First Responders and Crisis Map Symbols: Making Communication Clearer

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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. 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.

KEYWORDS: open-ended testing, pictorial map symbols, firefighters, human factors, cartography

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 personell during such disasters and common means of map symbol communication do not exist. 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, 2003). The Emergency and Hazard Management Mapping Standard – Point

Symbology was submitted to and accepted by the American National Standards Institute (ANSI) in 2006.

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

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.

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

-**Natural Events**: phenomenon created by naturally occurring conditions

-**Infrastructure**: the basic facilities, services and installations needed for the functioning of a community

-**Operations**: capabilities or resources available during or implemented due to an emergency

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.

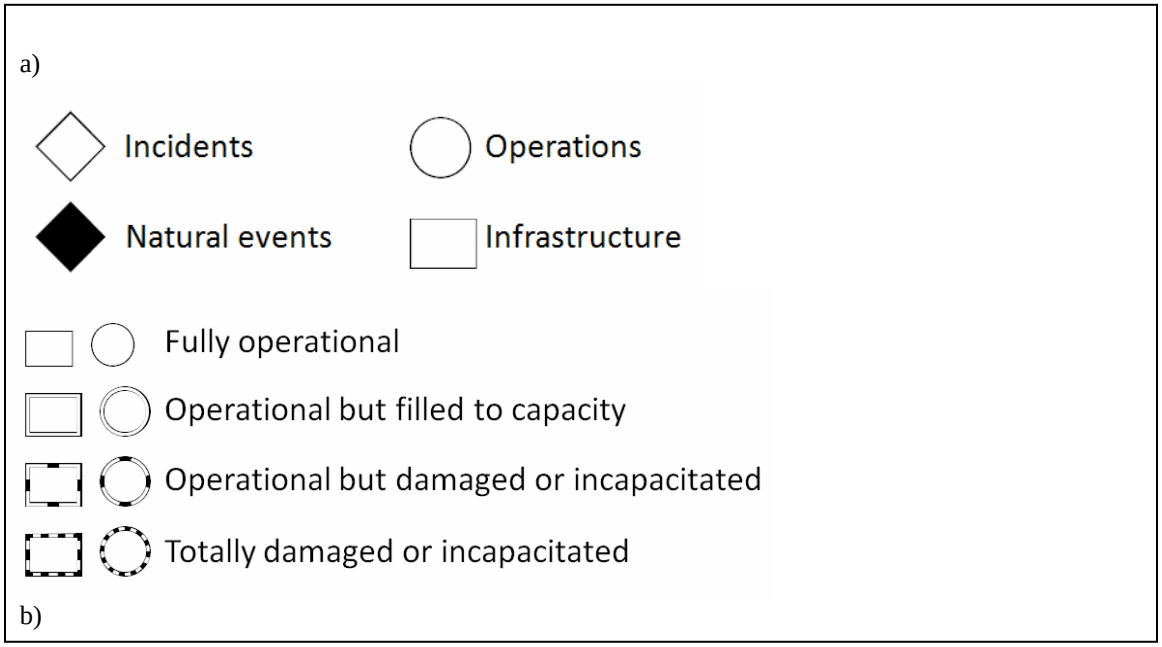

Figure 1: a) symbol category structure and b) damage status hierarchy for infrastructure and operations

FGDC HSWG Symbology Subgroup Testing Method

The evaluation process for the existing FGDC HSWG symbol set 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.

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.

Methods

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.

In 1979, the ANSI Z53 Committee on Safety Colors and the ANSI Z35 Committee on Safety Signs was combined to form the ANSI Z535 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 Criteria for Safety Symbols 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).

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.

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 (CalFire). Within LPFD participants were fire captains, engineers, firefighters and firefighter paramedics. Participants from CalFire 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.

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. A complete list of symbols tested with their accompanying definitions can be seen in Table 1 for Incidents and Table 2 for Operations.

