Usability of Geographic Information Systems

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ABSTRACT
With an increasing number of GIS, Geographic Information Systems, available online, many usability studies have been carried out. One such study defined the usability criteria that can be used for the future GIS usability tests. Some of the criteria include usefulness of functions, the level of visual efficiency and the level of user satisfaction. Another study evaluated twelve different GIS applications concluding that there are common weaknesses, for the currently available GIS applications, such as the level of data description and personalisation. One of the more focused studies have identified that the overview-activated maps, when compared to the same map with deactivated overview, are more satisfactory for the users because it creates a sense of control but it is slower in completing a task such as locating a specific site on the map. Another study concluded that multimodal systems with multiple input methods such as speech and gesture recognitions are much faster in navigating and searching. These studies all indicate that currently there is an unclear standard for GIS usability studies and any future study should focus on solidifying the general criteria that should be used with the tests. One of the core usability aspects should be the level of support provided by the system to quickly and efficiently train the users so they can fully utilise the GIS tools and functionalities. Any future usability tests should include this in the criteria and continue to refine the requirements in order to create a general criteria list that can be used to produce valid usability status of GIS applications.

Author Keywords
Usability, Map, GIS, Geovisualisation, Online Map.

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION
The four different categories of usability studies deal with different aspects of GIS applications. The first category makes criteria suggestions for analyzing qualitative aspects of GIS applications [1,2,3,4,5,6]. The second category investigates twelve different systems to search for the common strengths and weaknesses of the current GIS applications in general [2]. The third category looks closely at a specific GIS function by comparing a system with the overview function activated and the same system with the overview function deactivated [3]. The fourth category explores the effects of different multimodal GIS systems that support such interaction methods as speech and gesture recognition [7,8]. These categories are fundamentally testing the same concept but they each take different approaches and have different levels of granularity. It is important that all four categories of studies, along with other supporting studies, are discussed and compared in order to produce an overall picture and a better understanding of the current status of the GIS usability testing [1,2]. Therefore, the purpose of this report is to achieve this overall picture through combining the processes and the outcomes of the specific studies mentioned, with several other supporting studies of similar design.

PROBLEMS
Currently, there are three major obstacles in conducting GIS usability studies. These are defining the scope of GIS, creating common criteria for tests and using public participation throughout the development cycle. These problems need to be addressed before an accurate and effective usability study can be carried out. The following sections explain these problems and some solutions are suggested throughout the report.

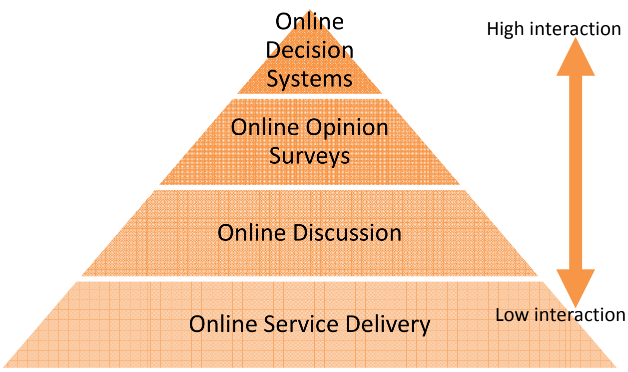

Figure 1. E-participation ladder

Definition of GIS

The concept of E-Participation ladder was introduced to categorise the different levels of online user interactions (see Figure 1). At the bottom of the ladder, the communication is purely one-way. This level of interaction is, in fact, no interaction at all. The users act merely as the passive viewers of the online system and the system allows no external inputs. Comparatively, at the top of the ladder, there is an effective two-way communication between the system and the users [2]. One of the major difficulties of testing GIS applications is the fact that GIS has not found a stable and widely accepted position on the E-participation ladder. In other words, many GIS applications are purely one-way, providing maps without any means of interaction, and some GIS applications are highly interactive, allowing the users to choose from such communication methods as text, visual, voice and gesture [7,8]. Clearly, it is a pointless exercise to create a universal definition of GIS as different GIS applications will have different levels of interaction requirements. For example, GIS for emergency management used at large hospitals may require voice recognition in order for them to quickly locate a geographical location but websites that provide online maps of local city areas need not be interactive at all. However, in order to ensure the effectiveness and the accuracy of usability test outcomes, an average position of GIS on the E-participation ladder must be defined [2]. The definition should outline the minimum set of functions and the minimum level of interactions of a common GIS application.

