Evaluation of e-government applications based on ISO/IEC 9126 model

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ABSTRACT: E-government is being adopted by many governments in recent times as a means for easier and faster way for the provision of government services to the citizenry. Despite the known advantages of e-government, literature show that some e-government implementations fail to meet the maximum quality standards. Poor quality e-government services fail to provide the needed quality of service to the citizenry. Like any other web platform, it is imperative to evaluate e-government platforms to ensure maximised quality of service for the benefit of the citizenry. This study evaluates five (5) e-government applications in Ghana based on the ISO 9126 quality model. Results from the study shows that all the five (5) evaluated applications are highly functional and portable. However, there were issues with the reliability test since some of the applications performed poorly when they were subjected to stress. It is recommended that the reliability of those applications be thoroughly reviewed.
KEYWORDS: E-government, software quality, web applications, mathematical model, ISO quality model

1. INTRODUCTION

Using the Internet as a platform for the provision of important services for the citizenry has become very affordable and convenient as a result of the proliferation of wide variety of smart devices such as smart phones, tablets, laptops and the likes. As a result, many countries all over the world have adopted e-government to their advantage [3][1]. E-government stands for electronic government and it is the use of telematics to provide improved government services in a more efficient and effective manner, thereby, providing better services and easy information access to the general public [25]. E-government has numerous advantages such as providing a 24-hour accessibility to public services, improving service and efficiency, among others [24][2]. Despite the known advantages, available literature show that some e-government implementations fail to meet stakeholders' needs and expectations and therefore, face several barriers such as usability challenges, portability problems, functionality issues and others [20]. It is therefore necessary to evaluate such web applications to enable software designers and developers identify potential problems faced by users in order to expose and eliminate the flaws most e-government and related systems are exposed to.

Web applications need to be designed to meet software quality standards. Software quality standards have been stipulated by researchers and international bodies such as IEEE and ISO as a benchmark for assessing developed software.

There exist various definitions for software quality by software quality expects. Software quality refers to the conformance to a specification and meeting customer needs which are independent of quantifiable attributes [12]. Software quality connotes the conformance to explicitly stated functional software requirements in other to meet the expected characteristics of professionally developed software [31]. It is also defined by [25] as the degree to which systems, processes and components meet specified user requirements [3]. Additionally, ISO defines it as the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs [22].

Incorporating software quality into the design of e-government applications is of great importance since it achieves stakeholders' needs and increases confidence in usage of application as users are provided with efficient and effective services. Software quality is ensured using quality models which contain quality attributes that may be used to determine the quality of software.

This research presents an evaluation of e-government applications in Ghana based on the ISO 9126 quality model. It also analyses and discusses the ISO 9126 quality model and bases on the mathematical models of its software quality attributes or factors to evaluate five (5) e-government web applications.

The rest of the paper is organized as follows: Section 2 discusses the related works done on ISO 9126

model and e-government web applications. Section 3 covers the research methodology used. Section 4 presents the results and discussions while Section 5 also presents the conclusion and recommendations.

2. RELATED WORKS

2.1. ISO/IEC 9126 Quality Model

ISO/IEC 9126 software quality model is an internationally accepted standard for the evaluation of software quality and was proposed by the International Organization for Standardization (ISO) in 1991 [34]. ISO 9126 evaluates the quality of a software product in terms of internal and external software qualities and their connection to attributes. It comprises two (2) parts [18].

The first part is an extension of previous works done by McCall [21], Boehm [6], and FURPS. It determines the quality of a developed software using six independent high-level quality attributes namely [32]: functionality, reliability, usability, efficiency, maintainability, and portability. These attributes further contain twenty-seven (27) sub-attributes.
The second part is the quality-in-use metric and contains four attributes namely: effectiveness, productivity, safety and satisfaction [14]. This determines the external quality of software and allows it to fulfil the explicit and implicit needs when used under certain conditions.

2.1.1. Efficiency

Efficiency refers to the ability of software to perform well, given that tasks are completed faster while using fewer resources and saving computer power with great performance. According to researchers in [15], for assuring and improving software quality, it is necessary to ensure that the developed software is highly efficient.

