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SELECTING AN EFFECTIVE INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) ARCHITECTURE FOR AN EDUCATION SYSTEM BASED ON NON-FUNCTIONAL REQUIREMENTS

by

Mujtaba Baballe ILA

July 2014
Kayseri, Turkey

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by

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APPROVAL PAGE

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ABSTRACT

Information and communication technologies (ICTs) have developed over the last few years and it has been adopted in the education scene due to its perceived advantages. Different nations have tried embracing various strategies in selecting the right infrastructure for their education system with varying degree of success. This is primarily due to the absence of a technique that guides in selecting an appropriate ICT infrastructure that meets the needs of a particular nation's educational demand.

This research proposes an approach that will assist mainly education policy holders in choosing the most suitable system architecture thus preparing the ground for selecting an ICT infrastructure. By eliciting and prioritizing Non-functional Requirements (NFRs) relevant for ICT in education from relevant stakeholders and validating these NFRs against some selected system architectures, a suitable architecture using multi criteria decision analysis can be determined.

Key words: Information and communication technologies (ICTs), Education, Non-functional requirements (NFRs), Architectures, Infrastructure.

BİR EĞİTİM SİSTEMİ İÇİN FONKSİYONEL OLMAYAN GEREKSİNİMLERİ DAYALI ETKİLİ BİLGİ VE İLETİŞİM TEKNOLOJİSİ (BİT) MİMARİSİ SEÇİMİ

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ÖZ

Bilgi ve iletişim teknolojileri (BİT) son yıllardaki gelişmeler sonucu sağlamış olduğu avantajlar nedeniyle eğitim alanına adapte edilmiştir. Farklı milletler, eğitim sistemi için doğru altyapının seçiminde farklı başarı derecelerine sahip çeşitli stratejiler denemişlerdir. Bunun temel nedeni, belirli bir ulusun eğitim sistemi gereksinimlerine uygun bir BİT altyapı seçiminde rehberlik edecek bir tekniğin olmamasından kaynaklanmaktadır.

Bu araştırma, eğitim sistemleri için gerekli BİT altyapısının seçilmesine zemin hazırlamak ve böylece ağırlıklı olarak eğitimde karar verme yetkisine sahip paydaşlara yardımcı olacak bir yaklaşım önermektedir. İlgili paydaşların eğitim bilgi sistemleri ile ilgili fonksiyonel olmayan gereksinimlerinin ortaya çıkarıp önceliklendirdikten sonra, bu bilgileri çok kriterli karar analiz yöntemini kullanarak bazı seçilmiş sistem mimarileri arasından sistem için en uygun mimari tesbit edilebilir.

Anahtar Kelimeler: Bilgi ve İletişim Teknolojileri (BİT), Eğitim, Fonksiyonel olmayan gereksinimleri, Mimariler, Altyapı.

Dedicated to my Family for their sacrifice in enduring the absence of a Husband and Father during the course of my study

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TABLE OF CONTENTS

LIST OF TABLES

TABLE

LIST OF FIGURES

FIGURE

LIST OF ABBREVIATIONS

COTS: Commercial off-the-shelf

FRs: Functional Requirements

MCDM: Multi-criteria Decision Making

NFRs: Non-functional Requirements

SAW: Simple Additive Weighting

TOPSIS: Technique for Order Preferences by Similarity to Ideal Solutions

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The attainment of national development in nations is tied to the way a nation plans and executes it education system. The major achievement registered by the developed countries of America, Europe and Asia is dependent on the efforts they place in improving the quality and applicability of their education system [1].

Education is a major requirement for achieving several development goals and research has shown that poverty and education are inversely proportional to each other. Further, it was also discovered to have a counteractive effect on other myriads issues such as health challenges and peaceful coexistence [1] . A report by UNESCO stated that if all the students of low income countries can achieve basic reading abilities before leaving school; over 171 million people will be lifted out of poverty. This is the same as 12% decrease in global poverty [2].

The existence of human societies is dependent on education as it evolves the conveyance of all knowledge that is considered beneficial. It improves the ability of a person to contribute to the development of his society. In the words of [3], it is to a nation what the mind is to a body.

For centuries, knowledge has passed from a Teacher (master) to student (pupil) in a one to one or one to few arrangement. This is a kind of apprenticeship form of education.

Over time, the idea of arranging classrooms at given locations and time where students are taught lessons was gradually accepted and is now generally accepted as the main delivery method for education [4].

According to the popular American psychologist and educational reformer, John Dewey “If we teach today as we taught yesterday, we rob our children of tomorrow” [5].This means that it is imperative that we find an alternative education delivery method that will fit into today’s world.

There is a general consensus that the innovation and advances witnessed in information and communication technology (ICT) in the last couple of years has made a significant impact in virtually every facets of our everyday lives. Businesses are making use of the potentials of ICTs to facilitate transactions, keep records, monitor and manage production and distribution activities of goods and services etc., high speed internet has afforded households to have access to better information, communication and entertainment among so many other things [6].

The benefits and potentials seen in ICTs in other spheres of life encouraged education policy holders to experiment the use of ICT in education. Even though there is no comprehensive data available on ICT in school initiative worldwide [7], it is a known fact that several nations have made a lot of investments in their attempt to introduce and promote the use of ICTs in their educational systems adopting different strategies such as Enlaces project in Chile [8] where computer labs are used in the schools, One Computer Per Child (OLPC) [9] initiated by Nicholas Negroponte which was adopted by various countries, Tiger leap program in Estonia [10] where each school is tasked with finding its own way of integrating ICTs and one of the largest initiatives in the world; Fatih project in Turkey [11] which aims at providing over 15 million tablets to teachers and students in addition to other ICT infrastructures such as interactive whiteboards and broadband internet for all schools.

It has also been discovered that ICT use effects learning positively. Students are making use of computers to carry out variety of activities. Furthermore, students with access to ICTs have been found to display higher learning gains than those without access [12] .

ICT Infrastructure is the most fundamental component among all the elements of ICT in education project [13] because teachers are trained based on the technology adopted, Curricula are developed based on the specification of the infrastructure, policies for maintenance and sustainability are introduced and implemented when the infrastructure to be adopted is known and Lastly, the ease of use and learnability of the infrastructure in place plays a major role on whether the technology will be used for teaching and learning or not.

1.2 STATEMENT OF THE PROBLEM

With all the benefits enumerated concerning the advantages of employing ICT in education, there is no fixed format that can be followed when introducing ICT in education. Accordingly, there is no method that can aide in selecting the most suitable infrastructure that will suit the local needs of a particular Nation's education system. This is because every nation has its peculiarities and challenges in addition to disparities in the level of technological know-how and skills [14]. This means that each country has to develop its own tailor made project that will suit their local demand.

Various models are available to guide policy makers to design ICT in education projects [15] but they are very vague when it comes to elucidating how to select the appropriate ICT infrastructure for the project. Consequently, due to the eagerness of most countries to join the ICT bandwagon and the persistence of vendors to push their products to these countries they end up adopting ICTs that are not ideal or suitable for their locality thereby leading to the failures of the initiatives. The reason behind the decision of the Turkish Government to distribute tablet computers as against other alternative computing devices for Turkish schools is not known [16]. It was also observed that as a result of bad choice of infrastructure, the government of Malaysia is spending more than necessary in the rollout of their ICT in education initiative [17]. After expending a lot of money and time on the NEPAD e-school Demo projects, only 2 countries adopted the scheme out of 16 were the project was initiated [18] .

It is evident from the challenges enumerated above that selecting a good and viable ICT infrastructure is of utmost importance when introducing ICT in education. As a result it becomes imperative for a strategy to be developed that can guide policy holders in making such a decision.

On the other hand, it was discovered that over 30% of all ICT projects are cancelled before completion and 50 percent exceeds their initial costs [19]. Majority of these failures occur during the requirements stage. 40% of discovered errors unearthed in a U S Air force project were linked to requirements [20]. NFRs are the most difficult requirements to manage and deal with as fixing them accounts for about 70 to 85% of all ICT cost [21]. This makes it to be among the 10 biggest risks in requirements engineering. Unfortunately, irrespective of the significance of NFRs, they are still not understood very well and are thus neglected when under taking an ICT project [22].

1.3 OBJECTIVE OF THE STUDY

It is a fact that Non-functional requirements translate into Architecture while having an architecture prepares the ground for selecting an Infrastructure [23]. Therefore, this thesis proposes an approach that will assist stakeholders especially education policy holders in selecting a system architecture that will suit the needs of their education system based on Non-functional Requirements (NFRs). This eventually paves the way for selecting a suitable infrastructure. It is noteworthy that a high level description depicts the comprehensive features of a system and is more interested with the system as a whole [24].

Architectures are not only crucial in civil engineering alone but are also important in system and software engineering. Architectures in systems and software engineering provide a means of designing complex systems and defining the behavior of the overall system [25].

A wrong architecture will produce a wrong system while the right architecture is the one that satisfies the NFRs of the proposed system [26].

By coming up with a blueprint which aides in identifying the relationship between different systems architectures and relevant NFRs of the systems, Education policy holders can easily select the most suitable among these architectures which meets their needs. In addition, by considering requirements in our approach, we avoid all the failures associated with requirements as stated above.

1.4 RESEARCH QUESTIONS

The research focuses on coming up with a strategy that can aide stakeholders especially education policy holders identify the most suitable ICT system architecture that meets the demands of their ICT in education project or initiative. The central question in this research is:

How can we identify the most suitable ICT system architecture for an education system based on NFRs?

The main question leads to 3 sub questions that will be answered in this thesis:

1. Which NFRs are relevant for an education system?
    - What are the potential conflicts amongst these NFRs?
    - What are the priorities and importance among these NFRs?
2. Which system architectures will be suitable for an education system?
    - What is the relationship between the relevant NFRs elicited above and the identified architectures?
3. Which architecture best support the relevant NFRs for an education system?

Since the research is based on NFRs, there is a need to discover specific NFRs that are relevant for the proposed system. NFRs are system specific therefore this is very important.

Additionally, NFRs are interacting in nature hence a need to pinpoint the potential conflicts that might exist amongst them. Establishing the priorities and importance of the NFRs is a must in order to validate them against the selected architectures.

Due to the fact that there are several system architectures in use today, a criteria has to be established that will guide in identifying the ones that are suitable in this context. The quality attributes of the architectures also need to be established for comparison purpose.

Lastly, it is necessary to discover a tool that can be used in making a decision among several alternatives based on multiple criteria. This will aide in selecting the best architecture that supports the elicited NFRs.

The relevance of this study is ternary. First, it will discover NFRs that are relevant to ICT in education hence contributing to the knowledge of NFRs. Secondly, suitable system architecture for an education system will be identified based on the elicited NFRs and lastly, an architecture that is most suitable will be determined. Moreover, the same method followed can be applied in related projects that require making selection of a similar nature.

1.5 ORGANIZATION OF THE THESIS

The next chapter presents the background which also contains related works and Chapter 3 contains the methodology that was employed in carrying out the research, Chapter 4 contains Data analysis, findings and discussions from the research and lastly Chapter 5 contains the conclusion and future works.

CHAPTER 2

BACKGROUND AND RELATED WORKS

In this chapter, the theoretical background and related works that concern the research will be discussed.

2.1 BACKGROUND

This section provides an overview of theoretical background related to the research.

2.1.1 ICT in Education

The acronym ICT stands for Information and Communication Technology. It sometimes take the plural form ICTs meaning Information and Communication Technologies when some certain devices or processes make up the technology together.

A good definition of ICT is that it:

…generally relates to those technologies that are used for accessing, gathering, manipulating and presenting or communicating information. The technologies could include hardware (e.g. computers and other devices); software applications; and connectivity (e.g. access to the Internet, local networking infrastructure, and videoconferencing) [27].

Advancements in ICT is seen to be more important than both the print and industrial revolution [28].Research indicated that using ICTs in education is more effective than the traditional method of teaching and learning [29]. It has the prospects of radically changing education even though there is no consensus on how this can be achieved [30]. This means that there is no fixed format that we can follow to introduce ICT in education. This is because every nation has its peculiarity and challenges coupled with disparities in the level of technological know-how and skills.

It should be noted that introducing ICT does not completely rid a developing country of its educational challenges or short comings because what it does if prudently introduced and implemented is to enable the countries to raise the quality of education in addition to increasing access to it [31].

2.1.1.1 How ICT in education started

ICTs that were used in Education in the past were passive in nature. This means that the only action that a student was required to do was to listen, may be watch and sometimes take notes. More modern ICTs however provides more interaction and flexibility where students can be able to not only control the pace of their studies but can additionally be able to select their topics, create and manipulate images, make presentations and run simulated experiments among several other activities [32].

Five phases were outlined to be critical in the history of ICT in education according to Professor Teemu Leinonen in his article ‘A critical history of ICT in education’ which was illustrated in a conceptual map as shown below [33]:

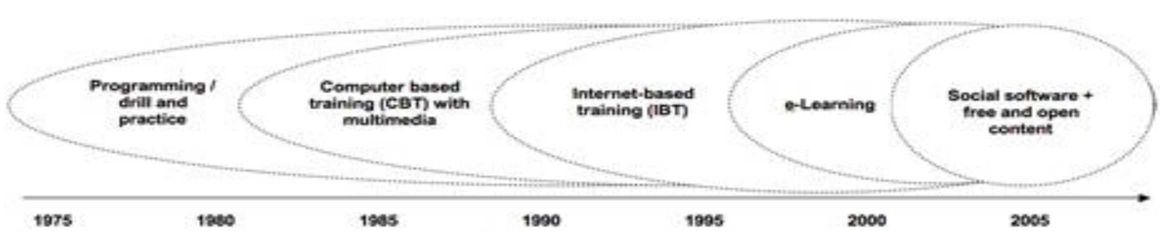


Figure 2.1 Evolution of ICT in education

• Late 1970s - early 1980s: Programming: The use of computers for pedagogical purpose in this period was mainly focused on programming. Students' logic and mathematics skills were horned with the help of programming.

• Late 1980s - early 1990s: Computer Based Learning: With the advent of multimedia computers with graphics and sound applications, the computer was put into use to aid the learning processes in basic subjects such as reading, mathematics and writing.

• Early 1990s: Web-based Learning: The third phase of using ICT in the education sector came with the advent of the World Wide Web. The challenges witnessed with updating contents of CD-ROMS and Floppy disk was more or less solved to a high degree during this period. Contents were easily and frequently updated as a result of the use of the World Wide Web.

• Late 1990s: E-Learning: E-learning provides the means for interaction between the teacher and the student and even among students themselves. It merges web based and computer based learning applications for the users.

• From 2005: The era of social software and free and open content, is emerging in our present day. This includes social networking that has revolutionized the way we interact with each other.

2.1.1.2 Current and Future trends in the use of ICTs in Education

Apart from the traditional ICT infrastructures in place such as Radio, Television, Computers etc., several new ICT infrastructures are available in the world today [34]. These include:

- **Mobile Learning:** The world has witnessed advances in the use of mobile devices. Most mobile devices can a perform actions that computers can only dream of performing some years back. At the moment there are more mobile devices with internet access than personal computers which make them a very good tool for use in the classrooms and beyond especially in developing countries.

- **Cloud computing:** the assumption that infrastructure is something that can be bought, housed and managed has changed. [35]. With cloud computing there is no need for local devices or servers to handle applications or storage as computing resources are accessible via the internet from servers that are based in remote locations.

- **One-to-One computing:** This is an initiative the aims to provide each student with an information appliance and internet access for use both in school and at home. More and more nations are adopting this strategy [36]. The information appliance can be a laptop, smart phone and of recent tablet is being adopted.

- **Ubiquitous learning:** This is a novel information and communication technology that makes use of many collective connective points such as laptops, tablets, mobile phones etc. with communication and computing capabilities. This gives students and teachers the ability to interact with each other anytime of the day and from anywhere in the world [37].

- **Gaming:** Electronic games have become very popular among the youth the world over especially as a result of improvement in access to ICTs. It can lead to increase in social interaction and healthy interactions among the youth. Studies have shown that games could improve the teaching and learning process, if properly integrated into the educational system [38].

- **Personalized learning:** Research has shown that it very important to compel students to take control of their learning process. Web 2.0 tools and technologies among others have an effect on the behavior of young people. If used appropriately they can aid in shifting control to the learner because learning experiences through social media are mostly driven by learner’s interest [39]. At the end of the day all students both the weak and the strong are carried along in class based on their individual needs.

User-generated open content: The emergence of web 2.0 technologies in particular has brought about a new phenomenon whereby users can easily create contents and knowledge online. Traditionally, teaching and learning are based on prepackaged materials but there are tools that are available now that allow teachers and students to edit and add information easily [40]. OECD school system are encouraging teachers to create contents they believe will be effective for their classrooms

Smart or electronic portfolio assessment: E-portfolios are tools that assist self-assessment and documenting personal and academic growth throughout educational program. It can contain text, audio and video. It helps teachers to discover learning gaps, aide students to find a pattern in their learning over time and also gives parents the opportunity to follow the academic progress of the children [34].

Teacher managers/enablers: With the proliferation of ICTs in education, the role of teachers is changing from teaching to enabling and guiding students. For example, there will be no need for blackboards if all students have access to the same materials as the teachers, this can be accessed through various channels. [41].

2.1.1.3 Benefits of ICT in education

Introducing ICTs in Education provides students and teachers unlimited opportunities. One of its key feature is that it has the ability to transcend time and space. Instructional materials can be accessed 24 hours a day 7 days a week. Addıtıonally, the teachers and students do not need to be ın one physical location to be able to communicate as this can be done remotely. Another Major benefit of ICT is that it provides unfettered access to millions of the educational materials thereby reducing dependence on limited printed books and materials. Further, it exposes students to tomorrow's work place where ICTs are becoming more ubiquitous. Moreover, students are more motivated to learn as multimedia ICT components provide contents that are very interesting and captivating [42] thus, they tend to spend more time using and appreciating it. This consequently leads to them spending more time horning their skills and knowledge [43], [44]. Besides directly affecting students and teachers, ICTs can also help in maintaining a link between the school, parents and the community to ensure the parents and community participates in school activities [45].

In addition to all the benefits listed above, they also serve as a powerful tool which aides in presenting data and information in a variety of ways. It enables complex mathematical and scientific models to be shown which might be extremely difficult if not impossible to show otherwise [43].

