

A COMPARATIVE ANALYSIS OF WEB-BASED GIS APPLICATIONS USING
USABILITY METRICS

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ABSTRACT

With the rapid expansion of the internet, Web-based Geographic Information System (WGIS) applications have gained popularity, despite the interface of the WGIS application being difficult to learn and understand because special functions are needed to manipulate the maps. Hence, it is essential to evaluate the usability of WGIS applications. Usability is an important factor in ensuring the development of quality, usable software products. On the other hand, there are a number of standards and models in the literature, each of which describes usability in terms of various set of attributes. These models are vague and difficult to understand. Therefore, the primary purpose of this study is to compare five common usability models (Shackel, Nielsen, ISO 9241 P-11, ISO 9126-1 and QUIM) to identify usability metrics that have most frequently used in the previous models. The questionnaire method and the automated usability evaluation method by using Loop¹¹ tool were used, in order to evaluate the usability metrics for three case studies of commonly used WGIS applications as Google maps, Yahoo maps, and MapQuest. Finally, those case studies were compared and analysed based on usability metrics that have been identified. Based on a comparative study, four usability metrics (Effectiveness, Efficiency, Satisfaction and Learnability) were identified. Those usability metrics were characterized by consistent, comprehensive, not vaguely and proper to evaluate the usability of WGIS applications. In addition, there was a positive correlation between these usability metrics. The comparative analysis indicates that Effectiveness, Satisfaction and Learnability were higher, and the Efficiency was lesser by using the Loop¹¹ tool compared to questionnaire method for the three case studies. In addition, Yahoo Maps and MapQuest have usability metrics rate lesser than Google Maps by applying two methods. Therefore, Google Maps is more usable compared to Yahoo Maps and MapQuest.

ABSTRAK

Dengan perkembangan Internet yang semakin pesat, Sistem Maklumat Geografi berasaskan Web (WGIS) telah mendapatkan sambutan yang menggalakkan, walaupun penggunaan aplikasi WGIS adalah agak sukar untuk dipelajari dan fahami kerana terdapat fungsi tertentu yang diperlukan untuk memanipulasi sesuatu peta. Oleh itu, adalah penting untuk menilai kebolegunaan aplikasi WGIS ini. Kebolegunaan adalah faktor yang penting dalam memastikan pembangunan yang berkualiti sesuatu produk perisian yang boleh digunakan. Tambahan pula, terdapat beberapa piawaian dan model dalam kajian-kajian sebelum ini, yang menunjukkan kegunaan dari pelbagai factor dan sifat. Model-model ini adalah agak kabur dan sukar untuk difahami. Oleh itu, tujuan utama kajian ini adalah untuk membandingkan lima model kegunaan biasa (Shackel, Nielsen, ISO 9241 P-11, ISO 9126-1 dan QUIM) untuk mengenal pasti kebolegunaan metrik yang paling kerap digunakan dalam model sebelumnya. Kaedah soal selidik dan kaedah penilaian automatik dengan menggunakan alat *Loop*¹¹ telah digunakan untuk menilai kebolegunaan metrik untuk tiga kajian pembelajaran yang biasa digunakan oleh aplikasi WGIS seperti *Google maps*, *Yahoo maps*, and *MapQuest*. Akhirnya, kajian kes ini telah dibandingkan dan dianalisis berdasarkan kebolegunaan metrik yang telah dikenal pasti. Berdasarkan satu kajian perbandingan, empat kebolegunaan metrik (Keberkesanan, Kecekapan, Kepuasan dan Keupayaan belajar) telah dikenal pasti. Kebolegunaan metric-metrik ini telah menunjukkan sifat yang konsisten (tidak berubah), komprehensif (menyeluruh) dan tidak kabur (jelas) dan wajar untuk menilai kebolegunaan aplikasi WGIS. Di samping itu, terdapat perhubungan positif yang kuat di antara kebolegunaan metrik-metrik ini. Berdasarkan analisis perbandingan, *Yahoo Maps* and *MapQuest* mempunyai kurang nilai kebolegunaan berbanding *Google Maps* yang menggunakan dua kaedah. Oleh itu, *Google Maps* adalah lebih mudah untuk digunakan berbanding *Yahoo Maps* dan *MapQuest*.

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LIST OF SYMBOLS AND ABBREVIATIONS

<i>GIS</i>	-	Geographic Information System
<i>WGIS</i>	-	Web-based Geographic Information System
<i>UEMs</i>	-	Usability Evaluation Methods
<i>ISO</i>	-	International Organization for Standardization
<i>QUIM</i>	-	Quality in Use Integrated Measurement
<i>SPSS</i>	-	Statistical Package for Social Science
<i>DBMS</i>	-	Database Management System
<i>GPS</i>	-	Global Positioning System
<i>GUI</i>	-	Graphical User Interface
<i>LCD</i>	-	Liquid Crystal Display
<i>HTML</i>	-	Hyper Text Markup Language
<i>UTHM</i>	-	Universiti Tun Hussein Onn Malaysia
<i>FSKTM</i>	-	Fakulti Sains Komputer dan Teknologi Maklumat

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Today, usability is an important feature of the software development process as it can help improve the usability of systems under development. Usability evaluations can save money, time and effort if correctly introduced into the process and at the right time (Trivedi & Khanum, 2012). Usability is an important factor in ensuring the development of quality and usable software products. Ignorance and unawareness about the concept of usability and the failure to address usability during software development process has led to usability problems in software products. In addition, software quality has emerged as an important part of the software development process can prevent serious consequences, such as financial loss and reputation loss. Therefore, quality improvement after the development of software is not recommended because it only increases the cost and is almost remaking the product. Thus, poor software quality has been identified as the key factor in the success or failure of a software product (Jayaletchumi *et al.*, 2014).

In the last three decades, Geographic Information System (GIS) applications have been developed, implemented, and enhanced by scientists in many fields including geography, computer science, environmental science and others. With the emergence of the internet, GIS applications got a new ride which brings them to the new era of Web-based Geographic Information System (WGIS) applications. The focus of GIS research and development has shifted from spatial analysis tools for information retrieval. The WGIS provides basic GIS functions to users with browsers. The ability to pan, zoom, turn data layers and, more importantly, to query and view attribute data linked to mapped objects, is widely available (Akhil *et al.*, 2014).