McCall defines efficiency as the number of computing sources and code required by a program to perform its function; Boehm defines it as the ability of the software to satisfy its purpose without waste of resources; Dromey defines it as the capability of the software to adequately perform irrespective of the number of resources used; ISO defines it as the degree to which software makes optimum utilisation of the resources [35].

2.1.2. Functionality

Functionality pertains to the degree to which software satisfies its stated needs [10] and serves as one of the important software quality attributes. It reflects how well a software complies with its given design. Developing a highly functional e-government website makes interactions efficient and effective as access to various functions turn out easier and faster. Although functionality is a key attribute in quality assurance, most works have not given much consideration to it and there are still ongoing works being done on functionality evaluation of software [30].

2.1.3. Maintainability

Software maintainability, according to a study performed by [16] is one of the important user's perspective software quality attributes and hence, needs to be considered during the development of applications such as e-government websites. It may be defined as the ease with which software can be modified to correct faults in other to improve performance. Maintainability of software has been evaluated by researchers such as [5] and is contained in most proposed software quality models [16][6][21].

2.1.4. Reliability

Software reliability is one of the important attributes in assessing the quality of a software product. It is defined by the American National Standards Institute (ANSI) as the probability of failure-free software operation for a specified period in a given environment [29]. It has gained importance due to its key function in the success or failure of software. Studies have been done by researchers such as [10][5] in measuring software reliability.

2.1.5. Usability

According to [23], usability connotes the ease of use of a product, its efficiency, and error tolerance; these are in addition to the easy navigation, memorability, learnability, readability, and satisfaction as affirmed by [17]. Hence, usability has been grouped by [11] under five (5) E's:

Efficiency, Engaging, Easy to Use, Effectiveness, and Error Tolerance. Usability is concerned with the software user interface, its design, and performance. Software usability evaluation is significant because it helps to evaluate performance as well as user satisfaction [26].
Software is designed for an organisation to ensure suitability, profitability, and accessibility [33]; therefore, usability evaluation is significant to improve performance and speed [13].
Once users find a software not usable and difficult to navigate, they leave immediately.

2.1.6. Portability

Portability is a measure of the ease of transferring software from one computing environment to the other. According to a study performed by [16], it is one of the vital software quality attributes that are of importance to users. In that regard, it is of essence to evaluate e-government applications for portability in other to assess its usage on multiple platforms. Software portability assessment has been performed by researchers such as [7][5] and others.

2.2. E-Government Applications

Organisations such as banking, finance, education, government, entertainment and business have incorporated telematics into the manual work to provide easier and faster services to clients. This is as a result of the increasing reliance on smart devices to perform human activities [19]. It has been recorded by [36] that the daily number of website users is about tens of millions and has led to an expansion in the number of developed web applications. Organisations are taking advantage of the increasing usage to disseminate their information through the internet to website users. As a result, there has been an evolution of e-government applications as government services seek to involve the general public into its operations in order to provide efficient and faster services.

Nonetheless, e-government services have failed to meet user satisfaction due to the provision of less quality applications [8]. In order to provide quality web applications, researchers have proposed various techniques such as website quality evaluation, usability evaluation technique and quality assurance models for evaluating e-government applications [19]. However, most works only focus on the usability of web applications and fail to evaluate the other software quality characteristics [4]. This study employs the use of the ISO 9126 model which contains six quality attributes namely: functionality, reliability, usability, efficiency, maintainability, and portability to evaluate e-government applications.
E-government website usability was evaluated by authors in [20] using a Systematic Literature Review (SLR) to access the best usability evaluation method. They initially selected 519 research works which were further extracted to produce 22 selected references. Furthermore, the method used was grouped into usability testing, inspection method and use of inquiry. The results obtained could aid academicians and practitioners in evaluating e-government websites.

Authors in [28] also performed a functionality evaluation where they assessed the functions and features of e-government websites in Indonesia. They used a survey approach and identified that functions related to transactions are focused on efficiency and appeal whereas functions for general services focus on appeal, quality and personalization. The authors suggested that developing a successful e-government website was dependent on considering the functionality and features that are of importance to the citizens.
In [1], the authors examined web developer's perspective on the accessibility of e-government services for persons with disabilities in Ghana. Qualitative survey approach was used for obtaining the data from the web developers and was transcribed using otranscribe. The data was then analysed using thematic analysis. Results obtained showed that web developers lack knowledge on accessibility needs of persons with disabilities.