2.1.1.4 Challenges of ICT in education

The major challenge of ICT in education is selecting an appropriate infrastructure (technology) when a decision has been taken to introduce it. Poor choice of ICT infrastructure has been associated with the failure of a lot of Projects in the past [17], [46]. Some experts are of the opinion that ICTs introduced at a very early stage is unhealthy as it affects the education of minors while other experts having a less extreme point of view simply believe that even though ICTs are good, students will be better off learning through traditional methods [47].

Furthermore, it was discovered that providing students with access to computers and the internet at home tends to affect their grades [48].

Other challenges which are more peculiar to developing countries include availability of electricity, telephony, available and appropriate rooms and buildings etc. [49], [50].

2.1.1.5 Elements of ICT In education

In order to successfully introduce and implement ICT in education, the following basic components need to be put in place:

- ICT Infrastructure
- ICT policies
- Teachers' Training
- Curriculum Development

- Usage of ICTs in Teaching and learning [51], [52], [53], [17].

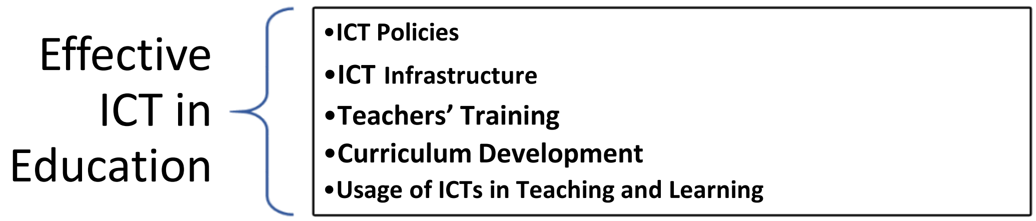


Figure 2.2 Elements of ICT in Education

ICT infrastructure: The infrastructure is the backbone of any ICT in education project as it is the determining factor for the success of any initiative.

ICT policies: There should be laws and policies in place which should encourage the introduction and use of ICTs in education.

Teachers' Training: Teachers need to be trained in the use of ICTs in order to maximize the benefits expected from the use of ICTs in education.

Curriculum Development: Appropriate curriculum which are compatible with the ICT infrastructure must be developed.

Usage of ICTs in Teaching and learning: It is not enough to provide ICTs but they need to be used in education before their impact can be felt.

ICT Infrastructure is the most fundamental element for a successful ICT in education [13]. ICT infrastructure is a general name which refers to the physical assets designed in a system which includes the hardware, software and network [54]. With an effective ICT infrastructure, Teachers can be trained on how to use the particular technologies selected, Curriculum will be developed based on the specification of the infrastructure and policies can thus be introduced to ensure the implementation and maintenance of the infrastructure for sustainability.

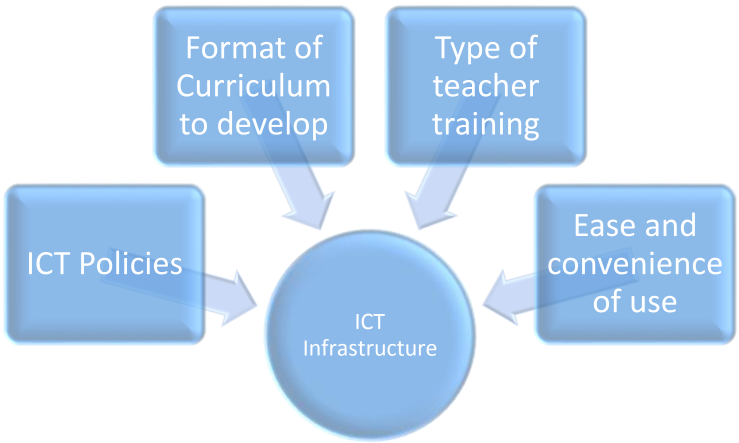


Figure 2.3 ICT Infrastructure: The backbone to any ICT in education project

2.1.2 Stakeholders

A stakeholder is any person or group of person that is affected or will be affected by the system directly or indirectly [55]. It can be a person who pays for the project, a person whose skills and experience is needed for the project, an external organization that can influence the success of the project etc. [56]. Stakeholders play a very important role in spelling out the way a system is to be selected or built in a layman's term [57].

Identification and characterization of stakeholders is known as stakeholder analysis. Identification of stakeholder can be achieved through information from written documents and records, authentication by other stakeholders and random method among others. Characterization of stakeholders on the other hand is achieved by examination of the interests of the stakeholder through deliberation with a group of stakeholders, searching data from reports and news outlet and the readiness of the stakeholder to participate through interviews and surveys [58].

Based on the above, stakeholders in education can be listed to include [59] :

- Teachers
- Students
- Administrators/Principals
- Government/Policy makers
- Researchers

- NGOs/Private organizations
- Parents/Community
- Alumni Associations
- Technology and Telecommunication Providers
- Professional development and training institutes
- ICT professionals

Due to constraints that are normally characterized by projects, it may not be possible to involve all stakeholders therefore sorting and prioritization needs to take place. This selection is normally done through a prioritization technique or as a result of some skills possessed by the stakeholder [60].

2.1.3 Requirement Engineering

A definition of Requirements Engineering (RE) says that *“requirements definition is a careful assessment of the need that a system is to fulfill. It must say why a system is needed, based on current or foreseen conditions, which may be internal operations or external market. It must say what system features will serve and satisfy this context. And it must say how the system is to be constructed”* [61].

It is both a science and a discipline that is primarily concerned with the analysis and documentation of requirements [62] which aims at discovering and eliciting the appropriate specification for a system [63].

The word “requirement” on the other hand is the condition that has to be meet in order for a system or its component to fulfill a contract, specification or standard [64]. They are the driving force of any system engineering effort [57]. They determine the systems architecture and interpret the needs of the stakeholders [65].

Through requirements the intentions and the needs of the stakeholders are discovered and understood. This is very important because it is normally difficult to elicit requirements from the words of the stakeholders [66].

It should be noted that Systems and software requirements are very similar because to derive them, the methods, tools and even techniques for documenting them are more or less similar. The most important factor that differentiates them is that systems requirements define the behavior of systems from the point of view of the primary stakeholders. System requirements provide the analysts, designers, users, and all the other parties that are interested in the development the systems components with a partial communication vehicle [67].

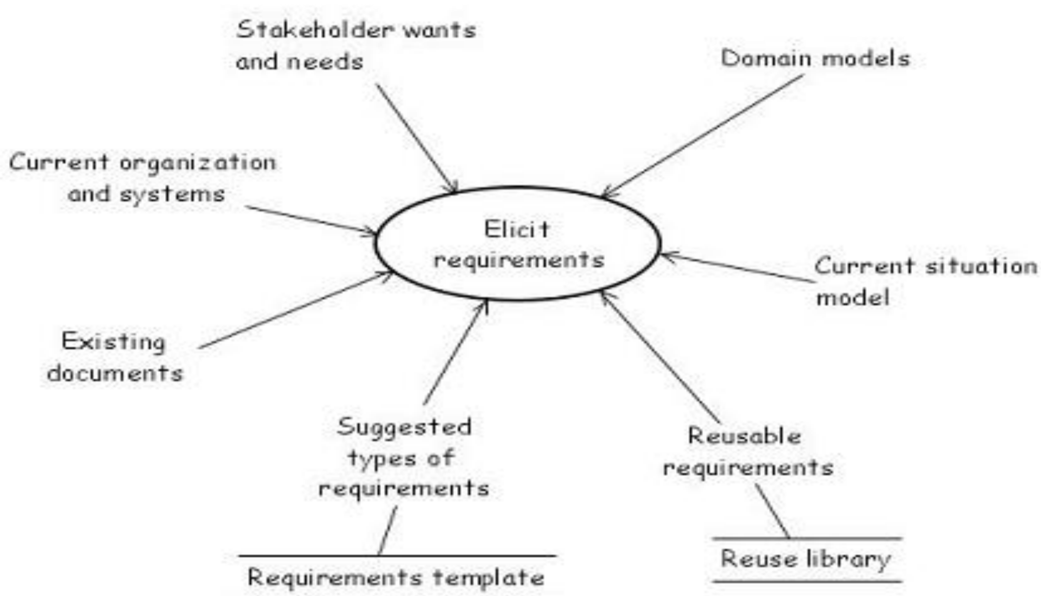


Figure 2.4 Sources of Requirements [68]

2.1.3.1 Classification of Requirements

There is no general consensus on the classification of requirements. Sawyer [69] classifies them as User and System requirements. User requirement are qualities and results that the users want which are elicited from the stakeholders of the system while System requirements consists of the requirements of the users and other stakeholders in addition to requirements that cannot be traced to any human source.

Another classification was offered by Bahill and Dean [70] where they classify requirement into Mandatory and Preference requirements. Mandatory requirements are requirements that are necessary and sufficient for the system to be accepted while Preference requirements are conditions that are desired by the stakeholders but are not a must in a system.

The most popular and generally accepted classification was given by Kotonya and Sommerville [71]. They classify requirements as Functional requirements (FRs) and Non-functional requirements (NFRs).

Functional Requirements have been defined as requirements that specify an action that a system must be able to perform, without considering physical constraints [72] while according to [73] they are requirements that specify input and output behavior of a system.

It is imperative that we define Non-functional requirement but the job is not as easy as it appears because different authors have given them different definitions [74]. [71] defined them as Requirements which are not specifically concerned with the functionality of a system. They place restrictions on the product being developed and the development process, and they specify external constraints that the product must meet.

Example of a functional requirement is “the system must shut down when an unauthorized entry is detected” while a Nonfunctional requirement will be “the system shall not allow unauthorized entry”. As observed from their definitions functional requirements describe the systems behavior while nonfunctional requirements elaborate the performance of the system.

2.1.3.2 Brief on Non-functional Requirements

Non-functional Requirements also known as quality attributes or quality characteristics are very significant in a system, therefore requirement engineers need to give it more attention [75]. They function as selection criteria when choosing among multiple decisions, architecture inclusive. [76], [77] For example the choice of a particular architecture can be justified in terms of maintainability or the choice of a particular database can be made in terms of its efficiency etc. [78]. In other words, different NFRs have different significance in a project or even sometimes different project. For example if a system is required to have a long-life, portability and modifiability need to be specified because they are very significant in that regard.

NFRs are elicited from stakeholders with no expertise in software or system engineering. The number of NFRs can be so large [79] as over 252 types of NFRs were identified by [80]. They are more diverse and complicated than FRs. They highlight the qualities that are desired in a system, product or software. For example, a tablet computer should be cheap, lightweight and reliable, these are qualities expected of the system. They are architecture dependent and usually conflict with each other requiring trade off [81].

NFRs are as important as FRs but they are very difficult and expensive to deal with. It has been observed that not taking them into consideration is one of the ten biggest risks in requirements engineering [82]. Some experts are of the view that they are even more important than FRs [71] because they place restrictions on the system being developed and the developing process in addition to specifying external constraint that the system must meet .Furthermore, due to their “critical importance” and they even went further to suggest that in certain situations FRs have to give ways for NFRs to be met.

Just like requirements, there is no consensus on the classification of NFRs. Malan and Bredemeyer classified them as constraints and qualities [83] while Sommerville classified them into Product (System), Process and External NFRs [84]. Process requirements concern the system to be built, Process requirements are defined by the body developing the system while External requirements neither come from the stakeholders nor the developing organization. This include legislation that define how such systems should be developed.

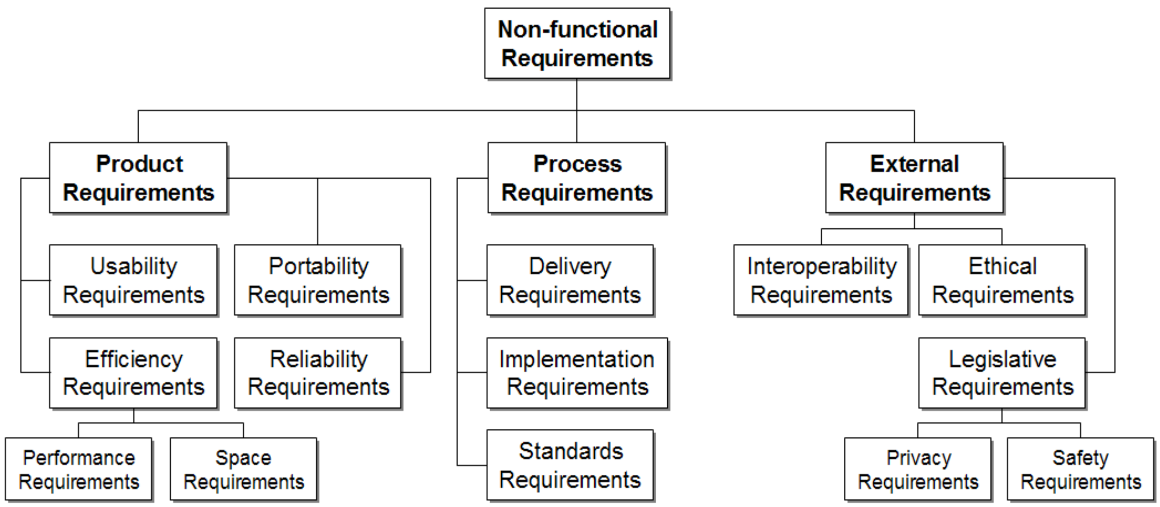


Figure 2.5 Sommerville's classification of NFRs

Identifying NFRs is essential for the development of any ICT system. It is of great importance to establish all the NFRs that the stakeholders require. Unfortunately, there are few methods available to achieve this task [85]. A popular method for carrying out this function is by making use of predefined metrics to carry out quantitative analysis to measure the extent a system meets a certain NFR [86], [87], [88], [89]. Example of NFR metrics include Time (Transactions/Sec, Time to complete an operation), Space (Main memory, Auxiliary memory), Usability (Training time, Number of choices etc.), Reliability (Mean time to failure, Downtime probability etc.) etc. [90].

2.1.3.3 NFR Approach

NFR approach is a strategy which is applied to figure out the extent to which the intention of a system are achieved [91]. NFR approach use the concept of "satisficing" which means satisfaction to a certain degree because NFRs are usually very difficult to satisfy 100% [92].

An NFR approach is defined as "*a set of similar methods and techniques, related to the same requirements engineering activity that can be used to deal with or manage NFRs"* [93]. Based on the classifications of Svensson [94] and Peach [95] , Poort et al [93] suggests the following approach when dealing with NFRs in a survey:

- Elicitation: Obtaining the requirements from the selected stakeholders usually the users or customers.
- Documentation: Writing down the requirements so that they can be conveyed to the stakeholders usually the developers or designers.
- Quantification: Making the NFRs explicit and verifiable usually through assigning numbers to them on a measuring scale.
- Prioritization: Giving the NFRs Priority based on their respective importance.
- Conflict analysis: Spotting the conflicts among the NFRs
- Verification: Verifying that the system meets the requirements usually through analysis, Simulation or testing etc.

According to Nuseibah and Easterbrook [96] , the following are some of the activities that need to take place in requirement engineering:

- Groundwork – Before any project can be started, there is need for preparation. This means assessment of the feasibility of the project and risks associated with the needs. This also includes identification and selection of the best processes, methods and techniques for all RE activities.

- Eliciting requirements – This includes all the activities involved in getting the requirements of the system. The information that is obtained has to be interpreted and analyzed before the requirement engineer can be sure that all the necessary requirements have been obtained. Elicitation requirement is achieved through the following methods:

    - Requirements to elicit – The purpose of elicitation are to define the problem needs that will be solved. This is achieved by defining the system boundary, identifying the stakeholders and indicating the objectives that must be met by the system.
    - Elicitation techniques – This is dependent on the time, resources and the kind of information needed. Some techniques include traditional techniques such as Surveys and interviews, Group elicitation, Cognitive techniques etc.
    - Elicitation Process – Requirement Engineer needs guidance on the elicitation technique to use due to their plurality. This guidance can be provided by Methods. Different methods are suitable for different application domain. Examples of methods are CREWS and Inquiry cycle.

However, it should be noted that in many instances, there might be no need for a method to be used as the selection of a good technique may serve the purpose of the project at hand.

2.1.3.5 Importance of individual NFRs

To measure the importance of individual NFRs in a system, it is not possible to simply ask for all the number of requirements needed in the system. Some requirements might be few but are more important that other requirements that are many. Fuzzy Logic and Rating scale questionnaires have proved to be very effective for measuring NFRs [97]. According to Poort et al, a credible approach when measuring the importance of NFRs is to forward NFRs that are deemed to be important to a system and thus very critical to it ; to the stakeholders to rate their criticality on a 5 point Likert scale (Low, Very low, Medium, High and Very high) [93].

2.1.3.6 Prioritizing NFRs

Making decision is a part of our daily life routine. People are made or in certain situations even forced to choose among several alternatives with the difficulty in making the choice increasing as the number of alternatives increase. The easiest way to make decisions is thus to prioritize among the options. However, such a decision might still not be easy to make as several factors must be taken into consideration. In certain cases tradeoffs have to be made on options that are not as important to the stakeholders compared to others. Decision making is not peculiar to systems engineering as other disciples have also studied it intensely [98].

Prioritizations assist in identifying the most important requirements among several requirements that are available [99]. It also aides in providing assistance in the following activities [100], [101]:

- For stakeholders to decide the most important requirements for the system.
- To guide requirement engineer in knowing which requirement to trade off over the other.
- To select a subset of requirements and still be able to produce a system that will suit the stakeholders' needs.
- Ensuring that all requirements are addressed and not just of individual stakeholder.
- To balance implications of the requirements of the system architecture and future evolution of the system.

During prioritization, stakeholders arrange requirements they consider more important to the system. It should be highlighted to the stakeholders the basis that will be used when prioritizing requirements as importance can have multiple angles to it such as urgency of implementation, importance of requirements for the system architecture etc. [102].

2.1.3.6.1 Challenges of prioritization

Prioritization is not without it challenges some of which include:

- Due to the mandatory nature of requirements some stakeholders may be of the opinion that all should be prioritized as high.
- Some systems might have a very high number of requirements, thousands in some cases which is normally very difficult to prioritize. Thus forcing the requirement engineer to group some requirements for easy prioritization.
- Priorities change over time.
- Stakeholders have different perspective and thus tend to prioritize requirement differently.
- Some requirements are incompatible (for example security and usability) and thus there will be a need to make tradeoffs.
- Poor prioritization can lead to grave monetary consequence including dissatisfaction by stakeholders [101].