Dependency of many human activities on information and communication technologies in general and on geographic information is increasing rapidly. This is one of the reasons why usability of specialized software tools WGIS today belongs to the top priorities of managers and users of information technologies because, nowadays spatial data and tools for their utilization in great demand from end-users too. WGIS applications can provide an easy-to-use solution to end users, but they must be properly designed (Komarkova *et al.*, 2009). WGIS applications are focused on end-users who have only a very limited knowledge of GIS, if any. For this reason, WGIS applications have to be user-friendly. In terms of software quality, WGIS applications have to be usable. Lately, various usability evaluation methods have been developed. Real users or their representatives are included in some of them. Other methods are based only on GIS experts' evaluation of applications. The advantage of deploying real users or at least their representatives is clear they are able to identify some usability problems which could not be identified by experts. Usability evaluation in a real situation done by real users is critical. Experimental user usability testing done by the representatives of users is the axis of this study (Komarkova *et al.*, 2010).

Usability evaluation is an important activity to ensure the quality of the user experience. Many usability evaluation methods can be used to assess transactional web applications, but problems come up when deciding which of the evaluation methods fetch more information. Usability evaluation methods (UEMs) are a set of techniques that are used to measure usability attributes (Otaiza *et al.*, 2010). Usability evaluation methods can be categorized into two groups: user-based methods and expert-based methods. User-based evaluation methods require a user to test the software and it mainly consists of usability tests and questionnaires. These empirical evaluation methods are better suited later on in a development process or when the system is already in use and its goal is to determine the overall usability of the system (Blecken *et al.*, 2010).

Currently, the user-based usability testing methods play a significant role in application development. The traditional usability testing approaches, such as formal user testing can be expensive, time consuming and effort intensive. On the other hand, the automating usability evaluation approach improves testing efficiency, and makes it more practical. In addition, it needs less resource-demanding and produce reliable results (Au *et al.*, 2008). In addition to automating usability testing method,

this study used a questionnaire method, because questionnaires are useful for studying how end users use the system and their preferred futures. User satisfaction, user preferences and possible uneasiness can be identified easily by using questionnaires, which can also be used to gather statistics. Due to this method, it was possible to involve a higher number of evaluators. Moreover, questionnaire is an inexpensive tool which is normally used to collect data from a large number of people 30 users being the lower limit for a study. It plays a very significant role in usability evaluation of the system. Questionnaire provides many advantages to the evaluation, the major benefit being that it gives a better understanding of the topic to the surveyor (Ali *et al.*, 2013). Therefore, the comparative analysis was achieved between questionnaire method and automating usability evaluation method for three case studies of WGIS applications.

The usability of software systems has been recognized as an important quality factor. Many definitions and models of usability have been given so far, but they are brief and informal. Most of these models also fail to cover all of the aspects of usability and are not well integrated (Ankita & Sanjay, 2012). Therefore, the main focus of this study is to describe the concept of software usability and explain it with a detailed classification of five usability models including the Shackel Model (1991), Nielsen Model (1993), ISO 9241-11 (1998), ISO 9126 (2001) and the QUIM model (2006). There are many different attributes of each model, but there are also similarities between these models.

1.2 Problem Statement

The interface of WGIS applications is difficult to learn and understand because special functions are needed to manipulate the maps (Irfan *et al.*, 2012). Hence, it is essential to evaluate the usability of WGIS applications. On the other hand, there are a number of standards and models in the literature, each of which describes usability in terms of various sets of attributes. Those models were overlapping and heterogeneous. Moreover, the lack of a cohesive model that defines usability in a uniform way leads to major problems in the evaluation of usability (Sanjay *et al.*, 2012). As a result, those models are vague and difficult to understand.

Therefore, the primary intention of this study is to compare five common usability models: Shackel (1991), Nielsen (1993), ISO 9241 P-11 (1998) ISO 9126-1

(2001) and QUIM (2006), to identify usability metrics that have most frequently in the previous models. Questionnaire method and automating usability evaluation method by using the Loop¹¹ tool were used in order to evaluate the usability metrics for three case studies of WGIS applications. Finally, the comparative study and analysis of three case studies based on usability metrics gives a better view of proper usability metrics in developing WGIS application.

1.3 Research Objectives

The main objectives of this study are:

- (i) To identify usability metrics those have most frequently used by comparing among five usability models.
- (ii) To evaluate usability metrics using the questionnaire method and automating usability evaluation method by using the Loop¹¹ tool on three case studies for WGIS applications.
- (iii) To compare and analyse the results obtained based on usability metrics using the questionnaire method and the automating usability evaluation method by using the Loop¹¹ tool among three case studies for WGIS applications.

1.4 Research Scope

This study highlights the usability evaluation of WGIS applications. For the purpose of this study, the focus was on five common usability models: Shackel (1991), Nielsen (1993), ISO 9241 P-11 (1998), ISO 9126-1 (2001), and QUIM (2006), to identify usability metrics. This study concentrates on using the questionnaire method to evaluate three case studies for WGIS applications by using the raw data that will be obtained from a survey of 45 students and staff currently in Universiti Tun Hussein Malaysia (UTHM) from different faculties, to apply Google Maps, Yahoo Maps and MapQuest for at least one week. The collected data will be analysed using the Statistical Package for Social Science (SPSS) (SPSS, 2015). Moreover, this study used the automating usability evaluation method by using the Loop¹¹ tool to evaluate three case studies for WGIS applications. Based on Effectiveness, Efficiency, Satisfaction and Learnability, three case studies for WGIS applications are

compared. The three case studies that were selected are commonly used WGIS applications (Google Maps, Yahoo Maps and MapQuest) as shown in Table 1.1.

Table 1.1: The case studies of WGIS applications.

WGIS application	URL
Google Maps	https://maps.google.com
Yahoo Maps	https://maps.yahoo.com
MapQuest	https://www.mapquest.com

1.5 Dissertation Outline

This dissertation describes and reports on the effort that was carried out throughout the duration of the project in order to achieve the project scope and objectives. This thesis is divided into five chapters that cover the whole project. Chapter 1 provides a brief introduction to usability evaluation and its role in ensuring the development of quality and usable WGIS applications. Furthermore, this chapter explains the problem statement, objectives and scope of this project. Chapter 2 introduces the different views of the authors through an overview of the literature relating to usability models, metrics and method, as well as WGIS applications architecture and components. In addition, this chapter previous related topics and works relevant to the study based on various journals, and publications are reviewed and summarized. Chapter 3 contains a discussion about the research framework. The sections in this chapter contain the framework with attached discussions of each activity conducted throughout the study. Chapter 4 presents the data gathered from the questionnaire and the automating usability evaluation method by using the Loop¹¹ tool. This chapter consists of three parts: data presentation, analysis and comparison. Lastly, Chapter 5 concludes the research. Furthermore, it also discusses research finding and future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of software usability in WGIS application. It also aims to establish significance of general field of usability engineering. The greater part of this chapter is about critical evaluation of different methodologies used in this field so as to identify appropriate approach of usability metrics in WGIS application.