Study Criteria

GIS systems have heterogeneous groups of users and, therefore, must be easy to use [2,5]. However, the general usability criteria for software engineering, such as the Nielsen's usability heuristics, do not apply to the GIS applications [2]. This is largely due to the fact that most GIS applications are not meant to be trivial in its operations and the users are expected to know, to some extent, the purpose and the functions of the tools provided by the application [4]. This problem has resulted in many researchers trying to define the test criteria for GIS [1,2,3,4,5,6] and it is now imperative to summarise the suggestions of different studies to generate a general list of usability test criteria.

Public Participation

In line with the definition problem, GIS applications must define the level of public participation according to the level of interactions allowed [2]. For example, if a GIS application allows a high level of user interaction and relies on the users to enter in bank locations on the map, then public participation is crucial for that particular function to become useful. Although there has not been any detailed studies proving the existence of any correlation between the level of public participation and the level of GIS application success, it is believed that an appropriate level of public participation is required for a GIS application to become useful [2].

METHODOLOGIES

The following sections describe the approaches used by the different studies. Each category is supported by multiple studies, where appropriate, in order to thread the different outcomes together for the overall view of the current usability study status.

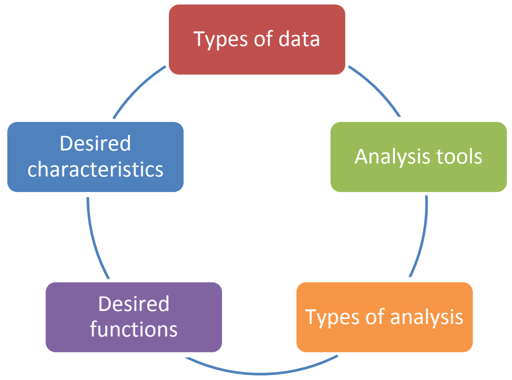

Figure 2. Criteria Categories

Criteria Study

The usability study that defines the criteria for further testing is essential. The participants for one such study were the analysts from the Population Division of the U.S. Census Bureau. All the participants had prior exposure to one or more GIS applications and, as part of the study, they were asked to come up with the appropriate criteria for five different categories [1] (see Figure 2). As this was the study designed to formulate a list of common study criteria for the GIS applications in general, no one particular GIS application was used. Instead, the participants were given the freedom to base their inputs and opinions on any GIS application with which they were familiar [1]. Comparatively, in other studies that attempted to define the common study criteria, the participants were asked to comment on a specific GIS application [2,3,4,5,6]. These studies often had other main purposes such as comparing different GIS applications, measuring the performances and testing a particular set of GIS functions. Nonetheless, the criteria outcomes of these supporting studies are useful in deciding what should be included in the general list of GIS usability study criteria. In summary, the general approach to criteria study was asking the participants to write down what they think should be included in the criteria after having some exposure to GIS applications.

Comparison Study

The comparison study explored twelve GIS applications on eight different categories (see Figure 3) [2]. Among these twelve GIS applications, seven were developed in the US and five in Europe. One of the interesting focuses of this study was how GIS applications developed in different countries had varying levels of strengths and weaknesses.