The result of prioritizing forms the basis for the decision of the requirements to include in a system [99].

Prioritization has been considered to be easy, medium and very complicated. However it has generally been agreed that is crucial to any project's success [99].

2.1.3.6.2 Prioritization Techniques

There are several prioritization techniques available which include:

- Analytical Hierarchy Process (AHP)
  This is a systematic method employed in requirements prioritization [103]. It is done by comparing all the possible pairs of requirement so as to achieve which is of higher priority in addition to the degree of priority. The number of comparisons carried out

in AHP is $nx\ (n-1)/2$ where n is the number of requirements. It is not suitable for the large number of requirements [104].

- The 100 Dollar Test

  In this technique, the stakeholders are given 100 Dollars to distribute between the set of requirements [105]. At the end, the result is highlighted as a ratio. The major challenge with this is that if the requirements are more than 25, there are only 4 points to distribute on average. Some research however use a bigger amount like 100,000 or more [103] to counteract the problem. Another problem is that the stakeholder or person undertaking the prioritization might miscalculate the points leading to them not adding up [106].

- Numerical Grouping

  This is based on grouping requirements into different priority groups which can vary but normally 3 groups are used [105]. The requests are normally categorized into critical, standard and optional so that the stakeholder does not believe that all of the requirements are critical [100]. However, the usefulness of the prioritization diminishes as the stakeholder are forced to look at the requirements are groups [107].

- Ranking

  Ranking is done on an ordinal scale without any ties to the rank. In this technique, the most important requirement is ranked 1^{st} and the least important is rank n (for n number of requirements). A unique rank is giving to each requirement but there is no difference between the rankings as is done in 100 Dollar test or AHP. The major advantage of this technique is that you cannot have a tie which is good and it is very easy to administer.

- Top Ten Requirements

  Stakeholders select the top ten requirements from a larger number of requirements without assigning any other to them. This is suitable for multiple stakeholders of the same importance [108]. The major challenge here is that it might be possible to have some stakeholders having all their selected requirements scaling through while others do not get any of theirs. The biggest challenge here is balancing and sorting out conflicts if they occur.

A general advice when selecting a technique is to choose one that is simple [104] .

Table 2.1 Summarized Table of Prioritization Techniques [99]

TECHNIQUE	SCALE	GRANULARITY	SOPHISTICATION
AHP	Ratio	Fine	Very complex
100 Dollar Test	Ratio	Fine	Complex
Ranking	Ordinal	Medium	Easy
Numerical Grouping	Ordinal	Coarse	Very easy
Top Ten		Extremely coarse	Extremely easy

2.1.3.7 NFR Conflicts

Conflicts occur in every field where there is interaction [109]. NFRs not being an exception usually contradict and conflict with each other. Conflict here can be defined as interference which means the negative contribution of an NFR to another [110]. Internal contradictions among several types of NFRs lead to this inescapable conflicts which is absent in FRs [76]. This means that combining some NFRs in a system might lead to tradeoffs [111] in other words obtaining one NFR can stop the realization of another NFR. Majority of systems go through serious tradeoffs among the main categories of NFRs for example performance conflict with reusability and maintainability [112]. The two main factors that cause conflicts in NFRs are different points of view and needs among stakeholders in addition to internal discrepancies among NFRs [109], [113].

Dealing with conflicts among NFRs is very important because they are unavoidable [114] and they have been classified among the three biggest problems associated with system development [115].

NFRs conflicts are broadly categorized into 3 groups namely [116]:

- Absolute conflicts: If NFRs are always in conflict.
- Relative conflicts: If NFRs are not always in conflict.
- Never in conflict: as the name suggests when NFRs are never contradicting or conflicting.

Dealing with NFRs is very important because:

1. Conflicts among NFRs are imminent [91].
2. NFRs are interactive in nature [91].
3. If some NFRs are combined in a system, tradeoffs are unavoidable [117] etc.

In order to be able to manage conflicts among NFRs, three major activities take place. These are:

- Conflict identification – to detect the possible conflicts.
- Conflict analysis – to evaluate possible conflicts and their tradeoffs.
- Conflict resolution – to resolve the possible conflict.

Most research on conflicts among NFRs provide a catalogue for possible conflicts. This is known as potential conflict model. For such a strategy to be implemented there is a need to have a uniform definition for all NFRs based on the system being developed. This is done to avoid different interpretations by different stakeholders [118]. However, present NFR conflict identification methods are unable to identify the nature of the conflicts but rather they are only able to capture high level conflicts. For example, NFR1 has a conflict with NFR2 but the significance and ranking of the conflict is not known [119].

It was also discovered that some potential conflict models are in disagreement with each other when representing conflicts among NFRs, for example Egyed and Grunbacher state that efficiency has a negative relationship with usability but according to [120] efficiency has a positive relationship with usability. A reason for this divergence might not be unconnected with the fact that there is no standard definition for NFRs [74], [121]. There is lack of empirical research to scrutinize NFRs in general, and the conflicts among them in particular [95].

Majority of architecture analysis methods that try to appraise the appropriateness of an architecture to satisfy NFRs focus mostly on single NFRs. Additionally none of the methods examines conflicts among NFRs but rather gives out warning when the selected architectures yields the tradeoffs against multiple NFRs [112].

A comprehensive catalogue of conflicts among NFRs was forwarded by [116]. The catalogue assists in identifying potential conflicts among NFRs. The Catalogue can be found in Appendix A.

2.1.4 System Architecture

Architectures are not only necessary in building constructions or civil engineering, but also system and software engineering. All systems have architecture and the behavior of a system is highly dependent on its architecture [25].

According to Kumar "*A good architecture meets the requirements of the stakeholders and does not breach entrenched principles of system architecture, it also takes into cognisance the relevant ilities by the customer needs'* [122].

The foundation for a working and workable system is a system architecture. System architecture is a generic discipline to handle objects (existing or to be created) called systems [25]. A working system is one that has subsystems that are fully functioning which cooperate to achieve a fully functioning whole system while on the other hand a workable system is one that can easily be managed and maintained in addition to being user friendly. Unfortunately this is normally overlooked when rushing to produce systems that look like they are doing something [123].

There is no general consensus on the definition of architecture as it has been defined differently by numerous authors which include:

Table 2.2 Definitions of Architecture

Definitions	Source
The fundamental organization of a system, embodied in its components, their relationships to each other and to the environment, and the principles governing its design and evolution [124]	ANSI/IEEE 1471-2000
A representation of a system, including a mapping of functionality onto hardware and software components, a mapping of the software architecture onto the hardware architecture, and human interaction with these components [125]	Carnegie Mellon University's Software Engineering Institute.
A formal description of a system, or a detailed plan of the system at component level to guide its implementation [126]	TOGAF

Before systems are designed, architectures have to be created or selected. The selection should be done based on the stakeholders' need as the purpose of existence of a system is to bring about value for its stakeholders [127].

2.1.4.1 Domains where architecture is important

Architecture is important in both natural and designed systems. Natural systems where architecture has been used include biological systems such as ecosystems and social systems such as military units. Control systems, simulations, graph theory have all been used to perform various activities such as determining how materials, energy, information move from one element to another.

Some other natural system however emerge without any design but have specific architecture. A good examples is the internet that has no rules guiding its growth but is interestingly efficient. On the other hand, there are systems that are designed such as cars, ICT infrastructure, shopping malls etc. they all carry out functions and most accommodate some constraints in design. Some of these accomplish their intended roles through a long life cycle, others outlive their initial objective and are made to take in new ones while others go out of service early and might not even be used for any other thing else.

It is easy to describe what functions a system should perform for example an airplane must fly, a manufacturing system must manufacture and produce products etc. but the underlying factor is that it has to be able to do these things very well. This is where NFRs come into play. The architecture has a major effect on how well and efficiently NFRs are attained [25].

2.1.4.2 Types of system architectures

There are several types of architectures in use today. Each type may be dependent on a distinct purpose or a topic of interest or on a distinct set of systems.

Architectures that focus on specific set of systems include System of systems and enterprise architecture. Example of architecture which address specific purpose include problem domain definition and example of architectures which focus on specific topics include security, information etc.

Furthermore, it is possible for one system to have more than one architecture for example security architecture and information architecture. This is because each architecture is regarded as a view point on to a single underlying architecture [128].

2.1.5 Multi-Criteria Decision Making

Multi-criteria decision making (MCDM) alludes to making decisions when faced by several criteria that are often conflicting. It is a systematic approach that is used when analyzing various alternatives in problems that concerns several criteria [129]. Problems of MCDM range from everyday problems such as if one wants to buy a car, decisions may be made based on size, price, comfort etc. to very complex ones. Even though MCDM problems are very popular, the field is not more than 30 years old. The advancement in the discipline is as a result of advancement witnessed in computer technology [130].

Several methods have been conceived and used in the last couple of years, each with its advantages and disadvantages coupled with specific areas they can be used for. It has also been discovered that combining several methods tend to address the deficiency of some methods. Each method is more suitable for use in specific area, thus the identification and selection of an appropriate method is of utmost importance. The authors summarized some MCDM techniques below [131]:

Table 2.3 Summary of MCDM Methods

Method	Advantages	Disadvantages	Areas of Application
Multi-Attribute Utility Theory (MAUT)	Takes uncertainty into account; can incorporate preferences.	Needs a lot of input; preferences need to be precise.	Economics, finance, actuarial, water management, energy management, agriculture
Analytic Hierarchy Process (AHP)	Easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data intensive.	Problems due to interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal.	Performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning.
Simple Multi-Attribute Rating Technique (SMART)	Simple; allows for any type of weight assignment technique; less effort by decision makers.	Procedure may not be convenient considering the framework.	Environmental, construction, transportation and logistics, military,manufacturing and assembly problems
ELECTRE	Takes uncertainty and Vagueness into account.	Its process and outcome can be difficult to explain in layman's terms; outranking causes the strengths and weaknesses of the alternatives to not be directly identified.	Energy, economics, environmental, Water management, and transportation problems.
Simple Additive Weighting (SAW)	Ability to compensate among criteria; intuitive to decision makers; calculation is simple does not require complex computer programs.	Estimates revealed do not always reflect the real situation; result obtained may not be logical.	Water management, business, and Financial management.
Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS)	Has a simple process; easy to use and program; the number of steps remains the same regardless of the number of attributes.	Its use of Euclidean Distance does not consider the correlation of attributes; difficult to weight and keep consistency of judgment	Supply chain management & logistics, engineering, manufacturing systems, business and marketing, environmental, human resources, and water resources management.

In addition to the techniques highlighted in the table above, there are soft wares such as Visual Interactive Sensitivity Analysis (V.I.S.A) developed by Val Belton, which can be employed to make informed decisions in a very facile way. In the software, hierarchy can be created, alternatives, scores and weight can be entered and plots can be created. The model can later be saved and printed if needed [132].

2.2 RELATED WORKS

This section provides an overview of related works done in the field. Various research have been carried out in the fields of ICT infrastructure, ICT in education and relevant NFRs for different systems. For clarity purpose the related work section will be categorized into three, namely:

1. Models of ICT infrastructure.
2. Integration of ICT in Education.
3. Systems and their relevant NFRs.

2.2.1 Models of ICT infrastructure

Baquero et al [133] developed an ICT infrastructure for an educational system using a Viable System Model (VSM). VSM is an organizational structure model which is established on the structure of the human nervous system [134]. The model was developed by Stafford Beer who was a leading figure in cybernetics [135] . Beer believed that there is a lot advantage in emulating the nervous system which has become an excellent tool for information and decision making process as a result of evolution witnessed over a couple of million years [134] . Cybernetics asserts that the way the nervous system controls its action is the same with the way species maintain themselves in their ecosystem and the way organizations maintain its existence in the work place are all govern by the same basic laws. Therefore, the VSM provides notations so that non mathematicians can understand and apply these general laws [136].

In spite of the success registered by in using this model in many public and private organizations, it is not popular because the concept is not easily understood and even if they understood, they are contrary to the general thinking of people regarding organizational management [137].

VSMs are made up of viable systems which are also viable on their own. This means that the systems are made up of sub systems which have the same collective characteristics [138].

The VSM models describes 5 major management functions within an adaptive systems or organizations namely [134].

- System 1 consists of units that carry out basic work organizations.
- System 2 consists of units which carry out scheduling and coordination.
- System 3 carries out middle management functions.
- System 4 carries out long term planning and the design of new products and services.
- Lastly System 5 carries out major policy decisions.

In Baquero et al’s model, the ICT infrastructure was broken down into different subsystem. This was done because VSM allows the management of decomposed parts in an integrated manner. The subsystems were designed in such a way that their complexities can be managed. Managing the complexities of each subsystem was applied using different framework whiles the design of the ICT center was done using a special treatment. The four subsystems are:

a. Infrastructure office which is responsible for infrastructure endowment of the whole system.
b. Software development office which is responsible for the continuous development of the soft wares for the system.
c. Educational support is responsible for training teachers and promoting of ICT infrastructure usage.
d. ICT center is responsible for guaranteeing the correct operation of the ICT infrastructure.

The major challenge faced by the designers of this infrastructure was the absence of any similar work that can used for comparative analysis with the framework designed.

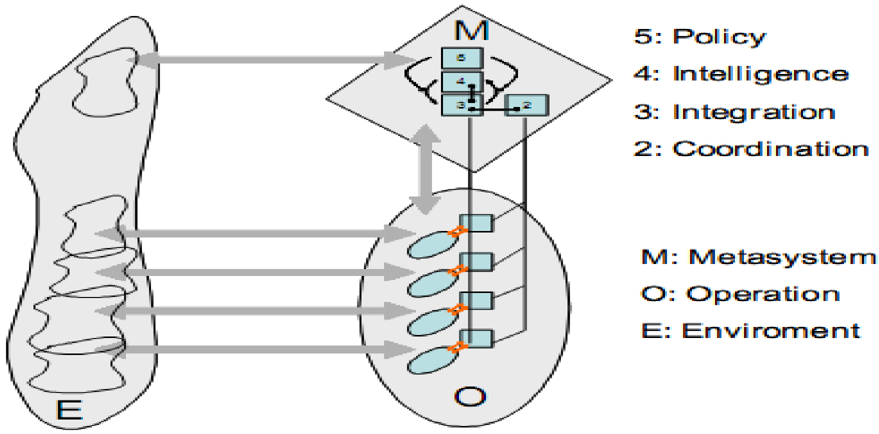


Figure 2.6 Viable System Model

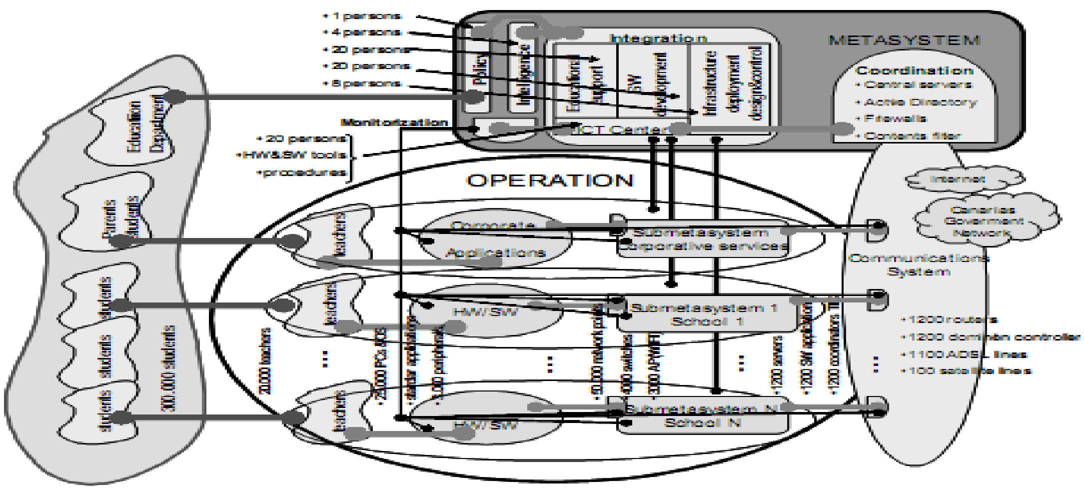


Figure 2.7 ICT Infrastructure as a Viable System Model

2.2.2 Systems and their relevant NFRs

All systems have NFRs and several research have been carried out to identify which NFRs are important and relevant to different types of systems. A project by the U S Army worth 2.7 Billion dollars which was meant for intelligence sharing was declared useless as a result of failure to meet NFRs such as Usability, Performance and Capacity [139]. Numerous works have been done on the topic of systems and their relevant NFRs. According to Kotonya and Sommervile, Reliability, Performance, Security, Usability and Safety are most relevant for critical systems [71]. Furthermore, Integration, Privacy, Performance and Security were discovered to be relevant for web based systems [88].

However, a very comprehensive work was carried out by Mairiza et al [80] to determine relevant NFRs for different types of systems. This was done by extensively analyzing over 182 sources of information which included Journals, Papers, Conference articles, IEEE/ISO standards and some industrial reports. The starting point of the research was a paper written by Chung et al in the year 2000. The work did not only cover relevant NFRs in different systems and application domain but also included definitions, terminologies and types of NFRs.

The researchers discovered that:

- There are over 252 types of NFRs but only 114 types among them have definitions which have been reviewed in connection to their quality.
- The most frequent types of NFRs mentioned in the reviewed articles are Performance, Reliability, Usability, Security and Maintainability.
- Some NFRs are seen as attributes of other NFRs such as Integrity, Availability and Confidentiality.
- Types of NFRs that are relevant in Education based systems are.
- Types of NFRs that are relevant in Education application domain are.

The full table for classification of relevant NFRs in different systems based on the work carried out above can be obtained in Appendix B.

However all the research mentioned above failed to establish the priorities and importance of the relevant NFRs for the various systems enumerated. Further, majority of them relied on secondary sources obtained in the last three decades. Thus there is a possibility that relevance of some of the NFRs might have reduced and there might be more NFRs that need to be added to the list due to additional needs of stakeholders and complexity of modern systems.

2.3.3 Integration of ICT in Education

In the last twenty years several countries, states and organizations have made attempts to introduce ICTs in the educational sector with varying degrees of success as enumerated below:

Nepad e-schools Initiative

The Nepad (New partnership for Africa's development) e-school initiative is one of the major projects of the e-Africa programme. It was introduced in 2003 and the aim of this multi – stakeholder and continental project is to make use of ICT to improve the quality of teaching and learning in African primary and secondary schools so as to avail young Africans with the knowledge and skills that will make them competitive in the global information society and knowledge economy [140].