2.2 Web-based Geographical Information Systems Applications

Geographical Information Systems (GIS) are computer-based systems that use geographical data in conjunction with analysis and management tools to improve decision-making abilities of organizations. Recent rapid development and increased accessibility of the internet has led to a huge tendency towards Web technologies. The applications that are being used now are called WGIS applications. Thus, it has become an indispensable part for general users and organizations. It combines decision-making abilities of GIS systems with customization, accessibility, and interactive power of the internet (Akanbi & Agunbiade, 2013).

WGIS applications are online services that provide maps and various spatial analysis and spatial processing to the users and help them to search and browse spatial data like locating different places and routes. A WGIS application is an

application that is accessible through a browser. It makes it possible for users to access GIS with its basic functionalities like searching locations, getting directions, zooming and panning and printing maps via web browsers. In other words, WGIS means that spatial data can be published, searched, analysed and displayed over the internet (Shen *et al.*, 2008). WGIS applications are defined as web-based applications that have desktop GIS application's attributes, and a WGIS application uses a browser to support an application in order to make its information accessible. WGIS applications focus on end users who often may have a very limited experience of GIS (Adnan *et al.*, 2010; Komarkova *et al.*, 2011). The WGIS architecture and GIS components in general will be discussed in the next subsections.

2.2.1 Web-based Geographical Information Systems Applications Architecture

GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes. Most WGIS applications today adopt three-tier software architecture for system implementation: client, web application server, and database server as shown in Figure 2.1 (Jyoti & Vimal, 2012; Senchenko *et al.*, 2013; Sonam & Rajan, 2014).

The first tier, called the client tier, includes the user-side web browser and user-resident Java applets/HTML documents. Users of the system can use popular web browsers: Internet Explorer, Opera, Google Chrome, and Mozilla Firefox. The Internet GIS user interacts with the client tier via a graphical user interface that is usually comprised of a map, map navigation, spatial attributes data query and spatial analysis tools. The primary function of the client tier is to edit and improve performance, user access the GIS functions, accept users' data requests and to display the results (Jyoti & Vimal, 2012; Sonam & Rajan, 2014).

The second tier, called the middleware tier, includes the web server and the server connectors, such as servlet connectors or active server pages connectors, which bridge the communication between clients and the map servers. Server side uses web remote in application server and address matching, where the server is performing storage and processing of the data file from the central database to the user query (Jyoti & Vimal, 2012; Sonam & Rajan, 2014).

The third tier is the data storage tier, which includes the map server and the spatial database server. The database side consists of many different databases for

different functionalities like storing and accessing the server in order to return the data to the client server. The web browser is used for generating server requests and displays the data results (Jyoti & Vimal 2012; Sonam & Rajan, 2014).

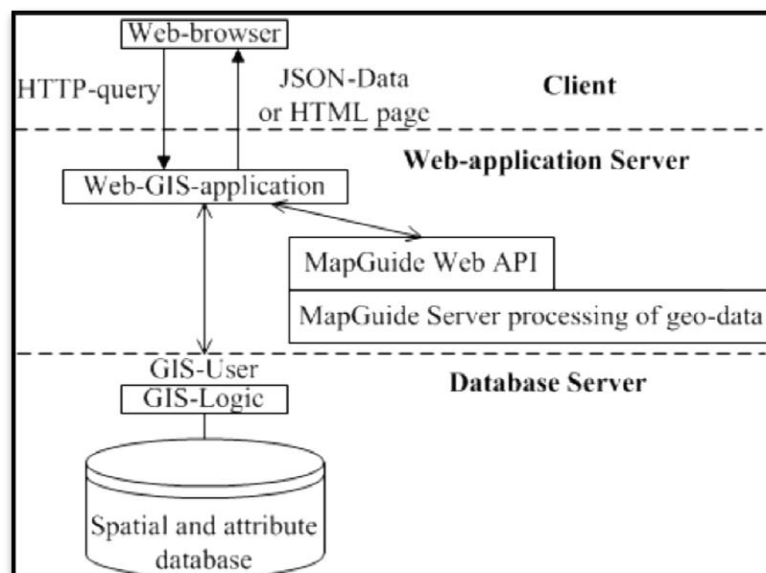


Figure 2.1: WGIS Architecture. (Senchenko *et al.*, 2013)

2.2.2 Geographical Information Systems Components

GIS is a set of computing systems having five components including hardware, software, people, data and method as shown in Figure 2.2 (Laxmana *et al.*, 2013; Sara *et al.*, 2012):

- (i) **Hardware:** It is the computer system on which a GIS operates. Today, GIS software runs on a wide range of hardware platforms. The central processing unit is the main hardware component of GIS. It is connected to a disk drive storage unit that provides space for storing data and programs. Peripherals include monitor, LCD, mobile screen, scanner, mouse, keyboard, projector, printer, a GPS instrument to collect coordinates, and a digitizer as well (Sara *et al.*, 2012; Shams *et al.*, 2012).
- (ii) **Software:** GIS software provides the functions and tools needed to store, analyses, and display geographic information. The GIS software includes the programs and the user interface to drive the hardware, including system software, such as operating system, Database Management System (DBMS),

tools for the input and manipulation of geographic information, tools that support geographic query, analysis, and visualization, a Graphical User Interface (GUI) for easy access to tools, and drawing software (Sara *et al.*, 2012; Shams *et al.*, 2012).

- (iii) **People:** GIS technology is of limited value without the people who manage the system and develop plans for applying it to real world problems. GIS users range of technical specialists who design and maintain the system for those who use it to help them perform their everyday work. The identification of GIS specialists versus end users is often critical to the proper implementation of GIS technology (Sara *et al.*, 2012; Shams *et al.*, 2012).
- (iv) **Data:** The data is the most important component of a GIS. A GIS can integrate spatial data with other existing data resources, often stored in a corporate DBMS. The integration of spatial data often proprietary to the GIS software, and tabular data stored in a DBMS is a key functionality afforded by GIS. Spatial data is data can be referenced to a location on earth e.g., country, road, river, etc. Attribute data is also called spatial data, and is data linked to the spatial data to describe those data, such as country name, road length, river width, etc. (Sara *et al.*, 2012; Shams *et al.*, 2012).
- (v) **Method:** Methods are the sets of procedures and rules for performing data input, output, storage, and management, transforming the data into information and analysis. Analysis can be performed whenever GIS users need it (Sara *et al.*, 2012; Shams *et al.*, 2012).