A quality model was proposed by researchers in [27] for evaluating e-government web services by employing the ISO/IEC 9126 model. The model was proposed to serve as a benchmark for web developers in designing e-government services and consists of twenty quality attributes which are grouped under supply side and demand side. The supply side includes fifteen (15) quality attributes which are suitability, accuracy, interoperability, security, maturity, fault tolerance, changeability, time behaviour, stability, testability, installability, recoverability, resource behaviour, analysability, and compliance. The demand side also consists of understandability, learnability, operability, compliance and privacy.

Authors in [5] carried out a usability analysis on a web application. The analysis was done based by administering a questionnaire to seventy-five (75) respondents. The reliability of the questionnaire was calculated using Cronbach Alpha's mathematical method and then modelled using SPSS software. The results showed that the web application was able to be understood, studied, used, and attractive to users. In addition to the usability analysis, a functionality analysis was done using a survey-based approach with 3 experts in web development. Sixty (60) web functions were assessed and all experts evaluated the functions as "working correctly".

3. METHODOLOGY

3.1. Web Applications Evaluated

The e-government applications evaluated are listed in Table 1 with their corresponding Uniform Resource Locators (URLs) and have been masked up due to ethical reasons.

Table 1: List of Web-applications

Web Application Name	Domain Name
Application1	https://www.application1.org.gh/
Application2	https://application2.gov.gh/
Application3	https://application3.gov.gh/
Application4	http://www.application4.gov.gh/
Application5	http://application5.gov.gh/

The applications are evaluated based on the ISO 9126 software quality attributes: Maintainability, Reliability, Portability, Functionality, Usability and Efficiency.

3.2. Research Method Used

The study performs an evaluation on e-government web applications based on the mathematical models of the six (6) software quality attributes.

3.2.1. Evaluation of Efficiency

The efficiency of a software is evaluated using throughput and bandwidth. Throughput is the number of items processed per unit time, such as bits transmitted per second, HTTP operations per day, or millions of instructions per second (MIPS) whiles Bandwidth is the measurement of the amount of data a software uses during a specific time frame. The efficiency of the selected web-based applications are evaluated using equation (1).

$$E = \frac{ST}{SB} . 100 \quad (1)$$

where,
ST = Throughput; and
SB = Bandwidth.

3.2.2. Evaluation of Functionality

Functionality has a direct relationship with the components of the software. It can be evaluated mathematically using the working and not working functions in the software as shown in (2):

$$F_n = 1 - \left(\frac{A}{B}\right) . 100 \quad (2)$$

where,
A= Number of functions that are not working correctly; and
B= Number of functions that are working correctly.

3.2.3. Evaluation of Maintainability

Maintainability of a software can be evaluated in terms of its Mean Time to Repair (MTTR) and is expressed mathematically in (3) as:

$$M = MTTR \quad (3)$$

MTTR is in turn expressed in terms of downtime and number of failures a web application encounters during operation. This is expressed in (4) as:

$$MTTR = \frac{\text{Total Downtime}}{Number\ of\ Failures} \quad (4)$$

3.2.4. Evaluation of Reliability

To test for the Reliability of a software, it is necessary to test it under ways it is likely to encounter failure. This is done by conducting high accelerated life tests where the software is put under stress to determine the limitations. Where failure occurs, the manner in which it occurred is determined. Reliability of a system varies exponentially as a function of time, t. It can be expressed in (5) as:

$$R = e^{(-\lambda.t)} \quad (5)$$

Software reliability is a probabilistic feature and ranges between 0 and 1, hence, increases when bugs are removed from software. Software reliability is a key feature in determining software quality.

3.2.5. Evaluation of Usability

The study assesses the usability of software using a survey approach based on questions modelled from the System Usability Scale (SUS) and Post-Study Usability Questionnaire (PSSUQ). The survey approach took responses from users regarding features of the web applications such as the navigation, clarity of information, effectiveness, learnability, understandability, and others.
The questionnaire as shown in Table 2 was administered to users and was filled using a survey scale defined from 1 to 5, with 1 as Strongly Disagree, 2 as Disagree, 3 as Neutral, 4 as Agree, and 5 as Strongly Agree.
Usability was then evaluated using (6) as:

$$U = \frac{TS}{MS} . 100 \quad (6)$$

where,
TS = Total Score; and
MS = Maximum Score.