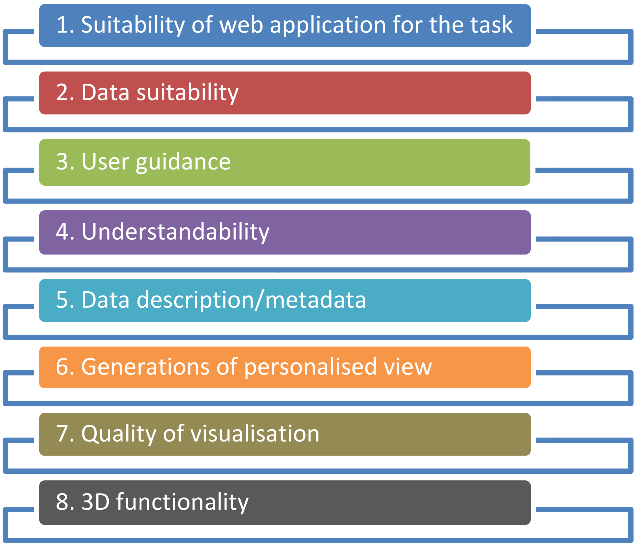

Figure 3. Evaluation Categories

For example, GIS in US may contain more detailed descriptions of public facilities than the GIS in Europe. A possible explanation is the differing levels of availability and difficulty in obtaining the required information. Nonetheless, the main focus of the study was comparing the functional aspects of the twelve applications. Prior to the test, each of the eight categories were explained to the participants in detail so they fully understood how they will be asked to assess the system. Each category was scored, for all twelve GIS applications, on a scale of 1 to 5, 1 being '*very good*' and 5 being '*very bad*'. The only exception to this scoring system was the last category, 3D functionality. This category was simply marked '*yes*' if the system supported some level of 3D functionality, and otherwise marked with a '*no*'. The results from the test were compiled and, due to the small number of participants, only the mean and median values of each category were calculated. By inspecting the results table, the aspects of GIS that needs the most improvement can be identified [2]. Additionally, it is clear that the first category of studies explored the qualitative aspects and the second category looked at the functional aspects of GIS. The results of these two categories can be combined together to produce a more complete list of criteria for future GIS usability studies [1,2].

Function Study

The specific function tested was the overview. The overview function allows the users to have a small additional window, on top of the main window, which provides a view of the entire map. By manipulating the overview window, the users can quickly pan across a large area. The overview can also give the users a sense of control. However, it may also have adverse effects such as reduced main map area, difficulty in switching between views and increased navigation time through the misuse of overview [3]. In order to prove and quantify these assumptions, 32 participants were given ten specific tasks to perform on both overview-activated GIS (see Figure 4) and overview-deactivated GIS (see Figure 5) [3]. The ten tasks belong to two main categories; browsing task category and navigation task category. The browsing tasks involve locating specific landmarks on the map and the navigation

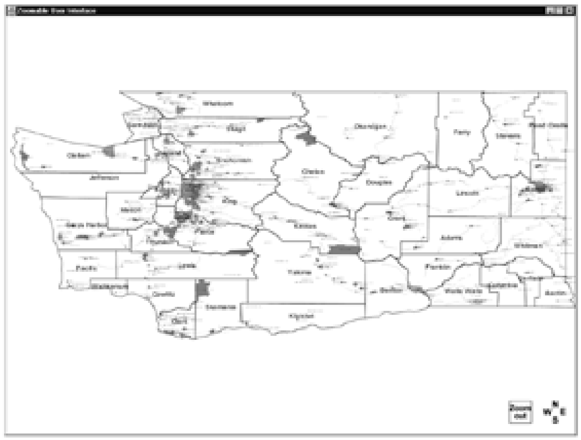

Figure 4. Map with no Overview

tasks ask the participants to scan through a large area to locate an object or a building that fits certain requirements. The performance on all the tasks was measured, for the 32 participants, across four different categories. The categories were accuracy, preference/satisfaction, task completion time and number of pan actions. The three pre-test hypotheses stated that no-overview interface will have higher accuracy because research has shown that the users have difficulty integrating multiple views, participants will prefer the overview interface as it gives them more control, and the overview interface would be faster for completing the tasks [3]. The statistical analysis of the outcomes, presented in the findings section, will either support or contradict the hypotheses.