A	Flammable Solid	@	Flammable Liquid
4	Origin	?	Flammable Gas
S	Vehicle Incident	T	Vehicle Accident
2	Hot Spot	1	Fire Incident
7	Smoke	>	Explosive
$	Civil Displaced Population	9	Wild Fire
D	Oxidizers	8	Special Needs Fire
3	Non-Residential Fire		

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

8	Emergency Teams	7	Emergency Staging Areas
4	Emergency Operations Center	>	Fire Station
=	Fire Suppression Operation	–	Hospital
1	Emergency Operation	+	Medical Evacuation Helicopter Station
?	Other Water Supply Location	'	Emergency Medical Operation
2	Emergency Collection Evacuation Point	>	Fire Hydrant
3	Emergency Incident Command Center		

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

Test Booklet Design

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. 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.

'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. 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. For each participant group, the appropriate map was used in the test booklet.

Each test booklet was separated into two sections. The same map was used for both sections of the test (the map varied depending on participant group) 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. For each test section, symbols were placed on the map to create a fictitious scenario.

According to the ANSI Z535.3 standard, participants should be asked two comprehension questions about each symbol being tested. The first ANSI recommended 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 1 of the test and reworded to "What role would this site play in firefighters' activities?" in Section 2 of the test. By rewording the second question for both sections of the test, there is a greater likelihood of getting a better understanding of what the participant thinks the symbol means.

Test booklets were prepared and delivered to LPFD and to CalFire. Any test booklet that was less than 75% complete was omitted from this study. A total of 50 test booklets from both groups were used for the comprehension testing. This is the minimum sample size ANSI Z535.3 recommends.

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). 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.

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. 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 firefighter 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. 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.

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.

Results Incidents Category

Of the 48 symbols available in the Incidents category, 15 were tested in this study. Figure 2 shows the percent 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%).

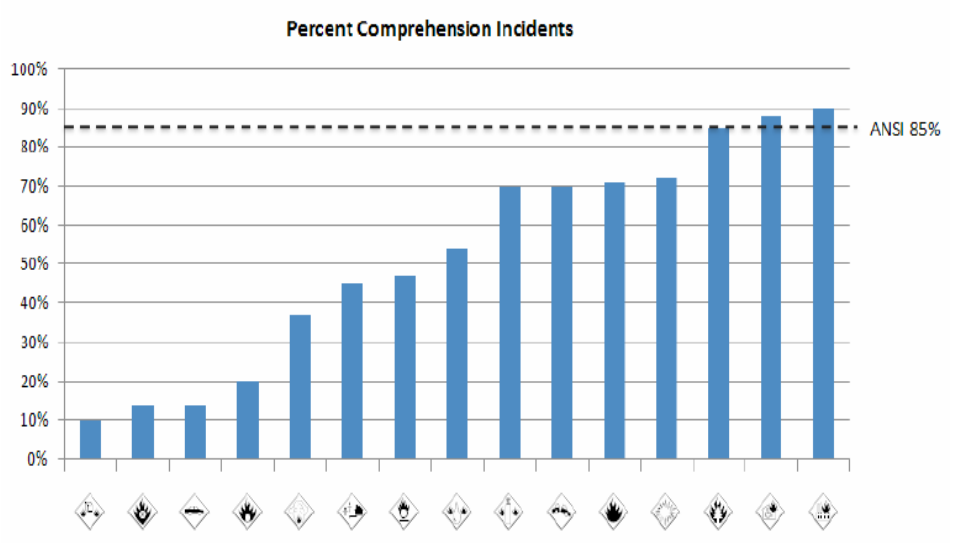

Figure 2: Percent correct responses per Incident symbol in ascending order

Results Operations Category

Of the 43 symbols available in the Operations category, 13 were tested in this study. Figure 3 illustrates percent 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%).