All high schools were to be covered within 5 years of the start of implementation and all primary schools within 10 years, a total of some 600,000 schools [141].

From the beginning, it was thought that project will be executed holistically, having at least the following available: infrastructure (including computers, networking, power, etc.); teachers' training, curriculum development, involvement and ownership of the process, health perspective issues, organization and management of the project, partnership issues, sustainability and financial issues [142].

The private sector was extensively involved in the initiative through the Information Society Partnership for Africa's Development (ISPAD), which brought together fiscal and human resources, ICT infrastructure and curriculum materials from private and public sector partners and civil society.

The initiative started with a Demonstration project (Demo) in 16 countries in collaboration with private sector partners that included HP, AMD, Microsoft, Oracle and Cisco. The Demo was carried out primarily to assess the effectiveness, cost and benefits of the project in addition to discovering the challenges that normally occur in such big projects. 6 schools were selected in each country for the take up of the project.

Mauritius and Kenya have adopted the NEPAD e-Schools Model and have already started rolling out ICT to 100 schools using resources mobilized internally and from partners [18].

Some of the challenges faced by the project included

- Managing a complex public private partnership that ran across several nations was more complex than all stakeholders anticipated.
- So many countries are yet to implement the model after the Demo stage.
- So many initial assumptions that were made were discovered not to be valid.

Fatih Project Turkey

Fatih Project which means movement to increase opportunities and technology is a Turkish Government initiative introduced in 2010 to integrate ICT technology into the country's educational system. It is the largest single allocation of resources to education in the history of modern Turkey for a project that is completely designed by Turkish engineers [143].

The project which is expected to be completed by 2015 will see schools receiving smart boards and students receiving tablet in addition with the extensive use of ebooks. It is estimated that over 17 million students and 1 million teachers will receive tablets. The project is being managed by ministry of nation education in collaboration with the ministry of transportation. Tablet PCs and smart boards were delivered to 52 schools across Turkey for the pilot phase of the project [144].

Challenges faced by the project include:

- The most interesting part of the project is that the reason for the selection of the system employed is not known and most probably done based on guts [46].

- The Ministry of education failed to file for patent early meaning that no royalty will accrue to the government if anybody decides to develop a similar tablet.
- More interactive courses are needed especially for Maths and Science courses [145].

OPON IMO – Osun State, Nigeria

In June 2013, the government of Osun state in Nigeria introduced Opo Imo initiative in its attempt to introduce ICT in education. Opon Imo which translates to Tablet of Knowledge is a learning tool which is expected to revolutionize teaching and learning process in the state with the help of the Opon Imo technology enhanced learning system (OTELS) [146].

The standalone tablet which runs on an android platform with a storage capacity of 32GB provide secondary school students with all materials needed for their final school examinations in the form of ebooks, video tutorials, practice questions and educative games. The devices have their internet deactivated to avoid distraction [147].

Some of the challenges faced by these project are:

- There is no clearly defined reason behind the selection of the system employed.
- The impact of the project is not ascertained as it is still in the experimental stage.
- Some critics see the project as a "white elephant project" [148].

One computer per child (OLPC)

The project introduced in 2005 is so far the most ambitious ICT initiative the world has ever seen [9]. It was aimed at providing over 100 million cheap laptops to Children including those at impoverished countries. The initiator of the program Nicholas Negroponte believes that by simply handing over computers to children, they can not only teach themselves how to use it but will be able to teach their family members [149].

OLPC developed its own laptop the XO along with its own software and package called sugar. The plan was that a minimum order of 1 million units will be made which was subsequently reduced to 250 thousand. In 2011 only 2.4 million were sold and it was discovered that over 80% were purchased by developed countries [150].

Short comings of the project:

- Most schools lack internet access thereby limiting how the laptops can be used.
- The spare parts are very expensive due to the uniqueness of the systems
- The idea of just giving a child a laptop and walking away in reality is rather very naïve.

Ipads for Schools in Los Angeles, America

In 2013 starting from Los Angeles, many cities in the United States introduced the use of iPad in class rooms. The tools are given to each student and the students are free to take them home. The tablets are connected to the internet but efforts have been made to block harmful websites [151]. Assignments and tests are expected to be done and submitted through the tablets.

A few weeks after introducing the project some students were able to breach the system in order to be able to access restricted websites. This prompted the school officials in Los Angeles to halt the billion dollar project and ban the home use of the systems until the problem is resolved [152].

Tiger Leap Program, Estonia

In 1996, Estonia introduced the Tiger Leap project which is aimed at developing ICT infrastructure in schools which will include provision of internet, ICT skills for teachers, updating curricula and development of local language soft wares [153].

Each school is tasked to find its own way of integrating ICT in different subjects for all students. Teachers create their own blogs and support distance learning [154].

Conclusively, it is observed that most of the countries tried to develop their own initiatives albeit copying some of the projects that were implemented by other countries in some cases, the imitation is done blindly without taking into consideration local peculiarities. It is very difficult if not impossible to develop a “one size fit all initiative” that will work effectively across nations due to the cultural and socio economic differences that exist amongst different nations. It is therefore it is imperative that countries look into their needs before embarking on an ICT in education project.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

Research methodology is defined as the procedure by which researchers go about their work describing, explaining and predicting phenomena. Its aim is to give the work plan of research [155].

The purpose of this study has been thoroughly explained in Chapter 1 of this write-up however the purpose of this chapter is to:

1. Describe the research methodology employed for this study.
2. Explain the different techniques and methods that were employed.
3. Describes the procedures that were followed in designing the instruments, obtaining the findings and data collections.
4. Provide and explanation of the statistical procedure that was used to analyze the data and lastly,
5. Explain the criteria that were used in selecting the most effective choice based on the results obtained.

Selecting a research method or methods is very crucial in any research undertaking. There is a possibility that no single method may be enough for requirement development. To this end different methods can be selected at different sessions or even within one session [156]. Further, time, available resources and the type of information to be elicited play an important role in the selection of an appropriate technique or techniques [96].

Various traditional techniques were employed in this research as suggested by [96]. The procedure that was followed in carrying out this research is described below:

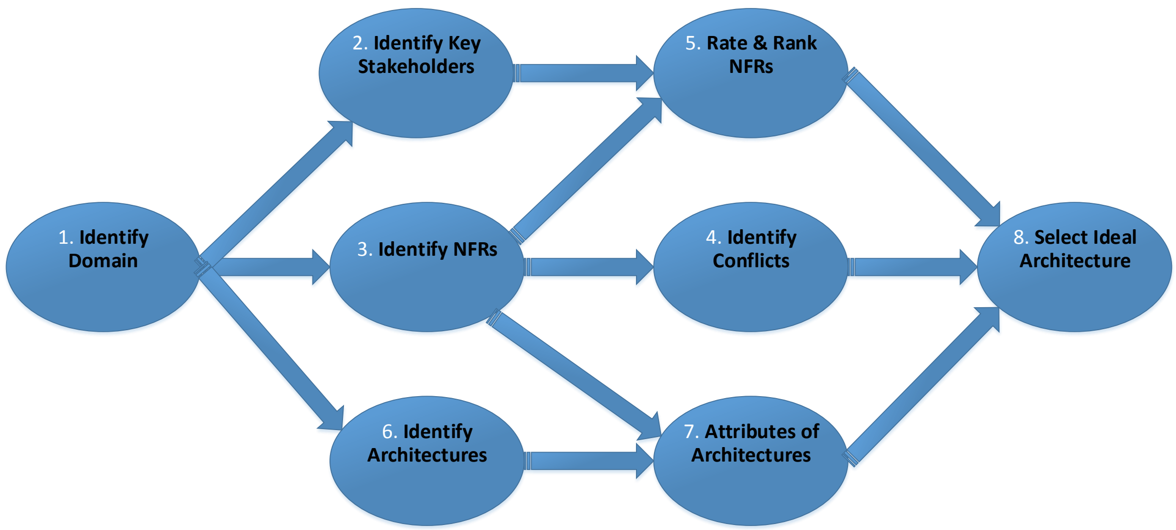


Figure 3.1 Steps followed for research

3.2 STEPS OF THE RESEARCH

The research was carried out in the following steps

3.2.1 Step 1: Identifying the domain and stakeholders

The first step in any requirement engineering process also known as systemic requirement analysis [157] is elicitation of requirements [96]. This is where the requirements needed for a particular system are discovered [158].

Before elicitation, the problem to be solved needs to be identified, thus boundaries of the proposed system should be established. The boundaries define, at a high level, where the proposed system will be adapted. The choice of the boundary determines the choice of the stakeholders of the system [96].

Nigerian secondary schools were chosen as our boundary for the research. The choice was made because there is no comprehensive ICT in education policy in Nigeria [49] thus bias is not expected from the stakeholders. Additionally, there is a need for acquisition of ICT skills and knowledge in Nigerian Secondary schools [159] because improved education in secondary schools is believed to be essential for the creation of effective human capital in any country [160].

On the other hand, various methods are abound for identifying and selecting stakeholders for requirement elicitation as explained in Chapter 2. However, due to time and logistics constraints it obvious that not all identified stakeholders could be reached. Additionally, the nature of the instrument that was designed for the survey could not have been easily comprehended by some of the stakeholders such as the students. To this end, a strategy to sort, prioritize and select the stakeholders had to be employed [60]. According to [161] the major categories of stakeholders are the managers that are involved in the organizational process of the system, the professionals that are responsible for the development of the system, those that will directly make use of the system and the regulators that have a say on how the system is to be developed. As a result the following stakeholders were selected in this research namely Managers – Principals and Vice principals (administrators), Professionals – ICT professionals, Users – Teachers and Regulators – Policymakers (staff of ministry of education/school boards). Therefore the above stakeholders were thus considered for the research because they cover the major stakeholder classifications.

3.2.2 Step 2: Identifying NFRs that are relevant for the education system

Literature review was used to unearth the NFRs that are relevant for the education system. An extensive research was carried out by [80] where different systems were categorized based on their respective NFRs. The work sighted 7 NFRs which were deemed relevant for an education system. However, other literatures that were reviewed contained different views regarding NFRs for education system. Furthermore, some papers listed NFRs that were detected to be relevant for all ICT systems which were missing from the list of Mairiza et al. It is also evident that with the rapid changes in the ICT field [41] some of the relevant NFRs mentioned in the literatures might not be relevant any more and/or some additional NFRs might now be relevant. Therefore in order to avoid any lapse, a criteria was developed for the elicitation. Any NFR that was discovered to be relevant for an education system, ICT system, Web based system (which most present ICT systems are based) were shortlisted. Further, characteristics of ICT based education systems were also reviewed. An NFR is shortlisted only once even if it appears more than once in different literatures. At the end of the day, the NFRs were merged based on ISO/IEC 25010:2011 [162] classification of NFRs. See Appendix C for the classification. The classification was adopted not only to reduce the number of NFRs that the stakeholders will have to contend with but also provide terminologies that are consistent for measuring and evaluating systems.

3.2.3 Step 3: Conflicts among elicited NFRs

Conflicts within NFRs usually lead to tradeoffs. This is an unavoidable phenomena in requirement engineering which means two or more NFRs cannot be satisfied at the same time [112]. There are several conflict identification techniques that assist in identifying high level conflict among NFRs [111]. The scope of this research is not interested in capturing the nature of the conflict but only in identifying the conflicts among NFRs so that appropriate action can be taken later. As a result, I decided to make use of a catalogue of conflicts among NFRs that was developed by [116]. The choice was based on the simplicity and categorization technique employed by the developer. NFRs were broken down into 1) Absolute conflict 2) Relative conflict and 3) Never in conflict and the conflicts can be identified by mere observation. Moreover, the catalogue was developed after meticulous blending of several reviewed literature thus making it an authoritative catalogue for NFR conflict identification.

3.2.4 Step 4: Measuring and prioritizing NFRs

A requirement cannot be included in a system until and unless it is obtained from prioritization based on a criteria [99]. Prioritization based on importance criteria aides stakeholders to select the requirements that are more important to them [101] and guides the requirement engineer during conflicts analysis. Several techniques are available for prioritization but the general advice is to choose a technique that is simple [99]. To investigate the importance of the NFRs, a survey was conducted. The objective is to discover the importance of each NFR (individual priority) and the order (rank) of each NFR (overall priority). In other words, By individual priority I mean what is the importance of NFR1 in the system, is it High, Medium or Low while the overall priority means how important is NFR1 compared to NFR2,NFR3…. etc. in the system.

To investigate these priorities, a survey was conducted using rating and ranking scale questions. Surveys are useful tools for collecting and analyzing data from stakeholders. They are widely accepted as a method of NFR elicitation in requirement engineering [96].

The word survey is normally applied to a research method were data is gathered from a population or a sample of a population usually by making use of a questionnaire or an interview as the instrument of survey [163]. According to Leary [164] the upper hand questionnaires have over interviews is that questionnaires are cheaper and easier to administer. In my case it was chosen because it is almost impossible to conduct interview due to the distance between me and the respondents. Furthermore, the questionnaire will ensure more respondents are obtained which will enrich the data.

By using both rating and ranking scale questions, the priorities and importance of the NFRs were determined. Rating scale questions allows respondents to the questionnaire to give responses that are better than close ended questions and at the same time easier to measure than open ended questions [165]. Likert scale was chosen over Fuzzy scale based questionnaires because Likert scale questionnaires are easier to conduct and analyze. Moreover, fuzzy logic ratings are not user friendly in addition to the fact that there are very few studies carried out for fuzzy rating scale data [166]. It has also been observed that Likert scale questionnaires are extremely useful for quantifying NFRs [97]. A 5 point Likert scale was employed to avoid extreme response styles where respondents only choose extreme options irrespective of the content of the questionnaire [167] . On the other hand, the ranking was carried out using simple ranking technique where the respondents were asked to rank the NFRs based on importance from the highest to the lowest. This technique was adopted because it is a simple prioritization technique as other techniques such as 100 Dollar technique and Analytical Hierarchy Process will confuse and discourage participants due to their complexity. Ranking scale questions are normally time consuming and more difficult to perform compared to rating scale questions. As the number of ranking items increase so those the difficulty and the inconsistency of the results [167].

3.2.4.1 Sample

For this study, I employed random sampling were the stakeholders that were targeted were all Nigerians that have worked or are currently working in Secondary schools, Federal and State Ministries of education and ICT professionals that have some knowledge in System architecture, ICT in education and or computer networking. Random sampling was adopted because it was adjudged to be the best single way of getting a good representative sample. It should however be noted that no single method can assure a truly representative sample but random sampling has a higher probability than other methods [168]. It further gives us the opportunity to make meaningful comparisons between different subgroups in the population. See Appendix D for Education system and ICT policy in Nigeria.

3.2.4.2 Instrumentation

Both online and offline questionnaires were employed for the survey. The filled offline questionnaires were later uploaded online for easy compilation and analysis. Google form was employed. The reason for the decision to use online questionnaire was obvious; it has a wider reach and the responses can be obtained immediately a questionnaire is filled in addition to ease of analysis [169]. The survey employed was meant to determine the importance of each NFR and the priority of the NFRs in the system.

The instrument was divided into four sections:

- Section A contains background information of the respondents. Items 1 – 7 address the sex, age group, Profession, working experience and level of exposure to ICTs of the respondents.
- Section B contains rating scale questions. Items 8 – 22 requires the respondents to rate the importance of NFRs based on the metrics of the NFRs. The definitions of the NFRs were not given less it will lead to bias responses. In order to reconfirm the correctness of our decision to group the elicited NFRs based on ISO/IEC 25010, some NFRs that were discovered to be sub attributes of other NFRs, were included in the survey so that it can be assessed if the respondents will rate them in the same manner with the main NFRs. Another question was also included to determine the population size of the schools which were chosen as our domain.
- Section C contains ranking scale questions. Item 23 requires respondents to rank the NFRs based on their importance from 1 to 12.
- Section D is an optional part. Item 24 requires responds to give additional information for reasons behind their choices and if they so wish leave their name and contact address.

Sample of the questionnaire is available in Appendix E.

3.2.4.3 Validity and reliability of the questionnaire

Validity and reliability of a questionnaire are very important as according to [170] only reliable questionnaire can elicit response that are consistent. Additionally, providing all the respondents with the same set of questions ensures that a good reliability is obtained [163]. On the other hand, to establish validity in a questionnaire all conclusions drawn from it by the respondents must be correct which made [170] to suggest that people of different back ground and points of view should review it before it is administered.

Based in the above, 11 stakeholders were preselected and a draft of the questionnaire was sent to them to fill and review. The collated responses and inputs were used to make corrections before the final instrument was administered.

3.2.4.4 Data collection

The web link to the questionnaire was sent to several emails, Linked-in and Facebook accounts of several people that were obtained through random and directed search. Further, link to the questionnaire was posted in several Facebook forums such as Nigerian Teachers Network, N.U.T Nigerian Union of Teachers, Nigerian Teachers Forum, OPON IMO, National Association of ICT Professionals, and Nigeria (NAIPN). Weekly reminders were sent to the emails and postings were made on the online fora were the link was placed. However in the course of the research, it discovered that the response rate was not encouraging and the main reason for this was some of the targeted respondents found it difficult accessing the online questionnaire for one reason or the other. Therefore a paper version of the questionnaire was made and sent over to Nigeria. It was distributed with the help of friends and at the end of the day; the filled questionnaires were recovered and uploaded online to allow analysis through a single channel for easy assessment.

3.2.4.5 Method of analysis

Analysis involved examination of the survey results and performing the analysis of the responses. Excel was used in analyzing the survey results. In the case of the rating scale questions; Ordinal scale (data) which are discrete measures were employed. The central tendency for discrete measures is best captured by the mode [171]. After computing the relative percentages, the data was presented in Diverging stacked Bar charts. Diverging stacked Bar charts is the most recommended way of presenting rating scale questions [172]. Percentages of respondents that have a positive opinion are shown in the right (High and Very high) and Percentages of those with a negative opinion are displayed in the left (Low and Very low) while those with a neutral or medium choice are split down the middle [173]. This is a good method as it is difficult to compare lengths without a baseline. We are not very much interested in breakdown into strongly agree or strongly disagree but rather the total percentage in the left, right and middle as the case may be thus converting it from a 5 point scale to a 3 point scale. The side with the highest percentage is considered as the popular opinion of the respondents and thus accepted as their decision.