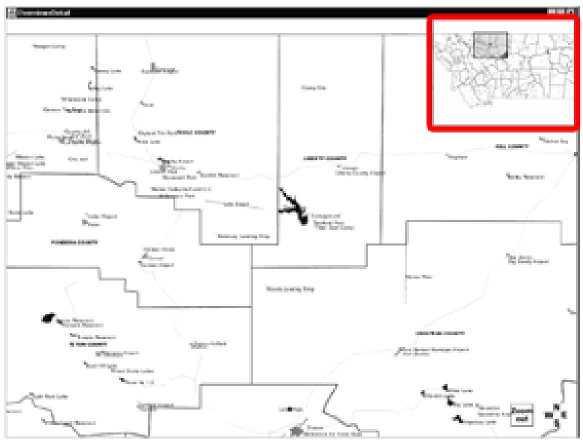

Figure 5. Map with Overview

MULTIMODAL STUDY

This category of studies compares the performance discrepancies of different multimodal interfaces. A multimodal interface allows more than one way of user interactions [6]. For example, a GIS application for emergency management supports visual manipulation through keyboard and mouse, speech recognition and gesture recognition as input methods [7]. For the purpose of this report three domains will be considered; visual, verbal and motion. Along with the overview function, multimodal input will be considered as a specific function of GIS applications. It is beneficial to compare the outcomes of the studies that test specific functionalities to see if the usability criteria are in line with the first two categories and, therefore, exemplifying how studies at different levels of the same concept can support and emphasise the outcomes of one another.

FINDINGS

The outcomes of the studies mentioned in the previous section are discussed and compared to one another.

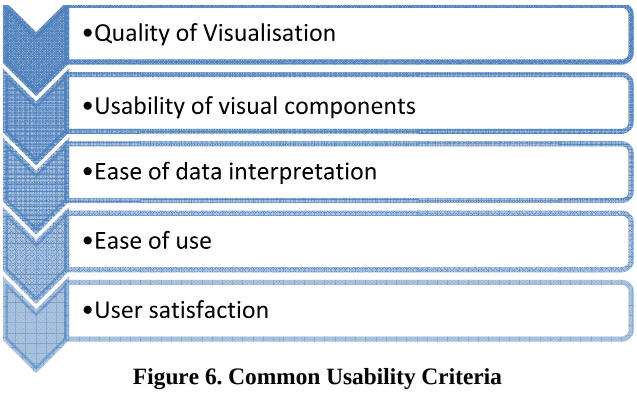

Figure 6. Common Usability Criteria

Criteria Suggestions

Almost all studies attempted to define some criteria that should be used with GIS usability testing [1,2,3,4,5,6,8,9]. Some of the interesting findings are as follows. From the study involving participants from the Population Division at the Census Bureau, US, preferences for three different categories were identified. The first category, types of data, indicated that the users wanted previous census figures, housing-unit counts/numbers, in-migration, out-migration and net-migration information incorporated into the GIS applications [1]. For the second category, desired functions of future analysis tools, the users wanted the capability to map migration rates, flows of each country to others, altitude levels, types of buildings (e.g. home, hospital, military, etc) and agricultural information. The third category, desired usability characteristics of future analysis tools, identified processing speed, visually appealing interface and more interesting interaction methods as the crucial improvements to be made to the current GIS applications. Since most of the participants utilised some GIS application at a professional level, the desired functions and characteristics are detailed and specific. However, many of the findings from this study overlap with the results from other studies. The most commonly overlapping criteria were quality of visualisation, usability of visual components, ease of data interpretation, ease of use and user satisfaction (see Figure 6) [2,6,8,9]. In regards to the usability of functions and interpretation of data, it was considered that being able to understand the purpose of a tool and recognizing when that tool can be used are two separate issues [4]. This meant that the successful tool usage during the pilot testing phase does not automatically translate to successful tool usage in the actual usability testing phase. The usability of tools and GIS applications as a whole depends largely upon individual understanding of when the tools are useful and how the tools can be used [4]. This is a crucial piece of information that links the criteria findings of different studies. The general criteria accepted by most of the studies may unify the ways the GIS applications are tested but they will not ensure that the functions and the tools of these applications meet certain usability criteria. The most effective measure that can be taken to ensure the usability of tools and functions is to introduce easy and effective ways to train the users that they may know how and when to use specific functionalities [4]. If GIS applications can achieve this, then and only then, the common criteria will become effective measures of usability status of GIS applications.