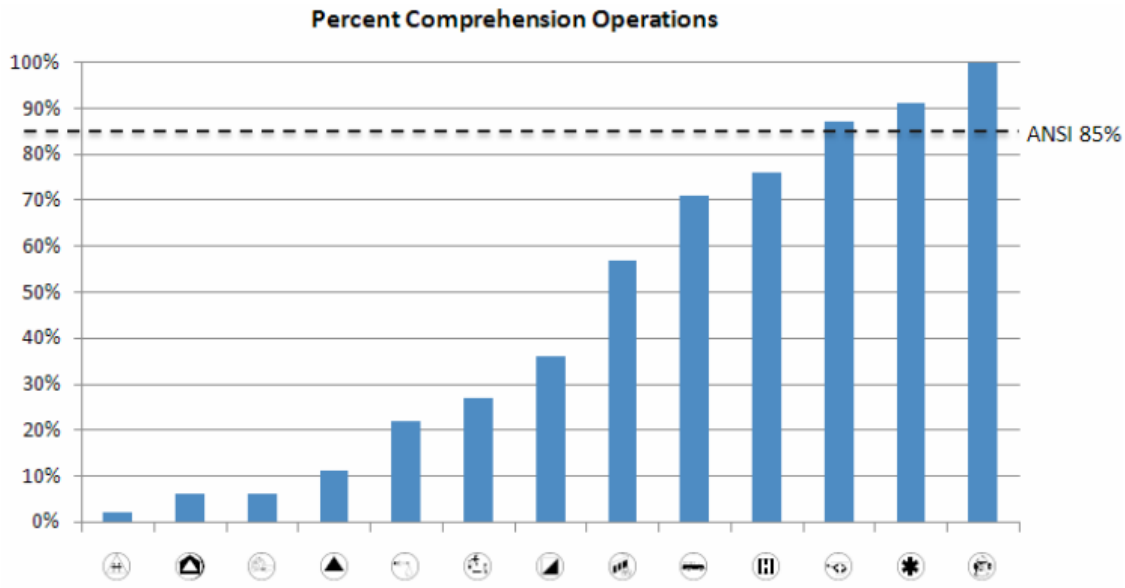

Figure 3: Percent correct responses per Operation symbol in ascending order

Discussion

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". Nineteen firefighters or 38% of participants interpreted the symbol representing "Origin" as no fire of fire extinguished. Eleven firefighters or 22% of participants interpreted the symbol representing "Vehicle Incident" as a safe route for cars to travel.

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 4 shows a classification of symbol type and representation type for the Incidents category and Figure 5 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 Incident Command System (ICS) symbology which is the symbology currently used by firefighters this symbol (an H with a circle around it) represents the location of a helipad. A direct (upper left of Figures 4 and 5) representation is not possible in the geometric category of symbols as these symbols typically never resemble their real world referent.

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.

