefighters responded either unknown or had no response

**Fire Suppression Operations**

Two firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5. The remaining 46 responses received a score of 0 by the judges and fall into the following categories:

- 25 firefighters interpreted this symbol as a fire station or command post
- 16 firefighters interpreted this symbol as firefighting personnel
- 2 firefighters interpreted this symbol as a fire helmet
- 1 firefighter interpreted this symbol as a path for fire use
- 2 firefighters had no response

**Emergency Operation**

One firefighter answered this correctly and received a score of 1 by both judges. Nine firefighters received a score of 0.5. The remaining 40 responses received a score of 0 by the judges and fall into the following categories:

- 4 firefighters interpreted this symbol as a staging area or command post
- 2 firefighters interpreted this symbol as a fire triangle
- 9 firefighters responded with other definitions such as: caution, some type of facility, route blocked, danger, etc.
- 25 firefighters responded either unknown or had no response
Other Water Supply Location

Nine firefighters answered this correctly and received a score of 1 by both judges. Four firefighters received a score of 0.5. The remaining 37 responses received a score of 0 by the judges and fall into the following categories:

- 16 firefighters interpreted this symbol as a fire hose
- 4 firefighters interpreted this symbol as a source of drinking water
- 4 firefighters interpreted this symbol as suppression activities
- 9 firefighters responded with other definitions such as: conserve water, medication distribution point, water delivery, low water pressure, building has sprinkler system
- 4 firefighters responded either unknown or had no response

Emergency Collection Evacuation Point

Eight firefighters answered this correctly and received a score of 1 by both judges. 11 firefighters received a score of 0.5. The remaining 31 responses received a score of 0 by the judges and fall into the following categories:

- 19 firefighters interpreted this symbol as an evacuation route or direction
- 4 firefighters interpreted this symbol as something involving children
- 3 firefighters interpreted this symbol as an evacuation in progress
- 1 firefighter interpreted this symbol as a triage location
- 4 firefighters responded either unknown or had no response
Emergency Incident Command Center

18 firefighters answered this correctly and received a score of 1 by both judges. The remaining 32 responses received a score of 0 by the judges and fall into the following categories:

- 4 firefighters interpreted this symbol as an incident base
- 4 firefighters interpreted this symbol as something water related (for example, scuba diving)
- 19 firefighters responded either unknown or had no response
- 5 firefighters responded with other definitions such as: check point, road block, person down, caution etc.

Emergency Staging Areas

23 firefighters answered this correctly and received a score of 1 by both judges. 11 firefighters received a score of 0.5. The remaining 16 responses received a score of 0 by the judges and fall into the following categories:

- 9 firefighters interpreted this symbol as some sort of storage or warehouse
- 5 firefighters responded with other definitions such as: drop point, distribution center, vehicle bay, etc.
- 2 firefighters responded either unknown or had no response

Fire Station

34 firefighters answered this correctly and received a score of 1 by both judges. Three firefighters received a score of 0.5. The remaining 13 responses received a score of 0 by the judges and fall into the following categories:
- 9 firefighters interpreted this symbol as a fire engine or apparatus
- 2 firefighters interpreted this symbol as a staging area
- 2 firefighters responded with other definitions such as: fire engine crossing and vehicle traffic

Hospital
37 firefighters answered this correctly and received a score of 1 by both judges. Two firefighters received a score of 0.5. The remaining 11 responses received a score of 0 from both judges and fall into the following category:
- 11 firefighters interpreted this symbol as a helipad

Medical Evacuation Helicopter
38 firefighters answered this correctly and received a score of 1 by both judges. 11 firefighters received a score of 0.5. One firefighter responded that this was a medical helicopter base which the judges determined was not a correct response.

Emergency Medical Operation
42 firefighters answered this correctly and received a score of 1 by both judges. Seven firefighters received a score of 0.5. One firefighter responded that the symbol had no meaning.