Criteria	Mean
Suitability of web application for the task	2.29
Data suitability	2.44
User guidance	1.98
Understandability	2.25
Data description/metadata	3.13
Generations of personalised view	3
Quality of visualisation	2.44
3D functionality	4 Yes/8 No

Table 1. Results of Usability Test on GIS Applications

Comparative Results

Pilsen Project, Orange County Interactive Mapping – Florida, Resource Management Mapping Service – Illinois, Virtual Slaithwaite Project and Bradford Community Statistics Project were some of the GIS applications used for the comparison study [2]. The outcomes of the study indicated that Data description/metadata and Generation of a personalized view of information were the two criteria with the highest mean values, meaning these were the worst performing categories (see Table 1). It is imperative to note, however, since the sampling pool was small in size such that it was only appropriate to calculate the mean and the median values for each criterion, there may or may not be a statistically significant difference between the score of 3 and 2. Therefore, for the purpose of this report, the assumption is that the two worst performing categories are the aspects of GIS that require most improvements. The first criterion, Data description/metadata, refers to the degree to which the application can provide the users with the correct information about the data it presents. For example, if a GIS application can display public facilities on the map, it is desirous to be able to tell apart public libraries from city halls. This is indirectly related to the findings from the criteria studies. The reason for the absence of correlation between successful pilot test outcomes and successful real usability test outcomes is lack of understanding of the system functions [1]. If the level of data and metadata description was sufficiently high such that the users are able to understand the purpose of GIS functionalities more clearly, then the outcomes of comparative study would be different. The second category was Generation of personalised view of information. The users wanted the option to be able to change the layout of the applications [2]. Being able to personalise the view gives the users a heightened sense of control and, therefore, the users feel more comfortable using the system [2]. The findings of this category should be incorporated into the future GIS usability studies to ensure an appropriate level of data description and personalization.

Criteria	Results	Hypothesis
Accuracy	$F(1,28)=0.144, p>0.5$	False
Preference/ Satisfaction	$X^2(1,N=32)=12.5, p<0.001$	True
Task Completion Time	$F(1,28)=5.27, p<0.05$	False
Number of Pan Actions	$F(1,28)=10.90, p<0.01$	N/A

Table 2. Results of Overview Study

Overview Function

Based on the hypotheses previously established, ANOVA and p-value analyses were conducted on the outcomes (see Table 2) [3]. The first hypothesis, which stated that no-overview interface will have higher accuracy because research has shown that the users have difficulty integrating multiple views, was proven to be false. There was no statistically significant difference in accuracy between the overview and the no-overview interfaces. The second hypothesis, which stated that the participants will prefer the overview interface as it gives them more control, was proven to be correct. Among the 32 participants, 26 preferred the overview interface as it was easier to keep track of the current position, easier to navigate and helpful when scanning a large area. Interestingly, the other 6 participants preferred the no-overview interface because locating objects felt faster with the no-overview interface, overview window was taking up too much space on the screen and, for that reason, the map appeared much larger without the overview screen. The third hypothesis was also disproven. It stated that the overview interface would be faster for completing the tasks. This hypothesis was based on the outcomes of prior GIS usability studies [3]. However, the results indicated that the no-overview interface was much faster in completing a given task. Possible explanations are that overview may be distracting, switching between views takes time, coarse control on the overview window decreases accuracy and increases task completion time and the users never really become competent in utilising the added complexity of the overview. As it can be seen from this study, there are clear advantages and disadvantages to using a particular function. The function must be properly designed and, as it was concluded from the second category, it must be accompanied by proper user training and description so it can be utilised effectively and efficiently by the end users [2,3,4].