For the analysis of the ranking scale questions, ranking data is achieved through data transformation. The conversion is done by multiplying the frequency for each choice which gives us a new scale [171]. The choice with the least total score is ranked 1st, the one with the second lowest is 2nd etc.

3.2.5 Step 5: Identifying different Systems Architectures and their characteristics

There are several system architectures that are available in the world today, each with its advantages and disadvantages. Different researchers have adopted different classification for systems architectures as seen in the literature review in chapter 2. The criteria that was adopted in selecting and adopting the systems architectures for this research is to pick architectures that are popular, modern, trending or appears to have potentials in the future. To validate the system architectures selected against the NFRs elicited, extensive literature review was undertaken were the quality attributes of the architectures were rated either High, Medium or Low as the case may be. The rating of the quality attribute is not perfect but it was achieved through meticulous systematic literature review. The criteria used was, for architectures were the ratings was explicit, it was directly adopted. This included cases were the attributes were provided as advantages and disadvantages of an architecture. Advantages were rated as high while disadvantages were rated low. Further, when an attribute is termed to be an improvement compared to another architecture then that attribute is rated ones step higher for the architecture with the improvement and if it is a deterioration the opposite takes place.

3.2.6 Step 6: Selecting the ideal Architecture

After collating and analyzing data from the questionnaires and literature review from the previous steps, a selection was made using Multi criteria decision analysis. The comparison was made with the Non-functional requirements being the criteria and the system architectures as the alternatives. As mentioned in chapter 2, there are various available methods that can be used when confronted with a complex problem to make a choice between several alternatives based on different criteria. Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) was adopted because it is not only suitable for engineering applications but is simple to use with consistent number of steps. In this technique, the selected alternative should have the least distance from the ideal solution and the farthest from the negative ideal solution. Ideal solution is composed of all the best criteria and negative ideal solution is composed of the worst criteria. Simple Additive Weighting (SAW) was used to verify the result obtained from TOPSIS. SAW analysis technique is used more in financial and business management. Though it is not as accurate as TOPSIS; it is easy to use thus making it ideal for verification [131].

CHAPTER 4

DATA ANALYSIS, FINDINGS AND DISCUSSIONS

This chapter presents the research findings gathered from the literature research and Survey carried out. The results are discussed and charts are used to visualize some of the findings for easy comparisons and understanding.

4.1 RELEVANT NFRS FOR AN ICT IN EDUCATION SYSTEM

The following NFRs were discovered to be relevant for and ICT in education system from the several literature reviewed [88], [93], [174], [80], [175].

Table 4.1 List of NFRs for an ICT in Education System

S/No.	NFR
1	Accessibility
2	Accuracy
3	Availability
4	Coherence
5	Data Retention
6	Integrity
7	Interoperability
8	Maintainability
9	Modifiability
10	Performance
11	Portability
12	Privacy
13	Reliability
14	Scalability
15	Security
16	Usability

However, based on ISO/IEC 25010:2011 [162] as stated in the methodology:

- Availability is a sub characteristics of Reliability.
- Integrity, Privacy, Confidentiality are sub characteristics of Security.
- Modifiability is a sub characteristic of Maintainability.

The list was thus reviewed based on the sub characterization above as follows:

Table 4.2 Review List of NFRs for an ICT in Education System based on ISO/IEC 25010

S/No.	NFR
1	Accessibility
2	Accuracy
3	Coherence
4	Data Retention
5	Interoperability
6	Maintainability
7	Performance
8	Portability
9	Reliability
10	Scalability
11	Security
12	Usability

The definitions of the NFRs are available in Appendix C

4.1.1 Conflicts among the elicited NFRs

It was thoroughly explained in Chapter 2 that NFRs tend to conflict and these conflicts can be Absolute, Relative or in some cases requirements are never in conflict. Absolute conflicts a situation whereby the NFRs are always in conflict while Relative conflicts portrays a situation whereby the NFRs are not always in conflict. From the catalogue of conflicts [176] which was used in this research, the following NFRs were discovered to have potential conflicts. See Appendix A for the catalogue.

Table 4.3 Potential Conflicts among the elicited NFRs

S/No	NFRs	Relative Conflicts	Absolute Conflicts
1	Accessibility		
2	Accuracy		Portability, Performance
3	Coherence		
4	Data Retention		
5	Interoperability		Performance
6	Maintainability	Interoperability	Performance
7	Performance	Interoperability, Reliability, Usability	Accuracy, Maintainability, Portability, Security
8	Portability		Accuracy, Performance
9	Reliability	Interoperability, Performance	
10	Scalability		
11	Security	Interoperability, Usability	Performance
12	Usability	Performance, Security	

What these conflicts mean is that when Security conflicts with Performance, it means it is not possible to have a system that is very secure and at the same time exhibiting high performance. Therefore to achieve security, performance will have to be sacrificed and vice versa. The same case applies for all the other identified conflicts.

It should be noted that even though the catalogue used is one of the most reliable catalogues of conflicts among NFRs, it is not comprehensive enough as it does not cover all the elicited NFRs in this research. Nonetheless it was created after extensive literature research making it one of the best for conflict analysis of NFRs [116].

Analysis and resolution of conflicts is beyond the scope of this research because the nature and scale of the conflicts are not known but rather we are only able to capture the conflicts at a high level. Most architecture analysis models center on individual NFR as against a collection of NFRs similar to the situation in this research. For analysis models that deal with multiple NFRs, they do not investigate the conflicts but rather produce a warning about the conflicts [112].

A suggested technique for resolving a problem like this is to negotiate with the stakeholders to review their ratings based on the identified conflicts.

4.1.2 Priorities and Importance of the elicited NFRs according to the system stakeholders

A survey was employed for this purpose. 62 offline responses and 61 online responses were obtained making a total of 103 responses. 78 offline questionnaires were not returned. 4 duplicate entries were discovered and removed leaving a total of 99 responses for analysis.

4.1.2.1 Demographic and Background characteristics

The first part of the questionnaire contains background information of the respondents. Although it is not part of the goal of the research, the data was meant to highlight the demographic variance of the sample and access whether it will have any influence in the research. The breakdown is as follows:

Job Profile

The chart below presents the respondents based on their job profiles which is formed the basis for stakeholder classification. Managers – Principals and Vice principals (administrators), Professionals – ICT professionals, Users – Teachers and Regulators – Policymakers (staff of ministry of education/school boards.

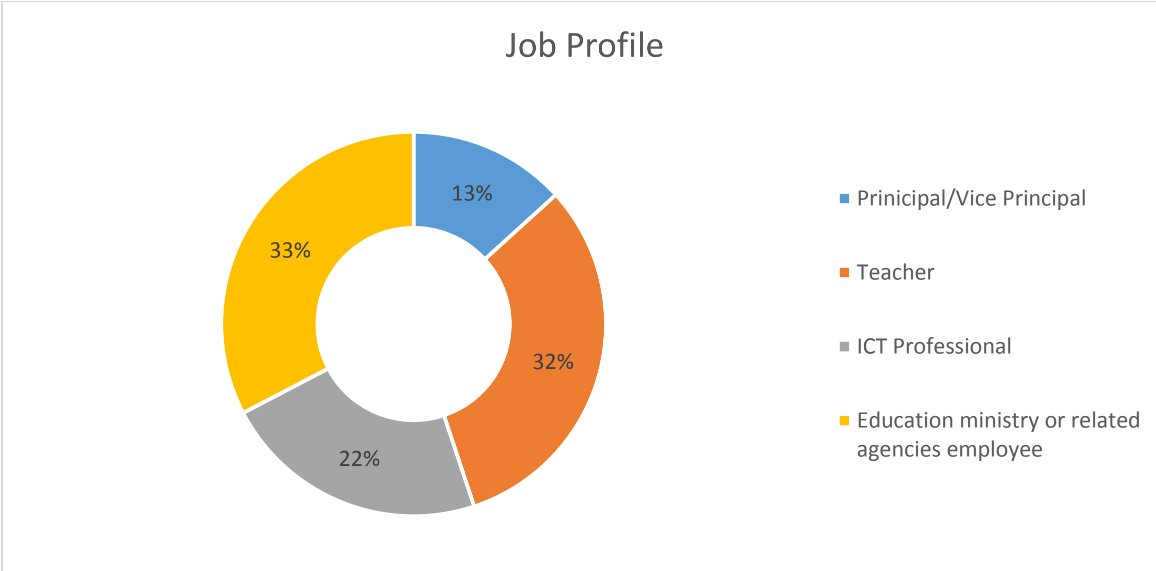


Figure 4.1 Job Profile

13 of the respondents were Principals/Vice principals, 31 were teachers, 22 were ICT professionals and 32 were staff of Ministry of education and related agencies. Effort was made to have almost equal number of respondents but unfortunately it was not achieved for obvious reason. The number respondents that fall under the category of principals/Vice principals is much lower than the other categories.

Gender

The chart below shows the number of respondents based on their Gender. 90 respondents were male and 9 respondents were female. The low number of female respondents cannot be explained as the survey was carried out randomly and there is a good number of female that suit the stakeholders' profile.

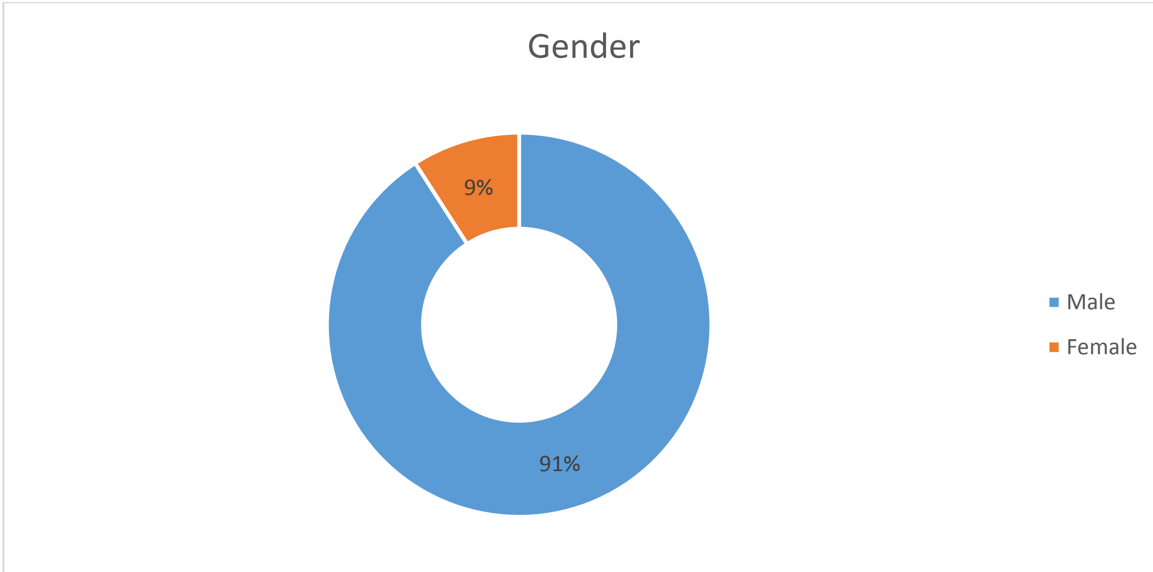


Figure 4.2 Gender Chart

Years of Experience

Experience is a very good measure for good decision making therefore this might be important. The graph below illustrates the respondents based on their working experience.

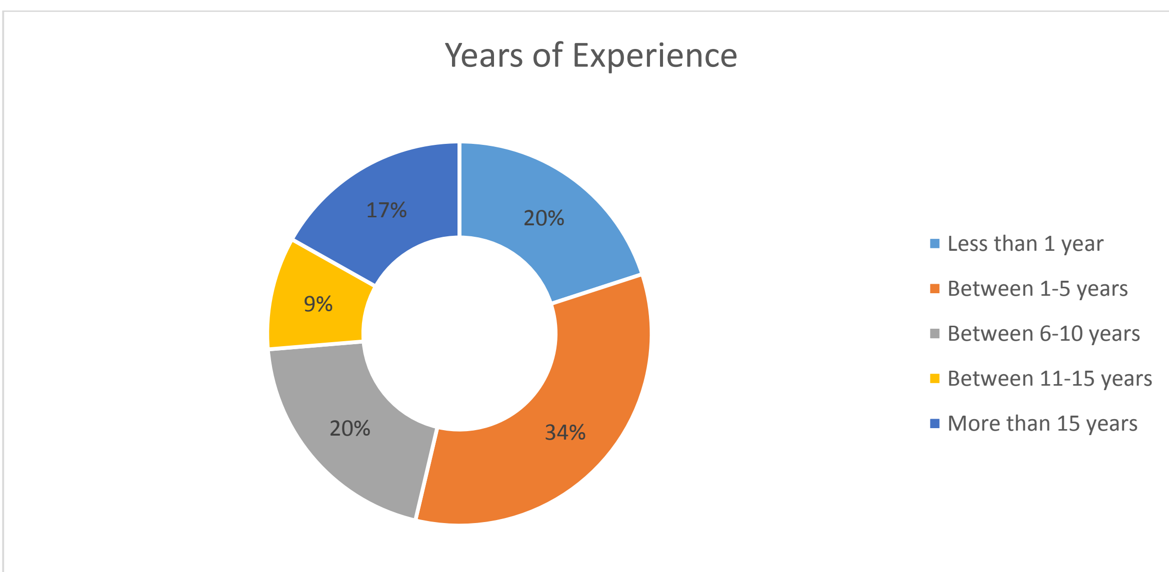


Figure 4.3 Years of experience Chart

19 respondents have less than one year experience in their Job while 32 have between 1 to 5 years' experience.19 have between 6 to 10 years' experience, 9 have between 11 to 15 years while 16 have more than 15 years' experience. From the breakdown it can be observed that there is a very good mix of experienced stakeholders that can be able to make informed decisions.

Age

The chart below contains the age categorization of the respondents.

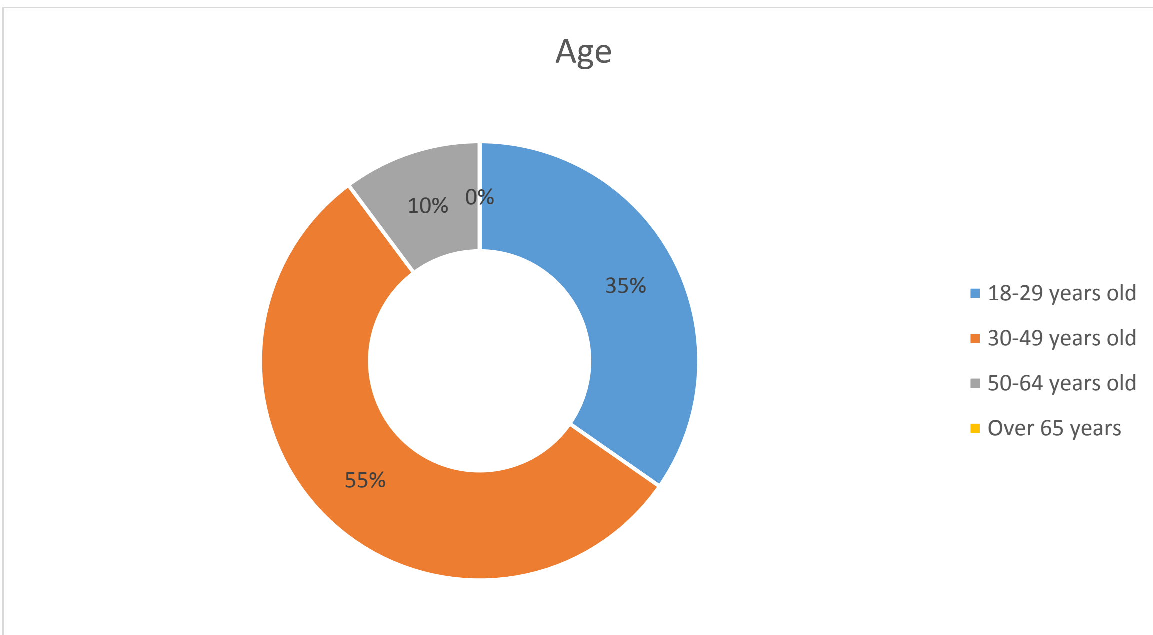


Figure 4.4 Age Chart

34 of the respondents are between the ages of 18 and 29, 54 are between 30 and 49, 10 are between 50 and 64 while there is no single respondent over the age of 64. Most of the respondents fall in the bracket of Generation X; who are exposed to ICTs and are therefore expected to contribute more meaningfully to the survey as they appreciate ICT more [177].

Experience with ICT

This presents the number of years the respondents had been exposed to the use of ICTs.

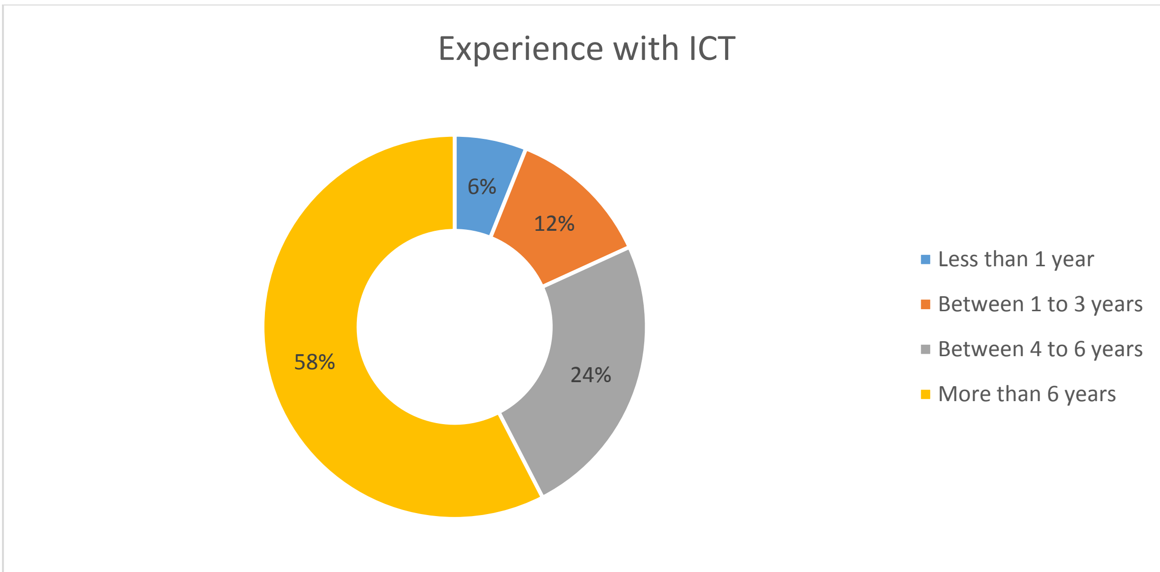


Figure 4.5 Experience with ICT

It can be seen that 82% of the respondents have a very good exposure to ICTs which is very important for this research. 6 respondents have less than 1 year experience in the use of ICTs, 12 respondents have between 1 and 3 years in the use of ICTs, 24 respondents have 4 to 6 years' experience while 54 respondents have more than 6 years' experience in the use of ICTs.