Fire Hydrant
All 50 participants answered this correctly and received a score of 1 by both judges.
Summary

This section has reported the raw results and scoring of the open-ended test. The next section will give a detailed discussion as to what the results show in relation to symbol comprehension and symbol design.
Chapter 5

DISCUSSION

The question that this study focuses on answering is whether or not the subset of FGDC HSWG symbols tested would achieve an overall comprehension rating of 85% using the ANSI recommended open-ended testing method. Previous research suggests that symbols that do not have a direct graphical link to their referent do not communicate as well as those symbols that do have a direct graphical link to their referent. The initial assumption of this study was that pictorial symbols would achieve the necessary 85% comprehension rating as these are the symbols that should cause the least confusion and be understood easily without the use of a legend. Based on the results and the comprehension scores for each symbol, this is not the case. The results of this study show that of the 28 symbols tested only six of the symbols achieved an 85% comprehension score.

Critical Confusion

Two symbols in the Incidents category had critical confusion. According to ANSI Z535.3 criteria, a symbol that has critical confusion is one that was interpreted by at least 5% of participants to have the opposite meaning. The two symbols that have critical confusion scores of greater than 5% in the Incidents category are “Origin” and “Vehicle Incident”.

Origin – Critical Confusion

Nineteen firefighters or 38% of participants interpreted this symbol as no fire or fire extinguished. According to the FGDC HSWG definition, this symbol represents the
location where a fire incident began. The X with a circle around it in ICS symbology represents origin. Once the flame is added to the symbol, firefighters take the opposite meaning. This symbol only achieved an overall comprehension rate of 14%

**Vehicle Incident – Critical Confusion**

Eleven firefighters or 22% of participants interpreted this symbol as a safe route for cars to travel. The FGDC HSWG definition for this symbol says that this symbol represents a sudden incident that involves a vehicle resulting in bodily injury or disruption to transportation services. The graphic is an indirect representation of the definition of the symbol. This is especially evident when this symbol is compared to the symbol used to represent “Vehicle Accident” which is a broken car. The symbol for “Vehicle Incident” may not be necessary. Both “Vehicle Accident” and “Vehicle Incident” are more or less communicating the same message. The results show that having two symbols representing similar incidents is confusing to firefighters.

**Direct Versus Indirect Representation**

In order to determine why particular symbols had higher comprehension rates than others, a useful way to evaluate each symbol is to compare point symbol type (geometric, associative or pictorial) to how well the symbolic representation reflects its real world referent. As previous research has shown (Clarke, 1989; Blok, 1987), the more a pictorial symbol does not bear resemblance to its real world referent, the greater the likelihood that the symbol will be misinterpreted. But there is also the case where a symbol is a direct representation of its real world referent and is still not interpreted
properly by map users. Categorizing the symbols by type and direct versus indirect representation reveals interesting patterns.

Figure 10 shows a classification of symbol type and representation type for the Incidents category and Figure 11 displays the same information for the Operations category. A symbol that is a ‘direct representation’ is one that is strongly associated with its referent. A symbol that is an ‘indirect representation’ is one that is not directly associated with its referent. The majority of symbols that are classified as a direct representation are pictorial symbols as they bear the most resemblance to their real world referents. There is an exception in the Operations category where the symbol for “Emergency Medical Operation” is classified as being an associative symbol with a direct representation. The reason for this is because the star-like medical symbol is considered a convention associated with some type of medical facility/operation. The reason the symbol representing “Hospital” is not categorized this way is because in ICS symbology this (an H with a circle around it) represents the location of a helipad. A direct (upper left of Figures 10 and 11) representation is not possible in the geometric category of symbols as these symbols typically never resemble their real world referent.