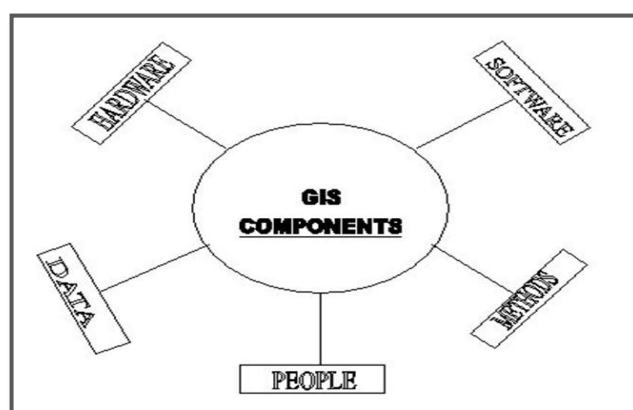


Figure 2.2: Components of GIS. (Laxmana *et al.*, 2013)

2.3 Usability Models

Usability is one of the focuses of Human Factors Psychology and Human-Computer Interaction. As the name suggests, it has to do with bridging the gap between people and machines. It assesses the quality of user interaction with the system's environment. It is considered to be one of the most important characteristics when targeting systems that will be used by widespread audiences, such as university students, without direct training and support (Tijani, 2014).

During the past few decades, several different standards and models for assessing usability have been proposed. This section reviews some of these models, highlighting the attributes on which usability has been considered to depend. McCall's model (1976) described usability as operability, training and communicativeness (Suman & Manoj, 2014). Boehm's model (1978) proposed that a software is usable if it is portable and maintainable (Suman & Manoj, 2014). Eason model (1984) has 3 aspects: task, user and system. For task, it has 2 sub attributes: frequency and openness. User has 3 sub attributes: knowledge, motivation and discretion. The system has ease of learning, ease of use and task match. The Eason Model cannot measure usability without considering users and their target task (Madan & Dubey, 2012). Shackel (1991) explained that a system is usable if it is effective, learnable, flexible and subjectively pleasing (Madan & Dubey, 2012). Nielsen (1993) refers to learnability, efficiency, memorability, errors and satisfaction as usability attributes (Leventhal & Barnes, 2008). ISO 9241 part 11 (1998) defines the usability by three metrics: Effectiveness, Efficiency and Satisfaction (Hair *et al.*, 2011). ISO 9126-1 (2001) defines a quality model that describes six categories of software quality; they are functionality, reliability, usability, efficiency, maintainability and portability. There are four metrics under usability, which are understandability, learnability, operability and attractiveness (Madan & Dubey, 2012). The QUIM model (2006) describes usability as comprising of 10 factors, namely, efficiency, effectiveness, productivity, satisfaction, learnability, safety, trustfulness, accessibility, universality and usefulness (Madan & Dubey, 2012).

Based on usability researches reviewed in the discussion above, these researchers spent much effort and time trying to find the best way to define usability by defining attributes that can be measured and compose the usability. In this study, finding or giving the best attributes of usability is the goal. Therefore, this study is

restricted to discussing five usability models including Shackel's model (1991), Nielsen model (1993), ISO 9241-11 (1998), ISO 9126 (2001) and QUIM (2006), which have been most widely recognized and used in practice (Aziz *et al.*, 2013).

Although there is a consensus about the term "usability", there are many different models of how usability should be measured, and it has been defined differently, because authors have different opinions on how to measure it. There are many definitions of usability: Shackel (1991), Nielsen (1993), ISO 9241-11 (1998), ISO 9126 (2001) and QUIM (2006). Although not all authors call the entities, which to them compose usability, usability attributes. Sometimes these entities are called dimensions, components, scales or factors of usability. It is the author's opinion that they mean the same. As a result, the term "usability metric" is used, which is the most appropriate term (Folmer & Bosch, 2004). The following subsections will discuss these models of usability.

2.3.1 Shackel's Model of Usability

Shackel's model was developed by Brian Shackel in 1991. He highlighted the importance of usability and the definition of its concept proposed to measure usability. His model offers a descriptive definition of usability as: the usability of a system is the capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and user support, to fulfill the specified range of tasks, within specified range of scenarios. He considered four metrics to measure the usability as illustrated in Figure 2.3: Effectiveness means speed and free from errors. Learnability means time to learn and retention, Flexibility means adaptation to tasks and environments and Attitude means likeability (Madan & Dubey, 2012). The model does not weight dimension, recognizing that the importance of each of these may differ from project to project. It emphasizes the measurement of a number of human factors relating to human performance and attitude (Leventhal & Barnes, 2008; Madan & Dubey, 2012).

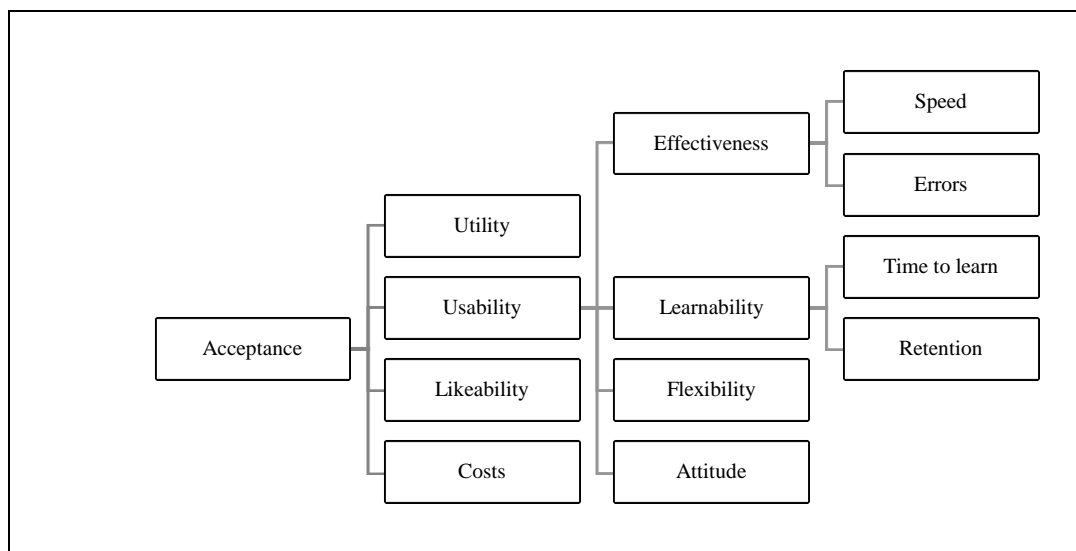


Figure 2.3: Usability definition of Shackel model. (Shackel, 1991)