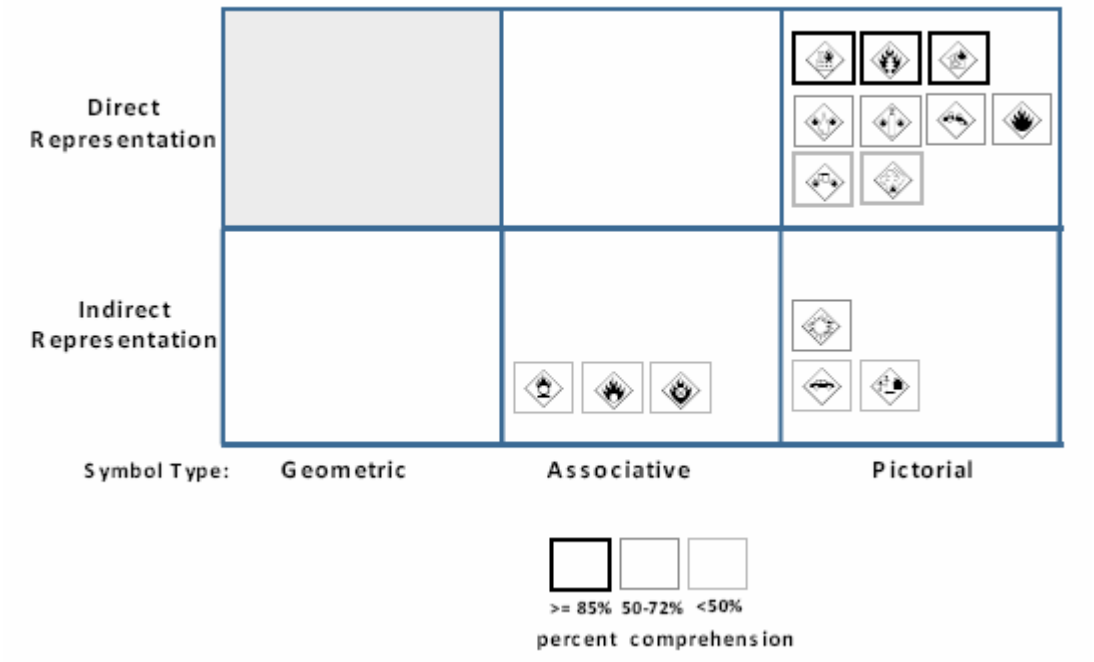

Figure 4: The Symbols from the Operations category classified by symbol type and representation type

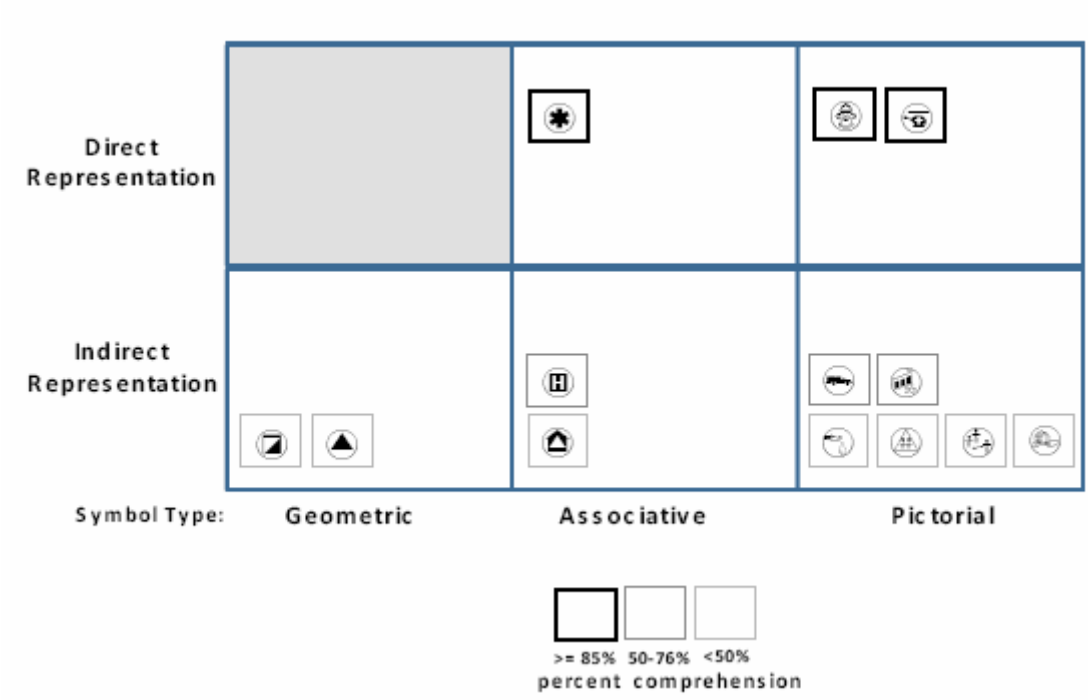

Figure 5: They symbols from the Operations category classified by symbol type and representation type

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. 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.

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. 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.

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