**Symbols That Passed the Comprehension Test**

As previously outlined in the results section, the three symbols that achieved an overall 85% or greater comprehension rate in the Incidents category are, “Wild Fire”, “Special Needs Fire”, and “Non-Residential Fire” and the three symbols that achieved the comprehension score in the Operations category are, “Medical Evacuation Helicopter Station”, “Emergency Medical Operation”, and “Fire Hydrant.” As seen in Figures 10 and 11, all of these symbols with the exception of “Emergency Medical Operation”
(which is associative and a direct representation) are pictorial symbols with direct representations of the incidents or events (upper right position in Figures 10 and 11). All of these symbols have graphic elements that are familiar and leave little room for ambiguity or misinterpretation. As seen in the results section (Table 3 and Table 4), these six symbols had the least variation in responses from participants. Also, very few participants answered with either unknown or no response.

<table>
<thead>
<tr>
<th>Symbol Type:</th>
<th>Geometric</th>
<th>Associative</th>
<th>Pictorial</th>
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</thead>
<tbody>
<tr>
<td>Direct Representation</td>
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<td></td>
</tr>
<tr>
<td>Indirect Representation</td>
<td></td>
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</tr>
</tbody>
</table>

Figure 10: The symbols from the Incidents category classified by symbol type and representation type.
Symbols That Achieved 50-76% Comprehension

Three symbols in the Operations category and five symbols in the Incidents category achieved scores of greater than 50% but less than the 85% necessary to pass the comprehension test. Unlike the symbols that passed, these symbols are designed in such a way that is ambiguous and allows multiple interpretations about what the symbol represents.

In the Operations category, the symbols for “Hospital”, “Fire Station” and “Emergency Staging Area” received over 50% comprehension. As seen in Figure 11, the symbol for “Fire Station” and “Emergency Staging Area” are pictorial symbols with indirect representations. As seen in the results, these two symbols had more variation in answers from participants due to this ambiguity. The symbol representing “Hospital” is a familiar or associative sign, but as previously mentioned is a symbol that in ICS
symbology represents a helipad and according to participant responses, this is what caused the most confusion about this symbol.

In the Incidents category, the four symbols that are pictorial with direct representations that did not achieve the 85% comprehension score but scored above 50% comprehension are: “Flammable Liquid”, “Flammable Gas”, “Vehicle Accident” and “Fire Incident.” The one symbol that is pictorial with an indirect representation is the symbol used to represent “Explosives.” These symbols, like the ones in the operations category, leave room for multiple interpretations. For example, five participants thought the symbol for “Flammable Liquid” meant flames reactive to water and four firefighters understood the symbol for “Vehicle Accident” to represent a junkyard or wrecking yard for cars.

Symbols That Achieved Below 50% Comprehension

Seven symbols in the Operations category received below 50% comprehension scores and were also the ones with the greatest variety of responses. In the Operations category it is somewhat obvious why geometric symbols were not easily understood. Typically, geometric symbols require the use of a legend. What is curious is the fact that there was such a low comprehension score for the symbol “Incident Command Post.” The symbol in the FGDC HSWG set is similar to the one in the ICS symbol set with the exception of the circle frame shape. This may be why firefighters misinterpreted this symbol. It is also not surprising that pictorial symbols with indirect representations had especially low comprehension scores; if the symbol is not meaningfully linked to its referent, there is greater room for misinterpretation. For example the fire hat used to represent “Fire Suppression Operations” is a pictorial symbol but with a minimal link to
its referent. Twenty-five firefighters took this symbol to represent a fire station or command post. Only two firefighters answered this correctly.

The same can be said for the other three symbols that are in the Operations category. The symbol representing “Other Water Supply Location” was interpreted by 16 firefighters as a fire hose. Although this definition is not entirely incorrect (the detailed definition says any water supply other than a hydrant), if it is interpreted this way a firefighter could be looking in a particular location for a fire hose during rescue operations and be confused that one is not located where it should be. This symbol is too specific to represent such a general range of potential water supplies. The symbol for “Emergency Teams” was answered correctly by only one of the 50 participants. The majority of firefighters understood this symbol to represent a shelter facility or restrooms, or they had no response. This sign generally encountered in public places shows the location of restroom facilities and therefore, it is not surprising that there were a variety of responses. The symbol for “Emergency Collection Evacuation Point” was answered correctly by eight firefighters. Nineteen firefighters interpreted this symbol to show an evacuation route or direction. What is most likely misleading in this representation is the use of the arrow and, again, this is not a completely wrong interpretation but it could slow down response and rescue efforts when encountered in the field.