Confidence Level in the use of ICTs

The chart below displays the confidence level of the respondents in the use of ICTs.

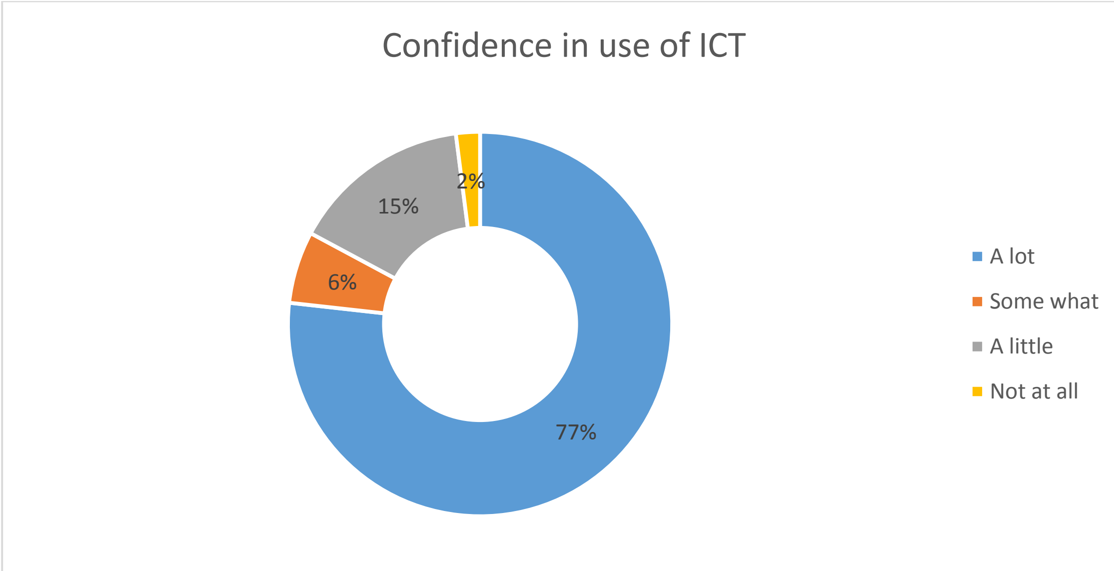


Figure 4.6 Confidence Level in the use of ICTs

Only 2% of the respondents are not confident in their capability to use ICTs. 76 respondents are very confident in the use of ICTs, 6 respondents are somewhat confident, 15 respondents have a little confidence and 2 respondents are not confident at all. It has been proved that competence, confidence level and satisfaction level towards ICT programs are correlated [177] which means persons with high ICT confidence level are more likely to make better informed decisions in ICT related matters.

In summary, from the breakdown of the respondents of the survey, it is assumed that an informed decision will be made as majority of the participants have a lot of experience in their chosen roles, are exposed to ICTs and have a lot of confidence in the use of ICTs.

Optional part of the questionnaire

Only 43 participants responded to Section D of the questionnaire by giving their names and contact information.

4.1.2.2 Rating of the elicited NFRs

The second part of the questionnaire contains the rating scale questions where the respondents were asked to rate the individual importance of the NFRs in the system. 11 out of the 12 NFRs were forwarded to the stakeholders to rate. The 12th NFR which is maintainability was not included because empirical research has proved that in any ICT project where Modifiability (a sub characteristic of Maintainability) is rated high, such a project is hardly successful [93]. Stakeholders that rate Modifiability high are not sure of what they want from a system. Based on this fact, Maintainability was automatically rated Low for this research.

The result of the survey is displayed in a diverging stacked charts where the total number of respondents that rate the NFRS high are shown in the upper part of the chart and the total that rate them low are shown in the lower part. The zero label cuts through the medium choice.

Regulators rating of elicited NFRs

The graph below presents the rating pattern of the Regulators:

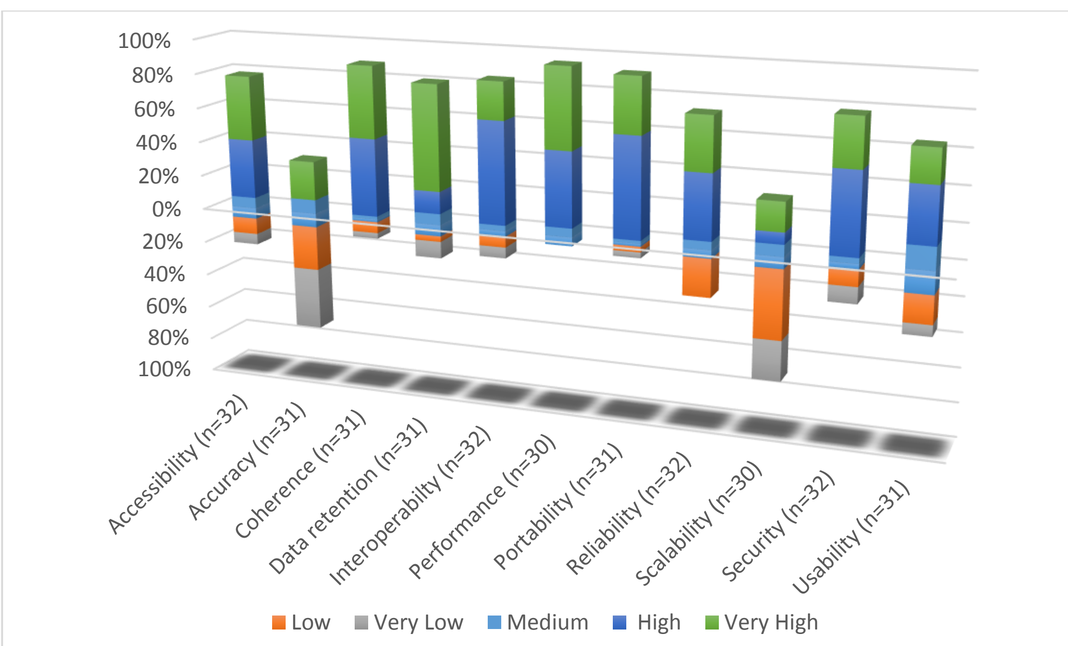


Figure 4.7 Regulators rating of the elicited NFRs

From the perception of the regulators, the priorities of Accessibility, Coherence, and Data retention, Interoperability, Performance, Portability, Reliability and Security should be high in the proposed system. Usability is also high even though only 52% of them have that opinion. Performance and Portability have the highest individual priorities. On the other hand, Accuracy, Scalability, are not considered that important and were thus rated low.

Developers rating of the elicited NFRs

The chart below presents the rating pattern of the Developers:

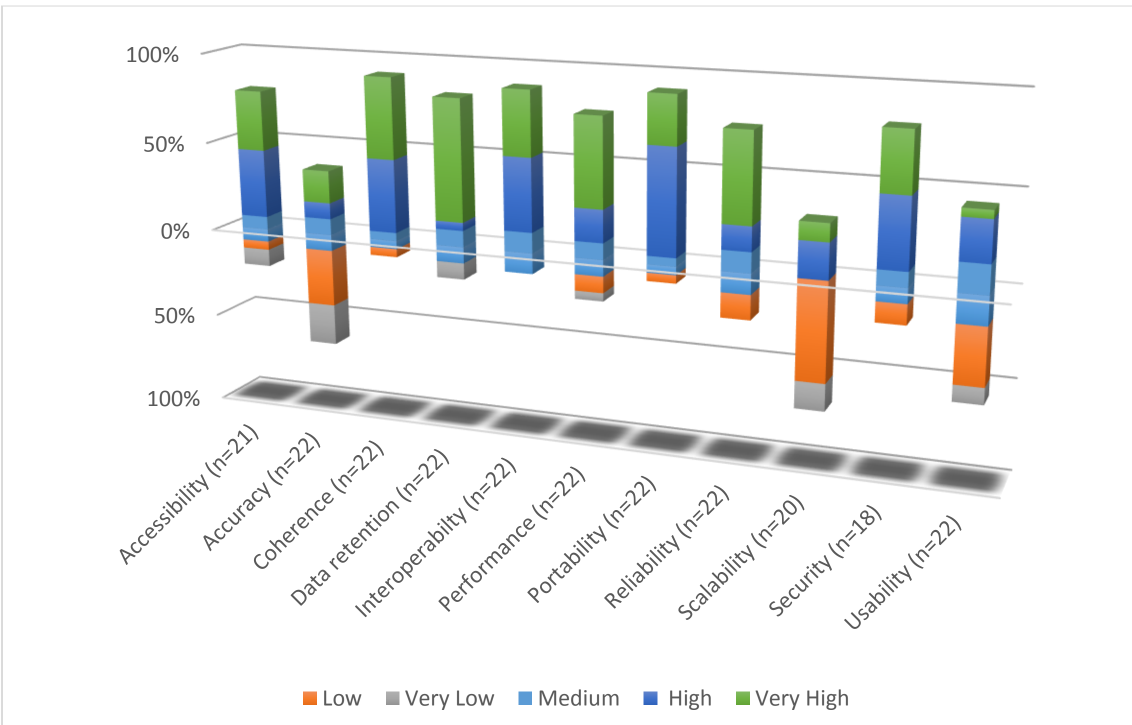


Figure 4.8 Developers rating of the elicited NFRs

From the point of view of the developers, Accessibility, Coherence, Data retention, Interoperability, Performance, Portability, Reliability and security are all important and were rated high. Coherence and Portability got the highest ratings. Accuracy, Scalability and Usability were rated low by the developers.

Users rating of the elicited NFRs

The rating pattern of Users is presented in the graph below:

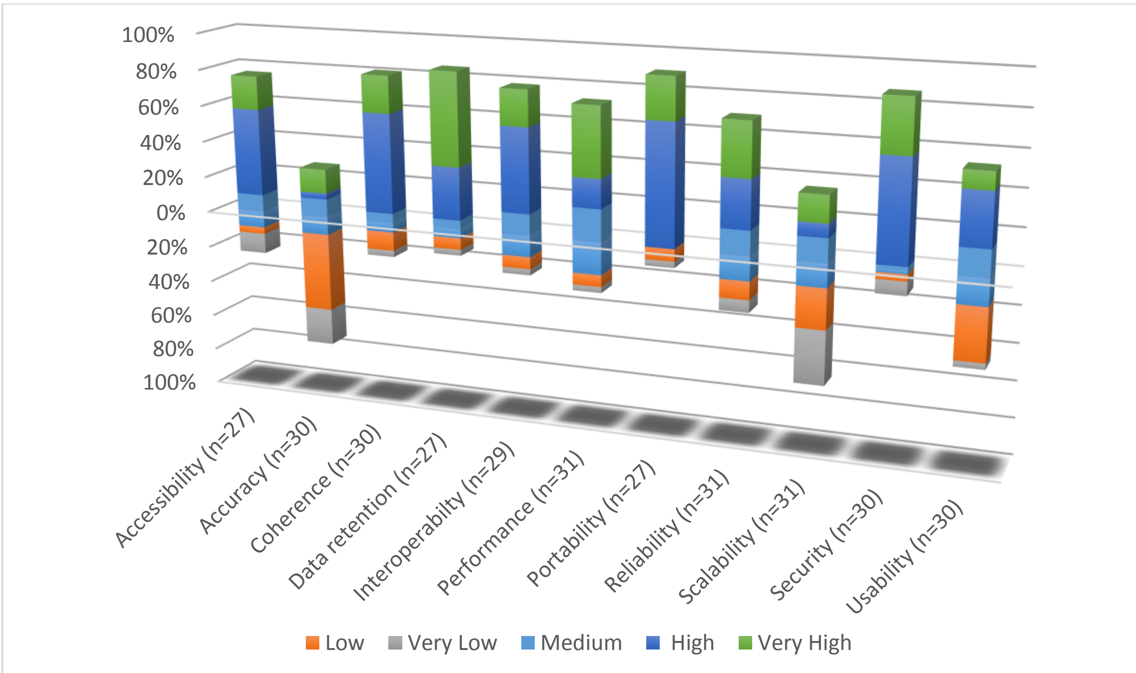


Figure 4.9 Users rating of the elicited NFRs

Accessibility, Coherence, Data retention, Interoperability, Performance, Portability, Reliability, Security and Usability should have high priority from the perception of the users. On the other hand, Accuracy and Scalability should have low priority. The NFR that got the highest priority rating was Portability.

Managers rating of the elicited NFRs

The chart below displays the rating pattern of the stakeholders that fall under the category of Managers.

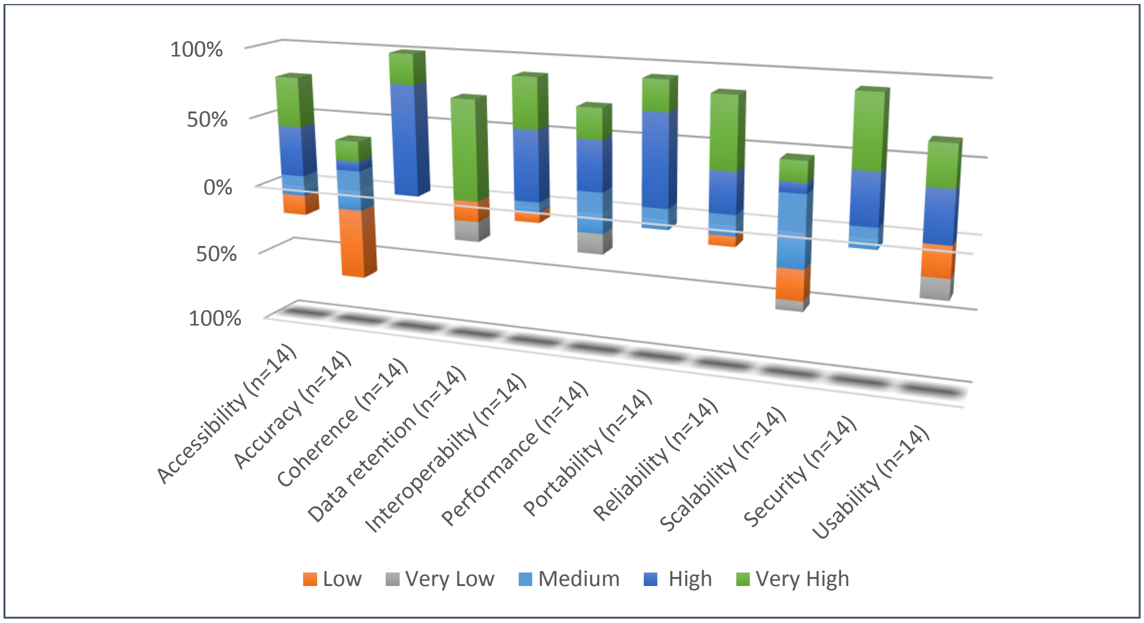


Figure 4.10 Managers rating of elicited NFRs

NFRs that should be accorded high priority in the proposed system are Accessibility, Coherence, Interoperability, Performance, Portability, Reliability, Security and Usability based on the Managers' perspective. While the NFR which should be accorded low priority is Accuracy. Coherence was rated very high priority based on this stakeholders' point of view.

Entire stakeholders' rating of the elicited NFRs

The general rating pattern of all the stakeholders combined is presented below in the chart

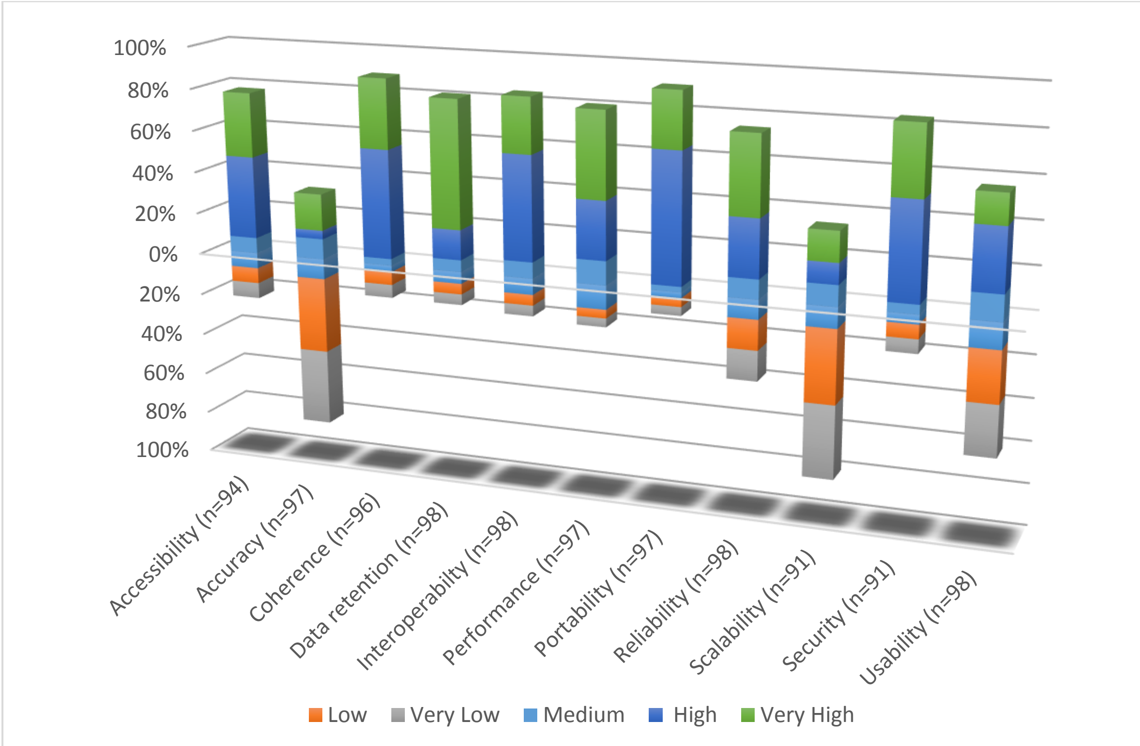


Figure 4.11 General rating of the elicited NFRs

The general point of view of all the stakeholders reveal that Accessibility, Coherence, Data retention, Interoperability, Performance, Portability, Reliability, Security and Usability should be given high priority in the proposed system while Accuracy and Scalability should be given low priority in the proposed system. The NFR that recorded the highest priority based on the perception of the stakeholders is Portability.