Table 2: Usability Questionnaire

No.	Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
		5	4	3	2	1
1	It is easy to navigate within the web application					
2	It was easy to find the information I need					
3	The organisation of information on the web application is clear					
4	The interface of the web application is pleasant					
5	I found the images on the web application useful					
6	Content on the web application was presented in the right manner					
7	The size of web controls was appropriate					
8	It took less time to load the web application					
9	The web application has all the functions I expect it to have					
10	Overall, I am satisfied with the web application					

Total Score was calculated by summing up the scores from the questionnaire.
Maximum score was calculated by multiplying the total number of respondents by the number of survey questions and the number of survey scale used.

3.2.6. Evaluation of Portability

This is an attribute of a software that depicts the ease with which software or an application can run across various computing platforms. Portability test can be done across hardware platforms, operating systems or web browsers. This helps to find out the ease of which a software component from one computing environment can be used in another. Portability is expressed as a form of accelerated motion in (7) as:

$$P = \frac{1}{2} . (at^2 + vt + T \qquad (6)$$

where
a = acceleration of the software on various platforms;
t = time to open on various platforms;
v = speed of opening on various platforms; and
T = ease of transfer on various platforms.

4. RESULTS AND DISCUSSIONS

4.1. Results

The six quality attributes discussed under section 3.2 were evaluated for each e-government application using a custom software quality assurance application. The custom application takes the URL of a web application and evaluates each of its quality attributes using the respective mathematical expression associated with it (except usability). Snapshot and working example of the custom application are shown in figure 1 and figure 2 respectively.

The custom application was designed using python programming language with scripts for evaluating the efficiency, portability, reliability, functionality and maintainability of each e-government application. The usability evaluation applied in the study was the external usability factor evaluation in order to analyse the user experience of the applications being used.