There are also seven symbols in the Incidents category that achieved below 50% comprehension scores. The symbols for “Origin” and “Vehicle Incident” as previously mentioned were critical confusions. Two of these symbols (“Oxidizer” and “Hot Spot”) that are associative with indirect representations, had comprehension scores of 47% and 20% respectively. Interestingly, the symbol used for “Oxidizer” is a Department of
Transportation (DOT) placard and all firefighters are trained to recognize these placards (Pers. Comm. Chief O’Keefe, March 2008). This explains why three firefighters understood this symbol as a tank fire. It is not clear from the results why this symbol achieved such low comprehension especially if it is an associative sign that is familiar to firefighters. Of the various definitions given for the symbol representing “Hot Spot”, 11 firefighters believed this was a fire involving oxidizers, chemicals or combustibles. The miscomprehension of “Hot Spot” is more likely than the misinterpretation of “Oxidizers”. The idea of a hot spot is not something that is easily symbolized and because this symbol is associative, we can assume that it would most likely require the use of a legend. All participants (other than the ones who had no response) knew that this symbol represented something to do with a fire, but the hollow circle is where the confusion arises and, hence, the variety of answers.

Two pictorial symbols with direct representations in the Incidents category also achieved less than 50% comprehension. “Flammable Solid” (discussed in further detail in the next section) achieved an overall comprehension rate of 10%. This symbol allows for ambiguity and multiple interpretations. The element of the symbol that seemed to cause the most confusion is the cube-like representation for a solid. Firefighters understood the two flames to represent flammable or on fire, but 22 firefighters thought the symbol as a whole meant flammable storage, storage on fire, or a flammable box. The symbol representing “Smoke” was also misunderstood by firefighters and had an overall comprehension score of 37%. This is a pictorial symbol with a direct link to its referent but I believe the reason for such low comprehension is the use of the flame symbol at the bottom of the smoke cloud. This is evidenced by the fact that 23
firefighters understood this symbol to represent a fire that is producing a toxic chemical cloud. As with other symbols, this is not a complete misinterpretation but firefighters may modify their suppression activities if this symbol was interpreted as a toxic cloud versus a heavy smoke cloud.

Other than the symbol for “Vehicle Incident” (that was determined to produce critical confusion), the second symbol in the Incidents category that is classified as pictorial with an indirect representation that received a comprehension score of below 50% is “Civil Displaced Population”. This symbol achieved an overall comprehension rating of 45%. Similar to the symbol in the Operations category used to represent “Emergency Collection Evacuation Point” this symbol does not bear direct resemblance to its real world referent and the incident may be too complex to represent pictorially. Five firefighters took this symbol to represent an incident involving children and the remaining 13 incorrect responses had no similarities and were quite varied.

**Inconsistent use of Graphic Marks**

Some of the decisions made while designing the symbol set are inconsistent. In the Incidents category the symbol for “Flammable Solid” uses a 3D cube shape to represent a solid. The same 3D cube shape is used in the Operation symbol for “Emergency Staging Areas.” In the symbol for “Flammable Solid” the cube is used to represent the solid and in the “Emergency Staging Areas” three cubes are used to represent a place where emergency supplies are available. In participant responses for “Flammable Solid” (that achieved an overall comprehension rating of 10%), 22 firefighters interpreted this symbol to mean flammable storage, storage on fire,
warehouse on fire or flammable box. Similarly, nine firefighters interpreted the symbol for “Emergency Staging Areas” to represent some type of storage or warehouse facility.