2.3.2 Nielsen's Model of Usability

The Nielsen's model was developed by Jakob Nielsen in 1993. He considered usability as one of many attributes of system's acceptability that must be able to satisfy users' needs. The model had divided acceptability into practical and social acceptability. As depicted in Figure 2.4, practical acceptability is the collection of reliability, cost, compatibility and usefulness, etc. Usability and utility together combine to achieve the usefulness of a system. He considered five metrics as depicted in Figure 2.4, without providing any descriptive definitions of usability, i.e. Learnability means easy to learn; Efficiency means efficient to use; Memorability means easy to remember; Errors means low error rate and Satisfaction means pleasant to use. It focuses on acceptability, which means that if the system is not useful, such as does not meet the user's requirement, it will not accept it whether it is usable or not. Like the Shackel's model, the Nielsen model also does not weight the dimension, recognizing that the importance of each of these may differ from project to project (Leventhal & Barnes, 2008; Madan & Dubey, 2012).

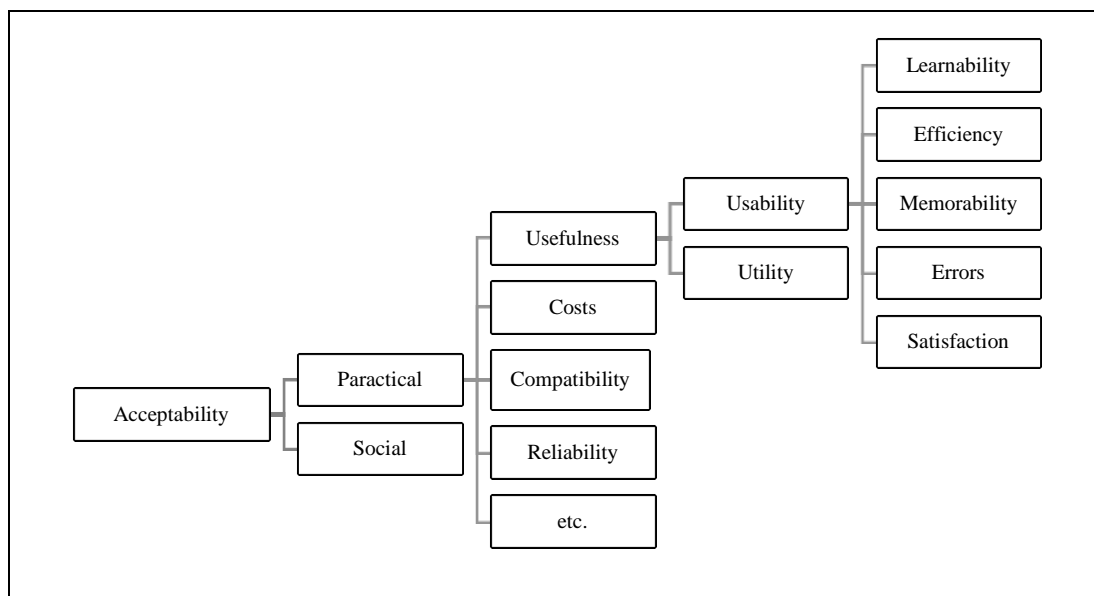


Figure 2.4: Usability definition of Nielsen's model. (Nielsen, 1993)

2.3.3 ISO 9241-11 Model of Usability

ISO is International Organization for Standardization 9241-part 11 in 1998 discusses usability for the purposes of product requirement specifications and product evaluation. It explains the benefits of measuring usability in terms of user performance and satisfaction. Usability is defined as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, and satisfaction in a specified context of use”. The three usability metrics presented according to ISO 9241 part 11 as depicted in Figure 2.5. Effectiveness, which is described the interaction from process viewpoint; efficiency, which focus on results and resources involved, and satisfaction, which is a user viewpoint (Hair *et al.*, 2011).

This definition accommodates two different views from users' perspective. One is the user performance that includes effectiveness and efficiency, and the other is the user view which is concerned with the issue of satisfaction (Madan & Dubey, 2012). This model adopted in Part 11 of ISO 9241 has advantages of objective measures of usability (Yen, 2010). The ISO 9241-11 model identifies usability aspects and context-of-use components to be taken into consideration during specification, design and usability evaluation. User performance and satisfaction provide direct measurements of usability in a particular context. User performance

and satisfaction measurements provide a basis for comparing usability with other design features for the same context. Usability can be defined and verified within quality systems conforming to ISO 9001. By contrast, this standard also has some disadvantages as it is too abstract and does not tackle the learnability metric, as recommended by majority of standards and experts (Hussain & Ferneley, 2008).

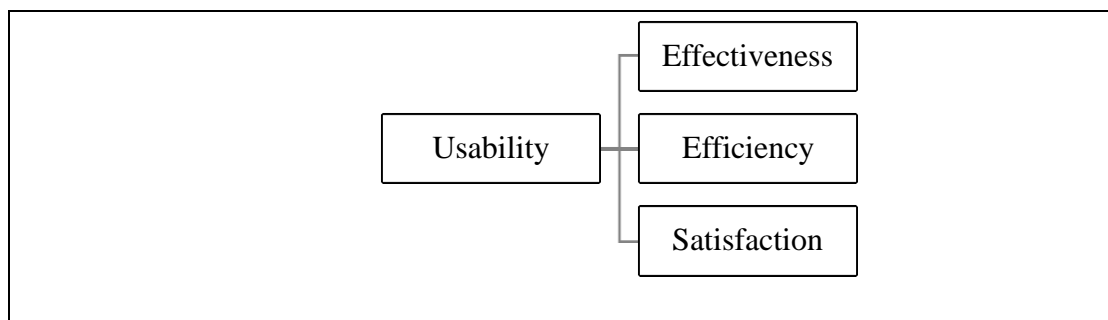


Figure 2.5: Usability definition of ISO 9241-11 Model. (ISO 9241 – 11, 1998)