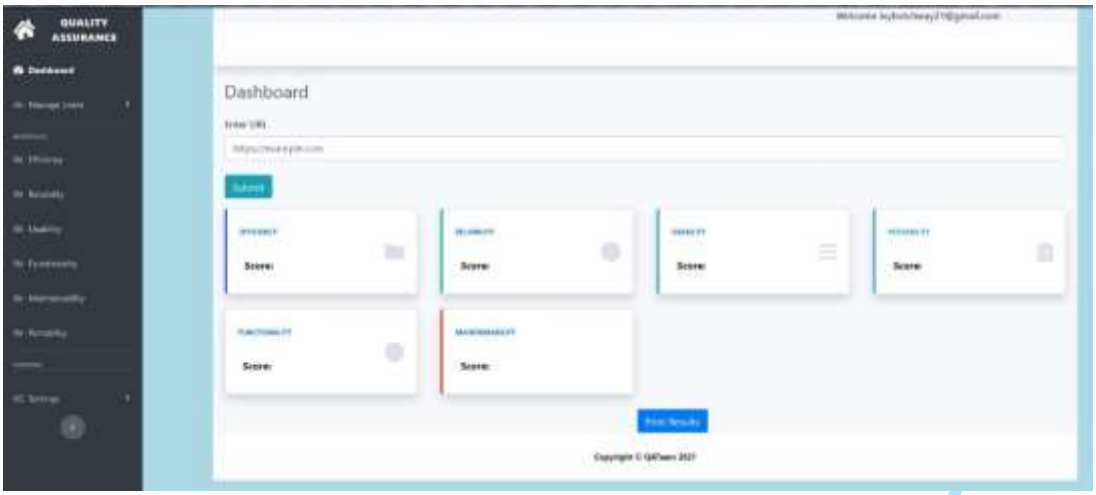

Figure 1: Snapshot of the Software Quality Assurance Simulator

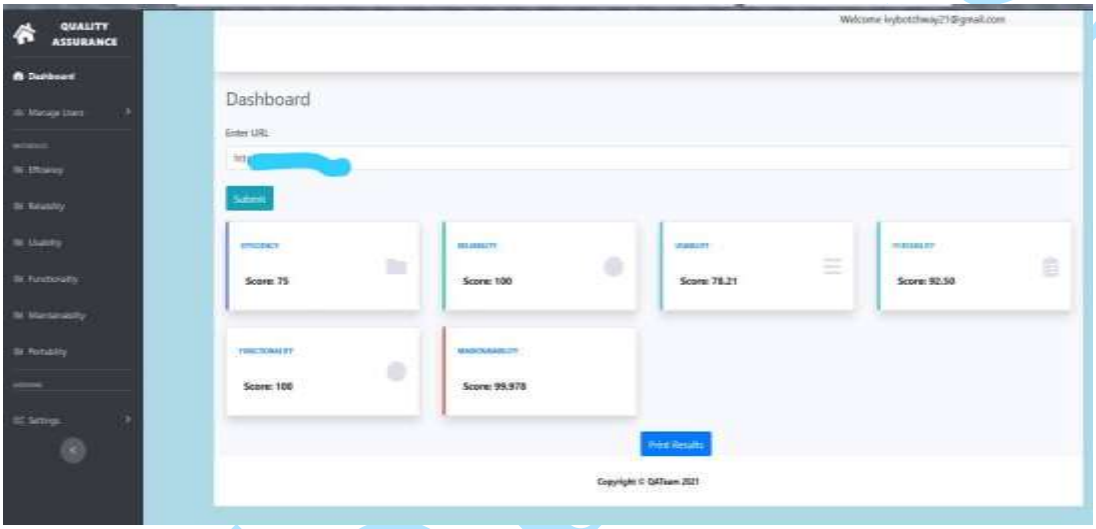

Figure 2: Results for Application1

4.1.1. Efficiency of the E-government Applications

The python script for efficiency evaluation in the custom application mirrors what users are expected to do, such as navigating through a web application, searching for an item, registering for an account among others.

Upon entering the URL of a website into the application, the python script opens the website and performs some activities to mimic a typical user on a website.

These activities were then automated and run for 500 users and the number of requests being sent over time to the web server of the website under review was measured as the throughput. The characters sent per second to the web server was also recorded as the bandwidth.

The efficiency test performed is network dependent, hence, better results were recorded with good network while poor network gave poor results. Therefore, the test was performed on wireless (Wi-Fi) and cellular internet networks respectively and an average of the scores was found and is shown in the Table 3.

Table 3: Results for Efficiency

Application Name	Through put (KiB/s)	Bandwidth (KiB/s)	Percentage Efficiency
Application1	236.25	314.98	75%
Application2	178.56	278.63	64%
Application3	206.61	268.32	77%
Application4	165.59	217.88	76%
Application5	131.58	185.32	71%

Application3 is seen in Table 3 to have the highest value of 77% as Efficiency with throughput of 206.61KiB/s and 268.32KiB/s as Bandwidth. Application2 is seen to have the lowest value 64% as Efficiency with throughput of 178.56KiB/s and Bandwidth of 278.63KiB/s. It can be concluded that Application3 is more efficient, followed by Application4, Application1, Application5 and finally, Application2.

4.1.2. Functionality of the E-government Applications

The python script also performed the functionality test by accessing 40 functions on the web application under review.
The test was done by clicking on submission forms, live chat feature buttons, social media tabs, internal links, site map aiding in user navigation, print page feature, events calendar, and others to assess if they are functioning as expected. The number of working and non-working functions was recorded for the functionality evaluation and shown in Table 4.

Table 4: Functionality Test Results

Application Name	Functions working correctly	Functions not working correctly	Functionality (%)
Application1	40	0	100
Application2	40	0	100
Application3	40	0	100
Application4	40	0	100
Application5	40	0	100

It can be deduced from Table 4 that the web applications have passed the software functionality test with correctly working features and functions. This shows that the software has been able to meet user requirements by providing the needed functions under specified conditions.