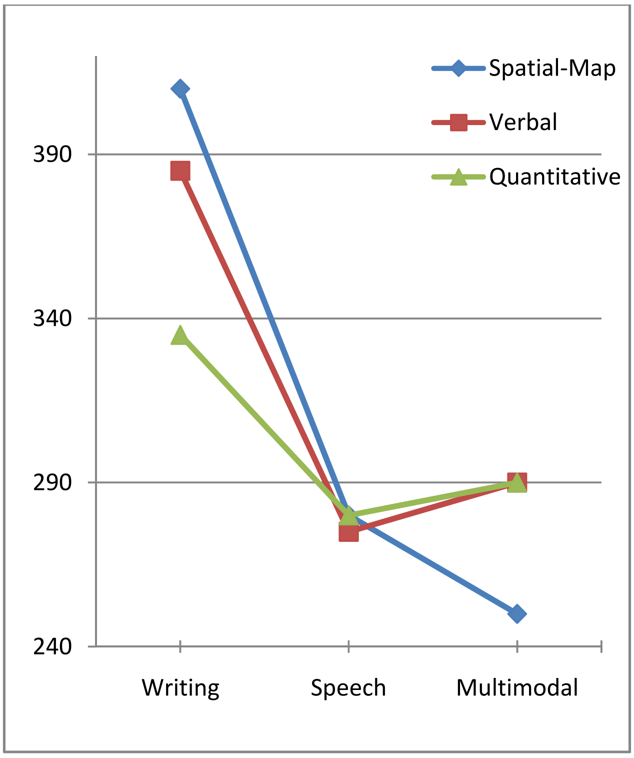

Figure 7. Results of Multimodal Study

Multimodality

The point of interest for the multimodal studies is the task completion time. The outcomes indicated that the multimodal GIS applications are much faster in completing the tasks within the visual/spatial map domain (see Figure 7). In other words, using both speech and visual manipulation through keyboards and mouse resulted in quicker response times for an average user [8]. In line with the findings from the first category, using multimodality not only has the potential to decrease the task completion time but it can also increase the usability of GIS applications through allowing more natural methods of interactions such as speech and gesture [1,7].

CONCLUSIONS AND FUTURE WORK

This report defined the current status of GIS usability studies. There are various kinds of tests with different approaches to suggest what should be included in the GIS usability study criteria. The comparison study, overview interface study and the multimodality studies all generated interesting results about the GIS applications at different granular levels. From the outcomes of these studies it can be concluded that the most important aspects of GIS applications are visual appeal, ease of use, description of data, description of functionalities and personalization. Having more sophisticated tools may increase the capabilities of GIS applications but, since knowing what a tool does and knowing when and how to use that particular tool are unrelated issues, it must be accompanied by effective ways to train the users that they may be able to fully utilise the functionalities. Therefore, in summary, the level of support provided by the GIS applications to quickly and efficiently train the users to use specific functions should be one of the core aspects of future GIS usability studies. Future studies should also explore the effectiveness of functionalities such as 3D visualisation, user participation and new interaction methods to determine how they affect some of the core study criteria identified throughout this report. Therefore, the ultimate goal of future usability studies should be to clearly identify where an average GIS application is located on the E-participation ladder and what specific requirements must be included in the study criteria. This will ensure that the GIS application usability studies are carried out properly and the outcomes of such studies can be considered as a valid indicator of the usability of GIS applications.

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