In summary, the priority ratings of all the stakeholders can thus be summarized in the table below:

Table 4.4 Summary of the general ratings by the stakeholders

Rating	**High**	**Medium**	**Low**
1	Accessibility		
2			Accuracy
3	Coherence		
4	Data Retention		

Table 4.4 Continued

Rating	High	Medium	Low
5	Interoperability		
6	Maintainability		
7	Performance		
8	Portability		
9	Reliability		
10			Scalability
11	Security		
12	Usability		

4.1.2.3 Validating the reclassification of the NFRs based on ISO/IEC 25010

As earlier stated in the methodology, in order to verify that the respondents would rate the NFRs and their sub attributes in the same manner, Integrity and Privacy which are sub characteristics of Security and Availability which happens to be a sub characteristics of Reliability were included in the rating scale questionnaire. This was done to validate the reclassification of the elicited NFRs with ISO/IEC 25010.

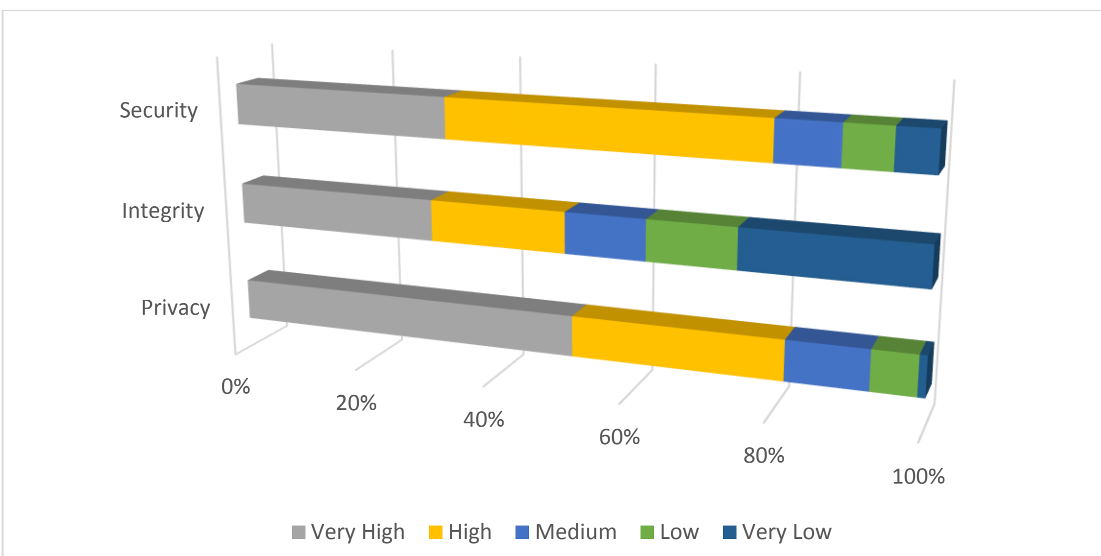


Figure 4.12 Comparing Security, Integrity and Privacy NFR ratings by all stakeholders

From the chart above, we can observe that the participants rated all the NFRs in the same manner even though Integrity was not rated as high as the others, it has passed the 50% mark therefore it is rated high based on our rating scheme.

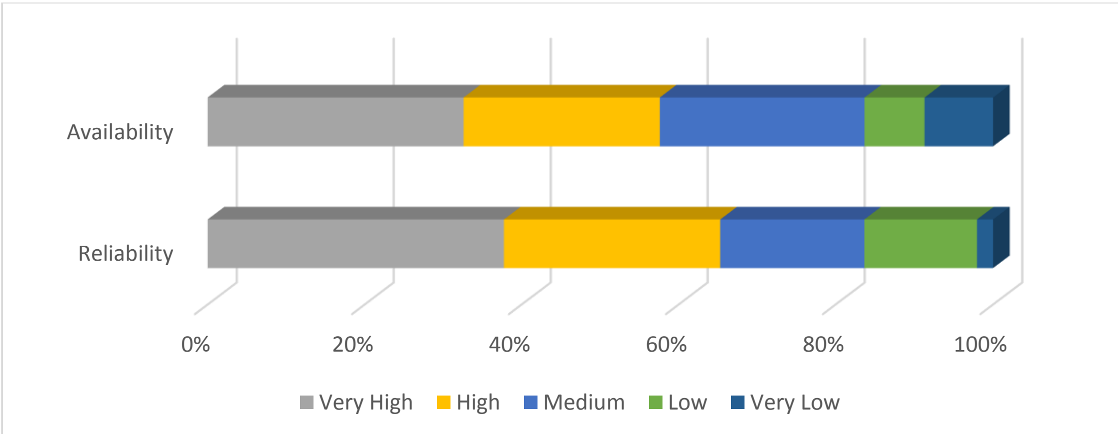


Figure 4.13 Comparing Availability and Reliability NFR ratings by all stakeholders

In the graph above, it is clearly obvious that the two NFRs were rated in a similar fashion by the stakeholders. To this end we can draw a conclusion that the reclassification based on ISO/IEC 25010 is valid.

Population size of the secondary schools that was selected as domain

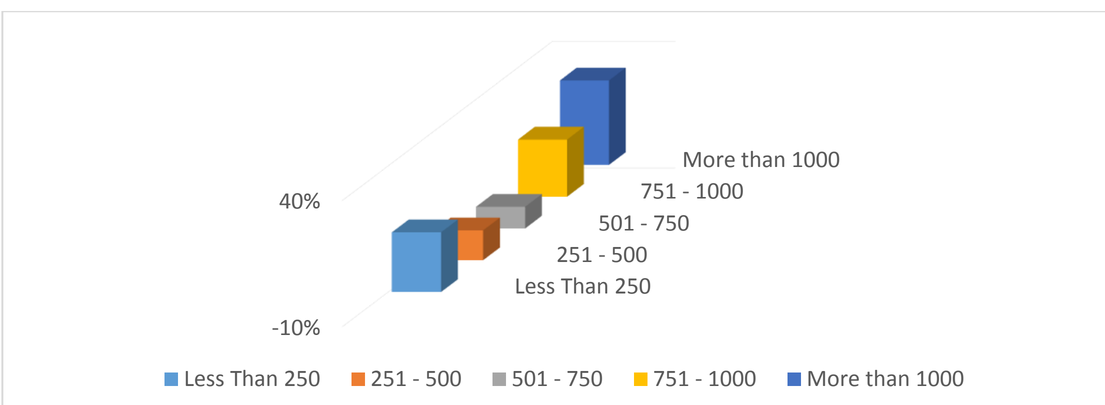


Figure 4.14 Population size of Schools chosen as domain

The chart above displays the population size of the schools 24% of the respondents state that the population of schools they are involved with is less than 250, 12% state they are between 251 to 500, 9% stated 51 to 750, 23% state the population is between 751 to 1000 while 33% state that the schools they are involved with have a population more than 1000.

In general, it is observed that over 56% of the schools have a population of over 750 which is very significant.

4.1.2.2 Ranking of the elicited NFRs

The third part of the survey contained the ranking scale questions. The respondents were asked to rate the 12 NFRs based on importance from the 1^{st} to the 12^{th}. Out of the 99 responses, only 76 were accepted with 13 discarded due to incomplete responses. The question is a single question therefore respondents were expected to rank all the 12 NFRs completely. Any shortage of more than one missing ranking was deemed incomplete and thus removed. The nature of response obtained is understandable as it take at least 3 times more effort to respond to ranking scale question compared to rating scale question [178].

To calculate the ranking order, the following steps were followed [171]:

1. Arrange the NFRs based on the rank ordered by the stakeholders.
2. Multiply each rank column by its rank order.(e.g. the contents of 1^{st} rank will be multiplied by 1,contents of the 2^{nd} rank will be multiplied by 2 etc. up to the content of 12^{th} rank which will be multiplied by 12).
3. Add up the values corresponding to each NFR.
4. The NFR that has the least total value is deemed the 1^{st}, the one following it is 2^{nd}, 3rd etc.

Entire Stakeholders' ranking of the elicited NFRs

The table below represents the raw data of the ranking of the NFRs from the entire stakeholders' point of view.

Table 4.5 Raw ranking data of elicited NFR for all the stakeholders

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**
Accessibility	23	19	14	9	2	2	2	1	2	1	1	0
Accuracy	21	22	6	6	8	3	0	2	1	4	1	2
Coherence	3	6	6	7	6	10	3	10	6	7	8	4
Data retention	1	3	15	14	8	5	3	6	10	3	4	4
Interoperability	2	0	4	5	11	4	12	8	6	10	10	4
Maintainability	4	0	4	7	5	12	11	7	12	7	4	3
Performance	4	3	10	4	7	15	9	7	3	9	3	2
Portability	0	3	1	1	5	8	7	9	9	8	6	19
Reliability	9	9	6	10	6	5	12	6	6	1	5	1
Security	6	4	5	5	8	4	4	8	8	12	8	4
Scalability	0	1	1	3	5	3	5	5	7	8	21	17
Usability	3	6	4	5	5	5	8	7	6	6	5	16
Total	**76**	**76**	**76**	**76**	**76**	**76**	**76**	**76**	**76**	**76**	**76**	**76**

In order to determine the respective ranks of the NFRs, each rank column is multiplied by its rank order i.e. all the values that fall under the 1st column are multiplied by 1, all those that fall under 2nd column are multiplied by 2 and so on until we reach the 12th column were the values are multiplied by 12.

The values that corresponds to each NFR row are then added up. The NFR whose total is the lowest is deemed to be ranked 1st, the NR with the second lowest total is 2nd and so on.

Table 4.6 Computation of ranking order from the entire stakeholders' point of view

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**Total**
Accessibility	23	38	42	36	10	12	14	8	18	10	11	0	222
Accuracy	21	44	18	24	40	18	0	16	9	40	11	24	241
Coherence	3	12	18	28	30	60	21	80	54	70	88	48	464
Data retention	1	6	45	56	40	30	21	48	90	30	44	48	411
Interoperability	2	0	12	20	55	24	84	64	54	100	110	48	525
Maintainability	4	0	12	28	25	72	77	56	108	70	44	36	496
Performance	4	6	30	16	35	90	63	56	27	90	33	24	450
Portability	0	6	3	4	25	48	49	72	81	80	66	228	434
Reliability	9	18	18	40	30	30	84	48	54	10	55	12	396
Security	6	8	15	20	40	24	28	64	72	120	88	48	485
Scalability	0	2	3	12	25	18	35	40	63	80	231	204	509
Usability	3	12	12	20	25	30	56	56	54	60	55	192	383

From the Total row of Table 4.6, the NFRs were ranked by the Managers as shown below

Table 4.7 Entire stakeholders' ranking of NFRs

Rank	**Total**	**NFR**
1	222	Accessibility
2	241	Accuracy
3	383	Usability
4	396	Reliability
5	411	Data retention
6	434	Portability
7	450	Performance
8	464	Coherence
9	485	Security
10	496	Maintainability
11	509	Scalability
12	525	Interoperability

In the opinion of all the stakeholders, the most important NFRs are Accessibility, Accuracy and Usability while the least important NFRs are Interoperability, Scalability and Maintainability. What this signify is that the stakeholders want to have a system that is highly accessible, accurate and is easy to learn and simple to use. The ability of the system to exchange information with other systems, the ability of the system to perform under increased workload and the ability of the system to accommodate changes are not important to the stakeholders.

Below are the results of the ranking of the stakeholders individually. See Appendix G for the computations of the results.

Regulators' ranking of the elicited NFRs

The table below represents the ranking of the elicited NFRs from the Regulators point of view:

Table 4.8 Regulators' ranking of the elicited NFRs

Rank	Total	NFR
1	46	Accessibility
2	69	Accuracy
3	102	Usability
4	115	Data retention
5	128	Reliability
6	132	Performance
7	133	Security
8	135	Coherence
9	148	Interoperability
10	151	Maintainability
11	154	Portability
12	205	Scalability

In summary, Accessibility, Accuracy, Usability are the most important while Portability, Maintainability and Interoperability are the least important from the regulators point of view.

Developers' ranking of the elicited NFRs

Table 4.9 Developers' ranking of NFRs

Rank	Total	NFR
1	66	Accessibility
2	69	Accuracy
3	96	Reliability
4	113	Data retention
5	119	Coherence
6	121	Performance
7	129	Portability
8	136	Security
9	142	Usability
10	148	Scalability
11	154	Interoperability
12	159	Maintainability

Accessibility, Accuracy and reliability are ranked most important while interoperability, Scalability and Usability are least important to the developers.

Users' ranking of the elicited NFRs

The table below represents the ranking of the elicited NFRs from the Users point of view

Table 4.10 Users' ranking of NFRs

Rank	Total	NFR
1	66	Accuracy
2	82	Accessibility
3	82	Usability

Table 4.10 continued

Rank	Total	NFR
4	101	Reliability
5	103	Portability
6	104	Scalability
7	112	Security
8	117	Maintainability
9	125	Performance
10	130	Data retention
11	145	Coherence
12	153	Interoperability

The users ranked Accuracy, Accessibility and Usability as very important but Coherence, Data retention and Performance are the least important.

Managers' ranking of the elicited NFRs

The table below represents the ranking of the elicited NFRs from the Managers point of view

Table 4.11 Managers' ranking of NFRs

Rank	Total	NFR
1	28	Accessibility
2	37	Accuracy
3	48	Portability
4	52	Scalability
5	53	Data retention
6	57	Usability
7	65	Coherence
8	69	Maintainability
9	70	Interoperability
10	71	Reliability
11	72	Performance
12	104	Security

The Managers are of the opinion that Accessibility, Accuracy and Portability are the top most important NFRs while Reliability, Performance and Security are the least important NFRs.

The Data from the Survey is available in Appendix F.

4.2 SUITABLE ARCHITECTURES FOR AN ICT IN EDUCATION SYSTEM

There are several system architectures that are available in the world today, each with its advantages and disadvantages. Different researchers have adopted different classification for systems architectures as seen in the literature review in chapter 2. However, Bildreek [179] classification was adopted in this research because it includes architectures that are already in use in several systems (e.g. Distributed and Integrated System Architectures) and modern architectures that are currently trending and have a lot of prospects (e.g. Pooled and Converged system architectures).

Previously data center computing was identified by mainframes computers but with the advent of more affordable and decentralized shared resources, it became possible to divide the resources into distributed computing layers of storage, networks, software and servers. To improve efficiency and save cost, the computing layers were pooled and virtualized. Nowadays, it has become possible to easily set up new pooled resources with the computing layers convey in a single chassis.

The figure below displays four major types of system architectures introduced above with some of their different and unique features.

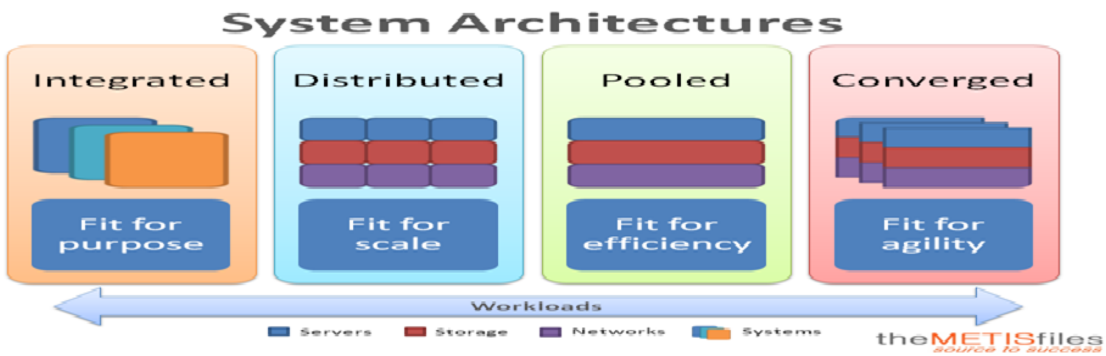


Figure 4.15 System Architectures

Integrated System Architecture: In this system architecture, orchestration, computing, storage, and networking are all integrated into a single system. In order to upgrade or enlarge the system, the entire system has to be changed in its entirety. This type of architecture is usually designed and adopted for unique purpose and workload.

Distributed System Architecture: Computing and storage are carried out in different system sections in this architecture. The sections are normally connected by a network but are orchestrated separately. Upgrading the system is achieved through changing a section of the component while system growth is actualized by introducing a new component. This architecture is usually designed to allow growth and scale out of many work load.

Pooled System Architecture: in pooled system architecture, the computing, storage and networks are all collected separately in resource pools made up of blocks and are orchestrated separately. Replacing blocks within a pool will lead to a system upgrade while system growth is realized by introducing new blocks to a pool. The architecture is usually promoted to allow efficient scaling and growth of many workloads.

Converged System Architecture: the computing, storage and networks are all in different resource pools but they are orchestrated collectively in a single chassis. Upgrading the system is realized by swapping components in the chassis and system growth is achieved by introducing new components to an empty slot in the chassis. This architecture is normally designed if there is a need to deploy many workloads swiftly.

4.2.1 Qualities attributes of the selected Architectures

In order to determine the quality attributes of the architectures for based on the elicited NFRs, a systematic Literature review was under taken and the findings reveal the following for each of the architectures.