Another example of an inconsistent use of a graphic symbol can be seen when comparing the symbol in the Incidents category for “Flammable Liquid” and the symbol for “Other Water Supply Location” in the Operations category. In the Incidents category the teardrop shape is used to represent a potentially dangerous liquid while in the Operations category the same teardrop shape is used to represent water. A closer look at the responses given for “Flammable Liquid” shows that some firefighters attach the meaning of water with this symbol. Some of the responses given include: flames reactive to water, sprinklers, and water source for firefighting. As illustrated above, such inconsistencies can lead to misinterpretations.

**Summary**

Based on the results of the open-ended comprehension test, several conclusions can be drawn. All of the symbols that passed contain easily recognizable graphic elements and allow little room for multiple interpretations. Symbols that are interpreted in multiple ways tend to be ones that do not have a defined or intuitive graphic link to their referent. Some of these symbols have a link to their referent, but the link is not effective enough to communicate the intended meaning and therefore the comprehension rates are moderate to low. The results also show that symbols used to describe action events (“Fire Suppression Operation”, “Civil Displaced Population”, “Emergency Collection Evacuation Point”, etc.) are too complex to be represented in a pictorial symbol. Finally, symbols that inconsistently use graphic marks (i.e., a cube to represent a supply location as well as a flammable solid or a teardrop shape used to represent water
as well as a flammable liquid) also have lower comprehension scores. In short, the
greater the ambiguity inherent in a symbolic representation of some real world event, the
greater the variation in responses, the lower the comprehension score, and the greater the
likelihood that decision making processes will be affected during emergency situations.
Chapter 6

CONCLUSIONS

The goal of this research project was to measure the comprehension level for 15 symbols in the Incidents category and 13 symbols in the Operations category developed by the FGDC HSWG Symbology Subgroup using the ANSI open-ended comprehension test. These symbols are a representative sample of over 200 symbols developed by the subgroup. The 28 symbols were tested with two groups of firefighters in California totaling 50 participants and it was found that only six of the symbols achieved an 85% or greater comprehension score. Previous cartographic studies carried out on pictorial symbol comprehension have typically focused on tourists and have measured comprehension with a lower threshold of 50%. There is a great need for further work in the area of pictorial symbol comprehension for first responders. It is critical that symbols be interpreted easily by responders at a glance during rescue efforts.

The results of the open-ended testing method give a detailed look into several factors relating to pictorial symbol comprehension. First, the decisions a first responder will make based on his or her interpretation of the symbol are elucidated. Secondly, based on participant responses to symbols, the graphical links that do and do not work are also highlighted. As shown in this study, symbols that do not have a concrete and very direct link to their referent are the ones that have the lowest comprehension scores and the highest rate of alternative responses. Pictorial symbols that leave little ambiguity for multiple interpretations and associative symbols that are familiar had the highest comprehension scores. Pictorial and associative symbols that do not have a strong graphical link to their referent achieved the lowest comprehension scores too. It is not
sufficient that a symbol is a picture for it to succeed. As expected, geometric symbols also had a low comprehension rate because they have no direct link to their referent and no legend was provided.

This study only tested a small subset of the symbols. If more symbols were tested, the ones that achieve the 85% comprehension level can be identified and the subgroup can begin working on redesigning and retesting the ones that do not achieve 85% comprehension. If the Symbology Subgroup can be confident that the majority of the first responder population understands the symbols and finds them easy to use, there will be wider use and adoption of the symbol set and previous problems of information sharing between multiple groups of responders will be alleviated.