2.3.4 ISO 9126 Model of Usability

ISO 9126 is an international standard for the evaluation of software quality from product perspective in 2001. It defines a quality model that describes six categories of software quality as depicted in Figure 2.6, which are relevant during product development; they are functionality, reliability, usability, efficiency, maintainability and portability (Abran *et al.*, 2003). There are four metrics under usability, i.e. understandability, learnability, operability and attractiveness. Understandability is the capability of software product to enable user to understand whether the software is suitable and how it can be used for particular tasks and conditions of use; Learnability is the capability of the software product to enable user to learn its application; Operability is the capability of the software product to enable the user to operate and control it; Attractiveness is the capability of the software product to be attractive to users, such as the use of colors or nature of graphical design (Madan & Dubey, 2012). The advantage of the ISO 9126 model is that it provides a framework for making trade-offs between software product capabilities and the attributes that are applicable to any kind of software including computer programs while providing consistent terminology for software product quality. The disadvantage of ISO 9126 is unclear architecture at detailed level of the measures, overlapping concepts, lacking

of a quality requirement standard, lacking of guidance in assessing the results of measurement and ambiguous choice of measures (Yen, 2010).

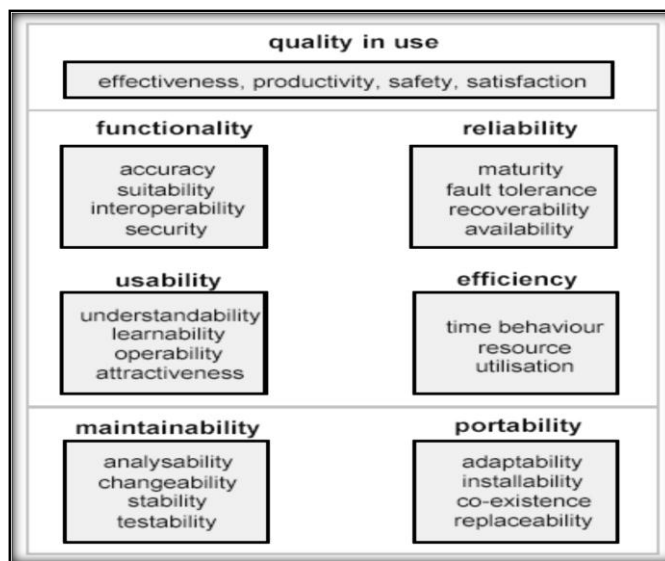


Figure 2.6: ISO 9126-1 Quality Model. (Folmer & Bosch 2004)

2.3.5 Quality in Use Integrated Measurement (QUIM)

QUIM or Quality in Use Integrated Measurement was developed by Seffah *et al.* (2006). QUIM is a consolidated model for usability measurement and metrics. It combines various standards and models such as ISO 9241 and ISO 9126 unified into a single consolidated, hierarchical model. It outlines methods for establishing quality requirements as well as identifying, implementing, analysing, and validating both process and product quality metrics. This model consists of 10 factors as depicted in Figure 2.7 which are: Efficiency, Effectiveness, Satisfaction, Learnability, Productivity, Safety, Trustfulness Accessibility, Usefulness and Universality (Seffah *et al.*, 2006). The model is used to measure the actual use of working software and identifying the problem. Since QUIM has limitations, it is not yet optimal and needs to be validated (Tijani, 2014).

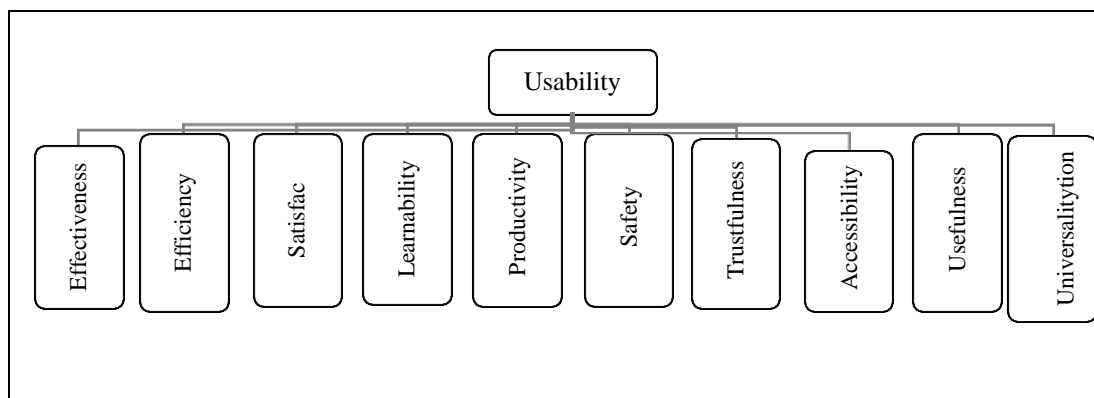


Figure 2.7: QUIM Model. (Seffah *et al.*, 2006)

2.4 Comparative Study of Usability Models

This section discusses the differences and similarities between usability models that have been presented here. In the usability models of Shackel (1991), Nielsen (1993), ISO 9241 P-11 (1998), ISO 9126-1 (2001) and QUIM (2006), there are many metrics of symmetry between usability models. Authors in the usability domain have different perceptions about usability metrics. However, usability has different definitions that are largely overlap. Some authors have used different names for the same metric. For example, error for Nielsen's model, effectiveness-error for the Shackel's model and effectiveness for the ISO 9241 P-11 model are similar; the attributes for the Shackel's model is similar to satisfaction for Nielsen's model, ISO 9241 P-11 model and attractiveness of ISO 9126 model as well. Moreover, Effectiveness-task time for the Shackel's model is similar to efficiency in the Nielsen's model and the ISO 9241 P-11 model. In addition, QUIM (2006) has efficiency, effectiveness, satisfaction and learnability, and these metrics have frequency metrics used in previous usability models. Therefore, they are very difficult to be used and to communicate. The lack of a consistent model leads to major problems in the evaluation of usability (Folmer & Bosch 2004).

Overall, most usability metrics with most frequently used are effectiveness, efficiency, satisfaction and learnability in some of the usability models that have been discussed in this study. Four attributes were selected based on frequency in each model. The selected metrics are effectiveness, efficiency, satisfaction and learnability.