4.1.3. Maintainability of the E-government Applications

Maintainability evaluation was done by sending HTTP get requests to the web applications. The python script was automated to send HTTP requests to the website being evaluated at every 10 seconds for a period of 3600 seconds.
The time the web applications were unavailable for usage was recorded as the total downtime and the number of times the unavailability occurred was recorded as the number of failures the software encountered. This is shown in Table 5.

Table 5: Maintainability Test Results

Application Name	Total Downtime	Number of Failure	Maintainability Score (100%)
Application1	0.010% or 1 min 20 secs	8	99.978
Application2	0.031% or 5 min 4 secs	27	99.850
Application3	0.013% or 1 min 59 secs	10	99.957
Application4	0.016% or 2 min 45 secs	13	99.927
Application5	0.043% or 5 min 36 sec	32	99.672

Table 5 shows that Application1 performed well with a total downtime of 1 min 20 secs with 8 number of failures and a score of 99.978%. Application2 had a downtime of 5 mins 4 secs with 27 failures; its Maintainability rate was 99.850%. Application5 recorded the highest downtime of 5 mins 36 sec with 32 failures. Application3 equally performed well with a downtime of 1 min 59 secs and 10 failures. Application 4 also performed fairly well with 2 min 45 secs as its downtime with 13 failures. Although the web applications passed the maintainability test, Application5 and Application2 recorded higher failure rates.

4.1.4. Reliability of the E-government Applications

The applications were evaluated for reliability by conducting a stress test to assess the ability of the website to cope well under stress. The stress test evaluates the error handling capabilities of the website under extremely heavy conditions (accessed by a lot of users concurrently) and ensures that the application does not crash under such instances.

The python script conducted the test by creating the test plan where the number of threads (number of users), the ramp up period (time it takes a thread to begin execution) and the loop count (how many times to repeat the test) were provided. Finally, an HTTP get request was sent to the website under review.
The test was run for 500 concurrent users and the number of users that failed the test was recorded as the failure rate. A failure rate of 0 shows that all the users could concurrently access the web application without failure. A failure rate of 120 showed that 120 out of 500 users could not access the web application and the system experienced failure.
The result for the test is shown in Table 6.

Table 6: Reliability Test Results

Application Name	Testing Time, t (s)	Failure Rate (λ)	Score	Reliability Score (%)
Application1	120	0	1	100
Application2	120	120	0	0
Application3	120	130	0	0
Application4	120	0	1	100
Application5	120	0	1	100

Table 6 shows that Application1, Application4, and Application5 performed well in the reliability test with no failure rate and had a Reliability score of 100% while Application2 and Application3 failed the test with failure rates of 120 and 130 respectively. This shows that Application1, Application4, and Application5 can perform well within a specified time frame without encountering errors. The average Reliability score was 60%.

4.1.5. Usability of the E-government Applications

The usability test adopted in this study was assessing the external usability factors. This was selected based on evaluating user experience on the web applications. To assess the usability of the applications, a survey was administered through email. To maximise the response rate, the people were assured that their responses and identities would be treated with utmost confidentiality. A total of 100 users were given the survey with the response rate being 65%.
The total score was calculated by summing up the scores from the questionnaire;
The number of respondents was recorded from the number of people who filled the survey questions;
The number of surveys was recorded from the total number of survey questions that were modelled;
The number of survey scale was recorded from the scale defined from 1 to 5 (1 as Strongly Disagree, 2 as Disagree, 3 as Neutral, 4 as Agree, and 5 as Strongly Agree) which was used to fill the questionnaire; and
The maximum score was calculated by multiplying the total number of respondents by the number of survey questions and the number of survey scale used. The result is shown in Table 7.

Table 7: Usability Test Results

Application Name	Total Score	Number of Respondents	Number of Survey	Maximum Score	Number of Survey Scale	Usability Score (100%)
Application1	2542	65	10	3250	5	78.21
Application2	2490	65	10	3250	5	76.61
Application3	2518	65	10	3250	5	77.47
Application4	2483	65	10	3250	5	76.40
Application5	2420	65	10	3250	5	74.46

According to Table 7, it can be seen that Application1 had the highest Usability score with 78.21% while Application5 had the lowest score with 74.46%. Application2 had 76.61%, Application3 had 77.47% while Application4 had 76.40%. The average Usability score was 76.63%.