Using a good testing method, one that has validity, produces results that are reliable. For symbols that tested poorly, there are modifications that should be made to make them easier for first responders to use. According to the ANSI Z535.3 standard, symbols that do not pass the comprehension test should be redesigned or have an accompanying word message. The Symbology Subgroup is at an advantage here. The end user community of this symbol set has already been identified and a set of symbols has been designed that covers a wide range of Operations, Incidents, Infrastructure and Natural Events. In order to achieve the goal of universal symbols for emergency personnel at all levels, the symbols have to be tested as they were in this study. I recommend that the FGDC HSWG Symbology Subgroup consider this ANSI-based method for official evaluation of the symbol set.
**Evaluation of the Open-Ended Testing Method**

Another question this study attempts to answer is whether or not the ANSI recommended open-ended testing method can be successfully tailored to mapping, and more specifically, to evaluation of pictorial map symbol comprehension.

**Advantages of the Open-Ended Test**

The results of this study indicate that this is a viable method for testing pictorial map symbol comprehension and should be considered for adoption by the FGDC HSWG Symbology Subgroup. One of the major advantages of this testing method is that it has gone through rigorous testing in the human factors research community and is used to measure the comprehension of warning signs and symbols that we encounter in our everyday lives. In order to modify the testing method to fit a mapping application, only slight alterations had to be made. These include using a map for context with the symbols being tested, modifying the second comprehension question by symbol category (i.e., Incidents versus Operations), and modifying the wording of the test taking instructions given to participants to be appropriate for emergency mapping.

As shown in the results and discussion sections of this thesis, conducting open-ended testing gives a detailed look into what participants understand when they encounter each symbol. The results can therefore be used as guidance to make modifications to symbols, see which ones need design reconsiderations, understand which ones work well, and evaluate components of particular symbols that make them easier to comprehend compared to ones that have low comprehension scores.
Disadvantages of the Open-Ended Test

The major disadvantage of this testing method is that it is time consuming and takes detailed planning for execution and evaluation of results. One way to circumvent this is to begin testing symbol variations in the beginning of the design process. In the ANSI Z535.3 standard, it is recommended that a range of possible symbolic representations for one meaning be tested prior to the actual open-ended comprehension testing. This way, designers can be more confident that the final symbol they are testing will have a high comprehension rate. For example, if a symbol was being designed to represent the location of a fire station, three symbol variations could initially be tested. The subgroup could come up with three symbol variations (e.g., a Maltese cross, a fire helmet and a fire truck) and ask test participants to rank them according to estimates of the percent of the first responder population that would interpret each symbol as a fire station. If the Maltese cross got the highest percentage, that would be the symbol that would be used in further open-ended comprehension testing. This may require additional work in the design stages, but will ultimately help the overarching goal of producing a usable, reliable universal symbol set.

Future Work

Considering the increasing frequency with which disaster and emergency situations are happening, it is very likely that technology will fail at some point and first responders will continue to rely heavily on paper maps. After conducting this research project and speaking with firefighters, it is clear that map symbology during these events should be reproducible by hand and easily memorized to decrease the reliance on a legend. One way I foresee this happening is to give a textual description of an
emergency event to responders from several different organizations. The participants could hand draw the symbols representing each event that is taking place in the scenario. Once the maps have been collected, common symbology used among the varying agencies can be examined and the most common symbols used by all participants can be a starting point for the design phase. Once this information is collected, open-ended comprehension testing can begin. This is also an effective way to gather symbology that can either be used on a computer or drawn by hand on paper maps.

One of the criticisms of this research expressed by a member of the Symbology Subgroup (Subgroup Meeting, May 2008) is that these symbols are not meant to serve the responders on the ground and that they are meant to serve the emergency manager mapping the situation at a computer. I strongly believe that this process cannot be top down. Ultimately, the first responder on the ground is the one who will be using the mapped information to make response decisions. Therefore, how all levels of emergency personnel comprehend and use these symbols is especially important.