2.5 Usability Metrics

Based on the previous discussion, this study used four metrics: Effectiveness, Efficiency, Satisfaction and Learnability. The author perception, these usability measurements will make usability concepts more ideal, realistic and meaningful. This refinement is done in order to ensure systematic measurements for evaluating the usability of WGIS applications thoroughly. The following subsections discuss the four main usability metrics:

2.5.1 Effectiveness

According to ISO/IEC 9126-1 (2001), effectiveness is defined as the capability of the software product to enable users to achieve specified goals with accuracy and completeness in a specified context of use. It has an objective definition that indicates whether the system is able to support the users in an effective way, whether the user can carry out the tasks by the fewest steps. Effectiveness is more about the accuracy and completeness with which users can achieve certain goals. This means that users are focused to complete the main reason to use the product. Effectiveness can measure the user's interactions with the system by error rates while attempting to complete the task or how many answers are correct (Sanjay *et al.*, 2012). Effectiveness is the ability of a user to complete a task in a specified context. Typically effectiveness is measured by evaluating whether or not participants can complete a set of specified tasks (Rachel *et al.*, 2013).

2.5.2 Efficiency

According to ISO (2001), Efficiency is the capability of a software product to provide appropriate performance, relative to the amount of resources used, under stated conditions. It has an objective definition, which refers to whether the system can achieve the objectives of users (Changqing *et al.*, 2005). Furthermore, efficiency is described as a quality of the user interface, which characterizes how efficiently the user can complete his task (Chang & Dillon, 2006). Efficiency is the ability of the user to complete their task with speed and accuracy. This attribute reflects the productivity of a user while using the application. Efficiency can be measured in a

number of ways, such as the time to complete a given task, or the number of keystrokes required to complete a given task (Rachel *et al.*, 2013).

2.5.3 Satisfaction

ISO 9126-I (2001) defines satisfaction as the capability of the software product to satisfy users in a specified context of use. Satisfaction also refers to users' subjective assessment of the system concerning how pleasant it is to use. Satisfaction is the perceived level of comfort and pleasantness afforded to the user through the use of the software. This is reflected in the attitudes of the user towards the software. This is usually measured subjectively and varies between individual users. Questionnaires and other qualitative techniques are typically used to measure a user's attitudes towards a software application (Rachel *et al.*, 2013).

2.5.4 Learnability

Based on Nielsen's usability model (1993), learnability refers to how easy it is for casual users to learn a system. In websites with high learnability, users feel they are able to start using the site with a minimum of introductions and everything is easy to understand from the start. In websites with low learnability, users feel that the site may be using concepts or terminologies which are unfamiliar and need more explanations (Mentes & Turan, 2012). Learnability is the ease with which a user can gain proficiency with an application. It typically reflects how long it takes a person to be able to use the application effectively. In order to measure Learnability, researchers may look at the performance of participants during a series of tasks, and measure how long it takes these participants to reach a pre-specified level of proficiency (Rachel *et al.*, 2013).

2.6 Usability Evaluation Methods

Usability evaluation is an important activity to ensure the quality of the user experience. Many usability evaluation methods (UEMs) can be used to assess transactional web applications, but problems come up when deciding which of the evaluation methods fetch more information (Otaiza *et al.*, 2010). UEMs play an

important role in the design of most WGIS applications because usability aspects included in product design give credibility to the company and customers are more satisfied with their products, and therefore several methods have been proposed by scholars for evaluation. However, UEMs are not standardized by classification on the basis of different usability expert's opinions (Woolrych *et al.*, 2011).

According to (Nielsen, 1993), usability testing with real participants is a fundamental evaluation method; it provides an evaluator with direct information about how users use products and what some of the problems are with the interface being tested. During usability testing, participants use the system or a prototype to complete a pre-determined set of tasks while the tester or software records the results of the participants' work. The tester then uses these results to determine how well the interface supports users' task completion and to derive other measures such as the number of errors and task completion time.

The questionnaires method can be used to collect both quantitative and qualitative data, which can consist of different types of questions, multiple choice questions and a rate scale as well as closed or open-ended questions. It is used to collect both quantitative and qualitative data and allows one to involve a higher number of evaluators to obtain their opinions, desires and expectations; it is an efficient and inexpensive method and does not require much time or effort from the participants (Blecken *et al.*, 2010; Preece *et al.*, 2011; Ali *et al.*, 2013).

Automated usability evaluation tries to remedy some of the disadvantages and problems associated with established usability evaluation methods. For example, traditional evaluation methods are often not systematic and predictable enough. One solution for this problem is to automate usability evaluation method. According to Au *et al.* (2008), automated usability testing is a logical solution because traditional evaluation methods carry several disadvantages, for example high complexity and resource inefficiency. Automated usability evaluation methods, on the other hand, can be very cost and time-efficient. Automation leads to several potential benefits, such as decreased costs, increased consistency between results, and a reduced need for evaluation expertise. Automation can help to boost the acceptance of usability evaluation and leads to better products and better market performances. Several existing tools are typical of the tools available today to meet requirements, such as Loop¹¹, UserZoom and Optimal Workshop. Loop¹¹ tool is a web-based usability and user experience testing tool. Loop¹¹ is a unique usability testing tool in that it allows

usability testing with actual users. It is simple to use with no code required, provides real data from real users, and can be used on any web site (Loop¹¹, 2015). Therefore, in this study the questionnaire method and automated usability evaluation by using the Loop¹¹ tool were used.

2.7 Related Works

Many researches have employed usability evaluation methods to evaluate web-based applications. Therefore, this section will review some of the research related to the evaluation of Web-based applications and WGIS applications by using usability evaluation methods. However, the main focus is on usability metrics.

Wang (2014) produced usability evaluation methods, such as usability testing and questionnaires, aimed at exploring the usability problems of four public web mapping sites Google Maps, Bing Maps, MapQuest and Yahoo Maps. In addition, analysing the problems quantitatively and qualitatively by using usability metrics effectiveness, efficiency and satisfaction. 42 people, having different WGIS skills, genders, ages and nationalities, participated in this test to complete the several test tasks in different teams. The test comprised three parts: a pretest background information questionnaire, several test tasks for quantitative statistics and progression analysis, and a post-test questionnaire. The pretest and post-test questionnaires focused on gaining verbal explanations of their actions qualitatively. The success rate from different public web mapping sites was calculated and compared. The answers from questionnaires were also classified and organized. Based on the analysis, discussions were produced about the problems and advice was proposed about aspects of user interface, functionality, search operations and visualization in order to enhance the performance of the websites.