4.1.6. Portability

Software portability test was carried out to assess the ease of porting the web of the E-government applications from one web browser to the other with the results shown in Table 8.

The web browsers used for the test were Google Chrome version 89.0, Mozilla Firefox version 87.0, Microsoft Edge version 89.0, and Safari version 5.1.
The python script that was written allows the web applications to open in the listed web browsers and records an average of the time it took to open in each web browser. It also recorded the average speed with which the website opened in web browsers.
Acceleration was calculated by dividing the average speed over the average time.
Finally, rate of transfer was calculated by dividing the average time over the total number of web browsers used for the evaluation. This study used 4 web browsers.

Table 8: Portability Test Results

Application Name	Acceleration, a (m/s^2)	Time, t (sec)	Speed, v (m/s)	Rate of Transfer, P_o	Portability Score (%)
Application1	0.550	10.0	5.50	60	92.50
Application2	1.000	8.5	8.50	51	95.625
Application3	0.611	9.0	5.50	54	99.00
Application4	0.906	8.0	7.25	48	95.00
Application5	0.722	9.0	6.50	54	96.75

Table 8 shows that Application3 had the highest score of 99.00% with an acceleration of 0.611 m/s2, testing time of 9 sec, speed of 5.5m/s, and transfer rate of 54 while Application 1 was seen to have the lowest score of 92.50% with an acceleration of 0.550 m/s2, testing time of 10 sec, speed of 5.5 m/s, and transfer rate of 60. Application 2 had a Portability score of 95.625% with an acceleration of 1.0 m/s2, testing time of 8.5 sec, speed of 8.5 m/s, and transfer rate of 51. Also, Application 4 had 95.00% as the score with an acceleration of 0.906 m/s2, testing time of 8 sec, speed of 7.25 m/s, and transfer rate of 48. Finally, Application 5 had 96.75% as the score with an acceleration of 0.722 m/s2, testing time of 9 sec, speed of 6.5 m/s, and transfer rate of 54.
The overall results from the e-government software evaluation are shown in Table 9.

Table 9: Results from Quality Evaluation

Application Name	Efficiency	Functionality	Maintainability	Reliability	Usability	Portability
Application1	75	100	99.978	100	78.21	92.50
Application2	64	100	99.850	0	76.61	95.625
Application3	77	100	99.957	0	77.47	99.00
Application4	76	100	99.927	100	76.40	95.00
Application5	71	100	99.672	100	74.46	96.75

4.2. Discussions

The web applications were tested for efficiency, functionality, usability, maintainability, portability and reliability based on the ISO 9126 quality standard as shown in Table 9. It can be seen that on performing the efficiency test, Application3 recorded the highest score with 77% while Application2 had the lowest score with 64%. All the applications were seen to have passed the functionality test with a score of 100%. Application1 had the highest score for maintainability with 99.978% while Application5 had the lowest score with 99.672%. In assessing usability, Application1 had the highest score with 78.21% while Application5 had the lowest with 74.46%. The reliability test was seen to have been passed by Applications 1, 4 and 5 with scores of 100% each. For portability evaluation, Application3 had the highest score with 99% while Application1 had the lowest with 92.50%.

5. CONCLUSIONS

This study has presented an evaluation of e-government web applications based on the software quality attributes of the ISO 9126 model. The evaluation was done using the mathematical formulae of six quality attributes comprising of maintainability, reliability, efficiency, portability, functionality and usability. Results from the study shows that all the five (5) evaluated applications are highly functional and can easily move across various web browsers. However, there were issues with the reliability test. While some of the web applications can be said to perform well within a specified time frame without encountering errors, there were other web applications that failed the stress test, hence, failed the reliability test. The applications also had scores ranging from 74% to 79% for usability test. This score falls in the good category of the System Usability Scale. Furthermore, the web applications can be said to be maintainable since they had scores of 99%. Also, the efficiency test showed scores ranging from 64% to 77%. This shows that the applications can perform well at an average of 72.6%. It is recommended that the reliability of e-government and related applications be given much consideration during development to prevent system crash when subjected to stress. Also, it is suggested that the applications be developed to perform faster whiles using less computer resources. This will boost up the efficiency scores attained by these applications during software quality assessment test.

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