If the Symbology Subgroup decides that these symbols are only to be used by emergency managers, then the symbols still need to be tested in an emergency mapping context. One way I foresee this happening is to give participants a textual description of an emergency event, have them map out the situation at their computer using the FGDC HSWG symbol set and record their mapping time. If this is the intended audience, then further research into previous studies and testing methods of computer and symbol use in emergency situations is necessary and is not within the scope of this current research project. The current research project has tested the comprehension of the symbol set on
paper maps that are currently used by two fire departments for decision making processes during an emergency event.
WORK CITED


APPENDIX A

TEST BOOKLET

(De-randomized)
TEST BOOKLET

Instructions:

Each of you has a test booklet that contains many examples of different symbols. These are symbols that you might encounter on emergency maps. We want to see how well each of the symbols is understood.

You will be helping us do this by writing down what you think each symbol means.

It is very important that you write down exactly what the message is. If your answer is too vague or general, we will not be able to determine whether the correct message is getting across.

The first page of the booklet is an example of what you will be seeing. Each page will have an illustration of a symbol that you might encounter on an emergency map. There is a blank for you to write down exactly what the symbol means and another blank for you to write down how this symbol is related to firefighters’ actions and response activities.

The first page shows you an example of a poor answer.

The example on the second page is a much better answer. It describes the exact meaning of the symbol and tells just what actions should be taken. Make sure that all of your answers are clear and precise, like the good example.

There are many different kinds of symbols in your booklets. Some may be familiar to you and others you may have never seen before. Just do the best you can for each, and take an “educated guess” if you are not sure of the meaning.

Remember, it is the symbols that are being tested not you. When you think about what the symbol might mean, remember that these are symbols that could be encountered on emergency maps.

It is important that you work alone. Do not talk to anyone or make comments out loud. Work through the booklet a page at a time.

Once you finish a page, do not go back over it. There is no time limit, but try not to spend too much time on each one. If you don’t know the meaning, just make your best guess and go on. When you have completed the entire booklet, please return it to Chief Zolfarelli.

Once you have read the instructions and signed the consent form, please begin the test. The test begins From SECTION 1.

Thank you for taking the time to participate in this research project.
Example of a poor answer

Context:

Exactly what do you think this symbol means?

a tent

What role would this site play in firefighters’ response activities?

a place to sleep
Example of a good answer

Context:

Exactly what do you think this symbol means?
emergency shelter

What role would this site play in firefighters’ response activities?
a place where victims of a disaster are taken for shelter
Section 1

The symbols in this section of the test are used to represent incidents.

They symbolize a cause of action or source of disaster.
Context:

Exactly what do you think this symbol means?

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________________________________________________________________________

________________________________________________________________________

What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

What action would firefighters take in response to this symbol?
Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Context:

Exactly what do you think this symbol means?

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What action would firefighters take in response to this symbol?

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Section 2

The symbols in this section of the test are used to represent operations.

These symbolize organizations, services, capabilities or resources available during or implemented due to an emergency management situation.
Context:

Exactly what do you think this symbol means?

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What role would this site play in firefighters’ response activities?

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____________________________________________________

____________________________________________________
Context:

Exactly what do you think this symbol means?

What role would this site play in firefighters' response activities?
Context:

Exactly what do you think this symbol means?


What role would this site play in firefighters’ response activities?


Context:

Exactly what do you think this symbol means?
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What role would this site play in firefighters' response activities?
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Context:

Exactly what do you think this symbol means?

What role would this site play in firefighters’ response activities?
Context:

Exactly what do you think this symbol means?

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What role would this site play in firefighters' response activities?

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Context:

Exactly what do you think this symbol means?

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What role would this site play in firefighters’ response activities?

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Context:

Exactly what do you think this symbol means?

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What role would this site play in firefighters’ response activities?

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Context:

Exactly what do you think this symbol means?

What role would this site play in firefighters’ response activities?
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What role would this site play in firefighters’ response activities?

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Context:

Exactly what do you think this symbol means?

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What role would this site play in firefighters’ response activities?

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Context:

Exactly what do you think this symbol means?

What role would this site play in firefighters’ response activities?
Context:

Exactly what do you think this symbol means?

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What role would this site play in firefighters’ response activities?

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