Martin & Thomas (2013) focused on a WGIS application for mapping purposes such as Google Maps or Bing Maps for educational purposes by using the thinking-aloud and questionnaires of usability evaluation methods. The test was in a common classroom at their school with a desktop computer. A camera was placed to record all tests. The testers were asked to think aloud while working on the given tasks. The tasks were focused on some specific functions. Immediately after completing the test tasks, the testers were given a questionnaire, in which they were asked to give some information about themselves, such as prior knowledge about

GIS or experience with computers and about personal opinions about the design. Test candidates were teenagers between 16 and 17 years old from a German secondary school. The test time was conducted 100 minutes to test the prototype with 9 testers, 4 of which were female and the 5 of which were male. During the test session problems and major issues with the tested prototype became apparent. The experimental results showed the efficiency of WGIS applications by comparing the total number of clicks needed by the users to complete each task and the needed time in seconds and show the correlation of these two parameters captured in the usability test.

Soohyung *et al.* (2011) proposed a usability evaluation model and a practical survey tool tailored to academic library websites. The authors verified the reliability and validity of the usability evaluation model empirically using the survey data from actual users by statistical analysis, such as descriptive statistics, internal consistency test, and a factor analysis, were applied to ensure both the reliability and validity of the usability evaluation tool. This study identified eighteen measurement items to survey the three constructs of the usability, effectiveness, efficiency, and learnability in academic library websites. The empirical examination based on 147 actual user responses proved that the survey evaluation tool suggested herein is acceptable in assessing academic library website usability.

Komarkova *et al.* (2010) proposed the think-aloud method as a suitable experimental method based on usability testing to identify the most serious usability problems of 14 equal WGIS applications, where all applications were run by the Czech Regional Authorities and are targeted at citizens and other end users. The proposed method is qualitative, so its main aim was to identify the most serious usability problems of the evaluated applications by preparation and verification of the task list which included 20 tasks. For each item on the task list, the percentage share of tasks completion as effectiveness. While the average time needed to finish a task as efficiency. The results showed that the proposed method of testing identified all usability problems that were found for each evaluated WGIS application and were classified into three main types: fatal, serious and slight problems.

Khan & Adnan (2010) evaluated usability issues of WGIS applications Google Maps and MapQuest to discover usability problems. For this purpose, think aloud, questionnaire and interviews were used. Special criteria were adopted for usability evaluation effectiveness, usefulness, user reaction, consistency,

architectural and visual clarity, and functionality for WGIS applications evaluation. Usability tests were performed with six graduate users and questionnaires were filled out by these users. Interviews were conducted with six users to validate the results. The authors provided a number of suggestions based on the problems that were identified in this study for Google Maps and MapQuest to improve the usability of these applications.

The overall summary is described in a tabular form for a quick review and comparison of the usability evaluation methods among the previous related works. Table 2.1 shows a comparison summary of the related works for evaluating WGIS applications.

Table 2.1: Review the comparison among the related works based on of usability metrics.

Author (Year)	Research Title	Usability Metrics	UEMs	Research Finding
WANG (2014)	Usability Evaluation Of Public Web Mapping Sites	Effectiveness, Efficiency and Satisfaction	Usability Testing and Questionnaire	His study aimed to explore usability problems of Google Maps, Bing Maps, MapQuest and Yahoo Maps. The results showed Google maps is the most suitable for participant to get the desirable results and can satisfy the participants' needs. And the less usable web mapping sites is Map Quest.
Martin & Thomas (2013)	Usability Engineering for Educational Web GIS	Efficiency	Think-Aloud Method and Questionnaire	In their study, usability testing with questionnaires used to assess the performance of the WGIS application such as Google Maps and Bing Maps for educational purposes in a realistic environment. Implications from this test give insight into design rules for usable WGIS for educative use.
Soohyung <i>et al.</i> (2011)	A Usability Evaluation Model for Academic Library Websites: Efficiency, Effectiveness and Learnability	Efficiency, Effectiveness and Learnability	Questionnaire	Their study proposed the eighteen measurement items to evaluate the main three usability attributes of academic libraries, effectiveness, efficiency, and learnability. The empirical examination proved the survey evaluation tool suggested is acceptable in assessing academic library website usability.

Table 2.1 (Continued).

Author (Year)	Research Title	Usability Metrics	UEMs	Research Finding
Komarkova <i>et al.</i> (2010)	Usability Evaluation of Web-based GIS – Case Study	Effectiveness and Efficiency	Think-Aloud Method	Their study used think-aloud method as usability testing to identify the most serious usability problems of 14 equal WGIS applications. The finding was that Google Maps was found interesting by evaluators. On the other side, they experience some difficulties in some applications user interface elements.
Khan & Adnan (2010)	Usability Evaluation of Web-based GIS Applications A Comparative Study of Google Maps and MapQuest	Effectiveness, Usefulness, User Reaction, Consistency, Architectural Visual Clarity, and Functionality	Think Aloud, Questionnaire and Interview Methods	In their study, usability issues of WGIS applications Google Maps and MapQuest were evaluated to discover usability problems. The number of problems that were identified in MapQuest. So, the results showed Google Maps has the highest usability metrics compared with MapQuest.

2.8 Research Gap

In recent years, the usability of software systems has been recognized as an important quality factor. Many standards and models in the literature are used for usability evaluation, each of which describes usability in terms of a various set of attributes. Those models are overlapping and heterogeneous. It is very complicated to choose many attributes among the models, therefore, the primary purpose of this study is to compare five common usability models: Shackel (1991), Nielsen (1993), ISO 9241 P-11 (1998), ISO 9126-1 (2001) and QUIM (2006), to reveal the existing research gap, which is the lack of a cohesive model that defines usability in a uniform way, which leads to major problems in the evaluation of usability (Sanjay *et al.*, 2012). As a result, those models are vague and difficult to understand. In this study, usability metrics were identified with the most frequent attributes that have been widely used in the previous models.

2.9 Summary

This chapter provides a comprehensive review of the relevant literature. It first offered an overview of WGIS applications architecture and elements. Then, it reviewed the usability models including five usability evaluation models, and gave a comparative survey of them. Usability evaluation methods and the representative literature were also discussed. The basic concepts and distinguishing characteristics were summarized. Moreover, it discussed previous studies that are closely related to this research regarding usability evaluation. The next chapter turns to the research methodology of this study.

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