Table 4.12 Quality attributes of a Distributed System Architecture

Distributed Systems Architecture			
S/No	**NFRs**	**Priority**	**Reference**
1	Accessibility	Medium	[180]
2	Accuracy	Medium	[181]
3	Coherence	Medium	[182], [183],
4	Data retention	High	[184] [181]
5	Interoperability	High	[182], [183],
6	Maintainability	Low	[182], [183],
7	Performance	Medium	[185], [186]
8	Portability	High	[182], [183], [187]
9	Reliability	Medium	[182], [183],
10	Scalability	High	[182], [183], [179]
11	Security	Low	[182], [183], [186]
12	Usability	High	[181]

Table 4.13 Quality attributes of an Integrated System Architecture

Integrated Systems Architecture			
S/No	**NFRs**	**Priority**	**Reference**
1	Accessibility	High	[180]
2	Accuracy	High	[188]
3	Coherence	High	[189]
4	Data retention	Low	[190]
5	Interoperability	Low	[191]
6	Maintainability	High	[180], [190]
7	Performance	High	[186]
8	Portability	High	[192]
9	Reliability	Medium	[190]
10	Scalability	Low	[190] [186], [179]
11	Security	High	[186]
12	Usability	High	[188]

Table 4.14 Quality attributes of a Pooled System Architecture

Pooled Systems Architecture			
S/No	**NFRs**	**Priority**	**Reference**
1	Accessibility	High	[193], [194]
2	Accuracy	Medium	[195]
3	Coherence	High	[194]
4	Data retention	High	[196]
5	Interoperability	High	[194]
6	Maintainability	Medium	[193]
7	Performance	High	[197]
8	Portability	High	[194]
9	Reliability	High	[197], [196]
10	Scalability	High	[197], [196] , [179]
11	Security	Low	[194]
12	Usability	High	[194]

Table 4.15 Quality attributes of a Converged System Architecture

Converged Systems Architecture			
S/No	**NFRs**	**Priority**	**Reference**
1	Accessibility	High	[198]
2	Accuracy	High	[199]
3	Coherence	High	[200], [201]
4	Data retention	High	[202]
5	Interoperability	Low	[202] [201]
6	Maintainability	High	[197] [202] [200] [190]
7	Performance	High	[203] [199] [201]
8	Portability	Medium	[204]
9	Reliability	High	[203] [205] [190] [201]
10	Scalability	High	[197] [202] [199] [190]
11	Security	High	[206]
12	Usability	High	[202] [203] [205] [201]

4.3 SELECTING THE MOST IDEAL ARCHITECTURE FOR AN EDUCATION SYSTEM

To select the best architecture that suits the needs of the stakeholders, a Multi-criteria decision making analysis technique is employed. The technique selected for this research is Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The idea behind this is to match the priorities of the NFRs from the stakeholders and the quality attributes of the architectures in order to discover which architecture fits best to the requirements of the stakeholders.

Values are assigned to the priorities set by the stakeholders for the elicited NFRs and the quality attributes of the architectures to allow computation.

Table 4.16 Quality attributes of Architectures

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	Medium	High	High	High
2	Accuracy	Medium	High	Medium	High
3	Coherence	Medium	High	High	High
4	Data retention	High	Low	High	High
5	Interoperability	High	Low	High	Low
6	Maintainability	Low	High	Medium	High
7	Performance	Medium	High	High	High
8	Portability	High	High	High	Medium
9	Reliability	Medium	Medium	High	High
10	Scalability	High	Low	High	High
11	Security	Low	High	Low	High
12	Usability	High	High	High	High

Quality attributes that are High are assigned values of 3,Medium are assigned values of 2 and Low are assigned values of 1 as shown in the table below.

Table 4.17 Quality attributes of Architectures with assigned values

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	2	3	3	3
2	Accuracy	2	3	2	3
3	Coherence	2	3	3	3
4	Data retention	3	1	3	3
5	Interoperability	3	1	3	1
6	Maintainability	1	3	2	3
7	Performance	2	3	3	3
8	Portability	3	3	3	2
9	Reliability	2	2	3	3
10	Scalability	3	1	3	3
11	Security	1	3	1	3
12	Usability	3	3	3	3

Legends: High = 3, Medium = 2, Low = 1

The priorities set by the stakeholders for the elicited NFRs undergo similar assignment. The table below presents the rating and ranking of the elicited NFRs obtained earlier.

Table 4.18 Priorities and importance of elicited NFRs

S/No.	NFRs	Rating	Ranking
1	Accessibility	High	1
2	Accuracy	Low	2
3	Coherence	High	8
4	Data retention	High	5
5	Interoperability	High	12
6	Maintainability	Low	10
7	Performance	High	7
8	Portability	High	6
9	Reliability	High	4
10	Scalability	Low	9
11	Security	High	11
12	Usability	High	3

Values are assigned to the ratings similar to the quality attributes, that is High = 3, Medium = 2 and Low = 1. In addition, the ranking of the NFRs are assigned as Multipliers. The NFR that is ranked 1st is assigned a multiplier value of 1.2, the NFR ranked 2nd is assigned a multiplier value of 1.1, NFR ranked 3rd is assigned a multiplier of 1.0 and so on up to the NFR that is ranked 12th which is assigned a multiplier value of 0.1.

Table 4.19 NFRs ratings and weights from survey

S/No.	NFRs	Rating	Multiplier
1	Accessibility	3	1.2
2	Accuracy	1	1.1
3	Coherence	3	0.5
4	Data retention	3	0.8
5	Interoperability	3	0.1
6	Maintainability	1	0.3
7	Performance	3	0.6
8	Portability	3	0.7
9	Reliability	**3**	0.9
10	Scalability	1	0.4
11	Security	3	0.2
12	Usability	3	1

Where High = 3, Medium = 2 and Low = 1

To obtain the weighted rating of the NFRs, the weights are multiplied by the ratings as displayed in the table below:

Table 4.20 Weighted Rating of the NFRs

S/No.	NFRs	Weighted Rating
1	Accessibility	3.6
2	Accuracy	1.1
3	Coherence	1.5
4	Data retention	2.4
5	Interoperability	0.3
6	Maintainability	0.3
7	Performance	1.8
8	Portability	2.1
9	Reliability	2.7
10	Scalability	0.4
11	Security	0.6
12	Usability	3

TOPSIS Analysis

The TOPSIS method is expressed in a succession of six steps as follows [207]:

Step 1: Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = x_{ij} \sqrt{\sum_{i-1}^{m} x_{ij}^2} \quad \text{i =1, 2, ..., m and j = 1, 2, ..., n.} \qquad (4.1)$$

Step 2: Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as follows:

$$v_{ij} = r_{ij} \times w_j \quad \text{i =1, 2,..., m and j = 1, 2, ..., n.} \qquad (4.2)$$

Where w_j is the weight of the j^{th} criterion or attribute and $\sum_{j=1}^{n} w_j = 1$.

Step 3: Determine the ideal (A^*) and negative ideal (A^-) solutions.

$$A^* = \{(\max_i v_{ij} \mid j \in C_b), (\min_i v_{ij} \mid j \in C_c)\} = \{v_j^* \mid j = 1,2,..., m\} \qquad (4.3)$$

$$A^- = \{(\min_i v_{ij} \mid j \in C_b), (\max_i v_{ij} \mid j \in C_c)\} = \{v_j^- \mid j = 1,2,..., m\} \qquad (4.4)$$

Step 4: Calculate the separation measures using the m-dimensional Euclidean distance. The separation measures of each alternative from the positive ideal solution and the negative ideal solution, respectively, are as follows:

$$S_i^* = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^*)^2}, \; j = 1,2,...,m \tag{4.5}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m}(v_{ij} - v_j^-)^2}, \; j = 1,2,...,m \tag{4.6}$$

Step 5: Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined as follows:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, i = 1,2,...,m \tag{4.7}$$

Step 6: Rank the preference order.

The result obtained from TOPSIS analysis is given below. Complete computations can be found in Appendix F.

The table below displays the separation of each alternative architecture from the ideal solution.

Table 4.21 Separation from ideal solution

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	0.42	0.00	0.00	0.00
2	Accuracy	0.05	0.00	0.05	0.00
3	Coherence	0.07	0.00	0.00	0.00
4	Data retention	0.00	0.82	0.00	0.00
5	Interoperability	0.00	0.02	0.00	0.02
6	Maintainability	0.02	0.00	0.00	0.00
7	Performance	0.10	0.00	0.00	0.00
8	Portability	0.00	0.00	0.00	0.14
9	Reliability	0.28	0.28	0.00	0.00
10	Scalability	0.00	0.02	0.00	0.00
11	Security	0.07	0.00	0.07	0.00
12	Usability	0.00	0.00	0.00	0.00
	Sum Total	1.01	1.14	0.12	0.16
Is	**(Sum Total)$^{1/2}$**	1.00	1.07	0.35	0.40

Where Is = Ideal Solution.

The table below displays the separation of each alternative architecture from the negative ideal solution

Table 4.22 Separation from negative ideal solution

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	0.00	0.42	0.42	0.42
2	Accuracy	0.00	0.05	0.00	0.05
3	Coherence	0.00	0.07	0.07	0.07
4	Data retention	0.82	0.00	0.82	0.82
5	Interoperability	0.02	0.00	0.02	0.00
6	Maintainability	0.00	0.02	0.00	0.02
7	Performance	0.00	0.10	0.10	0.10
8	Portability	0.14	0.14	0.14	0.00
9	Reliability	0.00	0.00	0.28	0.28
10	Scalability	0.02	0.00	0.02	0.02
11	Security	0.00	0.07	0.00	0.07
12	Usability	0.00	0.00	0.00	0.00
	Sum Total	1.01	0.87	1.89	1.86
Ns	**(Sum Total)$^{1/2}$**	1.00	0.93	1.37	1.36

Where Ns is the negative ideal solution.

The table below shows the calculation of the relative closeness to the ideal solutions. The alternative with the highest value is deemed to be closest to the ideal solution.

Table 4.23 Relative closeness to ideal solution

NFRs	Architectures			
	Distributed	**Integrated**	**Pooled**	**Converged**
Is	1.00	1.07	0.35	0.40
Ns	1.00	0.93	1.37	1.36
Is + Ns	2.01	2.00	1.72	1.76
Ns/(Is + Ns)	0.50	0.47	**0.80**	0.77

From the computation in the table above, it can be observed that Pooled architecture has the highest value which show that it is the closest to our ideal solution, thus the best option to choose. The second best solution is converged architecture, followed by a distributed architecture. An integrated architecture is the least ideal among the architectures compared.

Using SAW to validate the findings obtained with TOPSIS

In order to validate our findings which was obtained with TOPSIS, SAW method was used. The Simple Additive Weighting (SAW) method is expressed by the steps below [208]:

Step 1: Evaluate each alternative, Ai, by the following formula:

$$A_i = \sum w_j * x_{ij} \qquad (4.8)$$

Where: xij is the score of the ith alternative with respect to the jth attribute, wj is the normalized weight.

Step 2: If the scores for the criteria are measured on different measurement scales, they must be standardized to a common dimensionless unit before the SAW method. The simplest procedure for standardizing the raw data is to divide each raw score by the maximum value for a given criterion.

$$x_{ij}^{'} = x_{ij} \Big/ x_i^{\max} \qquad (4.9)$$

Where: $x_{ij}^{'}$ is the standardized score for the ith alternative and jth attribute, x_{ij} is the raw score, and $x_i^{\max}$ is the maximum score for the jth attribute.

The result obtained from the SAW analysis is shown in the table below. Complete computation can be seen in Appendix F.

Table 4.24 Evaluation score for each architecture using SAW

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	2.40	3.60	3.60	3.60
2	Accuracy	0.73	1.10	0.73	1.10
3	Coherence	1.00	1.50	1.50	1.50
4	Data retention	2.40	0.80	2.40	2.40
5	Interoperability	0.30	0.10	0.30	0.10
6	Maintainability	0.10	0.30	0.20	0.30
7	Performance	1.20	1.80	1.80	1.80
8	Portability	2.10	2.10	2.10	1.40
9	Reliability	1.80	1.80	2.70	2.70
10	Scalability	0.40	0.13	0.40	0.40
11	Security	0.20	0.60	0.20	0.60
12	Usability	3.00	3.00	3.00	3.00
	Summation	**15.63**	**16.83**	**18.93**	**18.90**

From the result above, it can be observed that Pooled architecture has the highest score thereby revalidating it as the best alternative based on the stakeholders' criteria.

4.4 DISCUSSIONS

The outcome of TOPSIS and SAW analyses returned Pooled system architecture as the best alternative among the selected architectures and thus the most suitable for an Education system based on the stakeholders and locality considered. On closer observation however, it was noticed that the MCDM evaluation scores which returned Pooled architecture as the best option is very close to that of Converged architecture thus encouraging further evaluation. It should be recalled that Mode is the preferred measure of central tendency for ordinal data but in order to analyse our results from a different perspective, Mean as a measure of central tendency was employed. Employing mean as a measure of central tendency lead to the reclassification of the NFRs slightly; rating for Maintainability became Very low, Accuracy and Scalability became Medium, Coherence, Data Retention and Portability became Very high while all the rest remained at High.

The table below shows the classification of the NFRs based on Mean and Mode.

Table 4.25 Mean and Mode as measures of central tendency

S/No	NFRs	Mode as MCT	Rating	Mean as MCT	Rating
1	Accessibility	3	High	3.79	High
2	Accuracy	1	Low	2.58	Medium
3	Coherence	3	High	4.08	Very High
4	Data Retention	3	High	4.15	Very High
5	Interoperability	3	High	3.92	High
6	Maintainability	1	Low	1	Very Low
7	Performance	3	High	3.98	High
8	Portability	3	High	4.07	Very High
9	Reliability	3	High	3.85	High
10	Scalability	1	Low	2.62	Medium
11	Security	3	High	3.95	High
12	Usability	3	High	3.19	High

TOPSIS and SAW analyses were carried out with Mean as measure of central tendency and the evaluation scores for both analyses returned converged system architecture as the best alternative. Interestingly, the scores for converged architecture and pooled architecture are still very close. The table below displays the results of the evaluation scores showing both Mode and Mean as measures of central tendencies.

Table 4.26 MCDM analysis using Mean and Mode as measures of central tendency

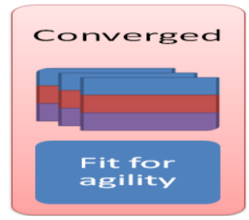
M C T	MCDM	ARCHITECTURES			
		Distributed	**Integrated**	**Pooled**	**Converged**
Mean	TOPSIS	0.51	0.47	0.74	0.78
Mode	TOPSIS	0.5	0.47	0.8	0.77
Mean	SAW	21.35	22.84	25.6	25.96
Mode	SAW	15.63	16.83	18.93	18.9

MCT: Measure of Central Tendency

MCDM: Multi criteria Decision Making Technique

In probing further, it was discovered that the NFRs that give Pooled system architectures the upper hand over Converged architecture are Interoperability and Portability while those that give Converged architecture the upper hand are Accuracy, Maintainability and Security. The Table below displays the weighted standardized decision matrix for pooled and converged architectures based on the identified NFRs.

Table 4.27 Weighted Standardized decision matrix for Pooled and Converged Architectures



S/No	NFRs		
1	Accessibility	1.94	1.94
2	***Accuracy***	***0.43***	***0.65***
3	Coherence	0.81	0.81
4	Data retention	1.36	1.36
5	***Interoperability***	***0.2***	***0.07***
6	***Maintainability***	***0.13***	***0.19***
7	Performance	0.97	0.97
8	***Portability***	***1.13***	***0.75***
9	Reliability	1.59	1.59
10	Scalability	0.23	0.23
11	***Security***	***0.13***	***0.4***
12	Usability	1.5	1.5

This means that, the decision for selecting the ideal architecture among these two alternatives is dependent on these NFRs. If the stakeholders need more Interoperability and Portability then Pooled system architectures will be a better alternative while if Accuracy, Maintainability and Security are needed more, then Converged will be a better option.

Finally, it can be recommended that both architectures can serve the purpose at hand due to the closeness in the evaluation scores obtained from using both Mode and Mean as measures of central tendency.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter presents the final conclusion of this research. Some recommendations are also made for future research.

5.1 CONCLUSION

The work described in this thesis has been concerned with coming up a strategy that will assist education stakeholders especially policy holders in selecting an effective ICT architecture for an education system.

The research however makes several noteworthy contributions to the study of NFRs, System architectures and ICT in education.

The main research question that was formulated in the beginning of this work was as follows:

"How can we identify the most suitable ICT system architecture for an education system based on NFRs?"

This question was further broken down into 3 sub questions which were answered in the research.

In the first subsection, relevant NFRs for ICT in education, their importance and priorities as well as the potential conflicts amongst themselves were discovered thus contributing to the knowledge of NFRs which is still not properly understood.

In the second part, four systems architectures namely Distributed, Integrated, Pooled and Converged were identified and their quality attributes determined. The benefit of this particular work transcends this thesis as it can also be used in other research of this nature.

Finally in the last subsection which is concerned with selecting the ideal architecture, Multi criteria decision making techniques (MCDM) namely TOPSIS was used to compare the identified architectures against the elicited NFRs while S A W was used in reconfirming the results obtained from TOPSIS. The obtained result showed that Pooled and Converged system architectures are the ideal architectures for ICT in education based on the stakeholders' need in the locality considered.

5.2 RECOMMENDATION FOR FUTURE WORKS

Although the strategies adopted in this research have shown to be effective, the work could still be further improved by expanding the scope and employing more tedious albeit more accurate methods.

The relevant NFRs that were elicited by literature review in this project should be investigated and elicited directly from the stakeholders through interviews or "Joint system development" where selected stakeholders can be brought together to brainstorm and come up with NFRs that are most relevant and critical for the education system of that particular locality.

To rate the NFRs, the same methods of rating scale and ranking scale questions used in this research can be maintained but a Delphi method should be adopted. This method enables one to get concurrence between the stakeholders on the research being carried out. It is accomplished by an iterative process of brainstorming that involves forwarding the survey questionnaires to the selected stakeholders so as to get their opinions on a particular issue being researched. The survey is carried out in a minimum of two rounds where the analysed response to the questionnaires are forwarded to the panelist for them to adopt or modify. This continues until a general consensus is achieved. To rank the NFRs on the other hand, 100 Dollar test can be used where not only the ranks of the NFRs can be obtained but also the degree of priority between the NFRs It should be noted that employing this methods will require a lot of effort from the stakeholders and a lot of convincing power on the part of the researcher.

To determine the quality characteristics of the selected architectures, Subject Matter experts (SME) that are very familiar with the architectures should be involved in coming up with a list. A Delphi method should also be used for this purpose to assure concurrence.

A tool can also be created in the form of an application or a website which can assist key stakeholders to easily select the best architecture for their locality. Rankings and ratings of the NFRs as well as the quality attributes of the architectures can be inputted and a result obtained within a very short period of time. Same can be expanded to incorporate other domains such as health and telecommunication sectors.

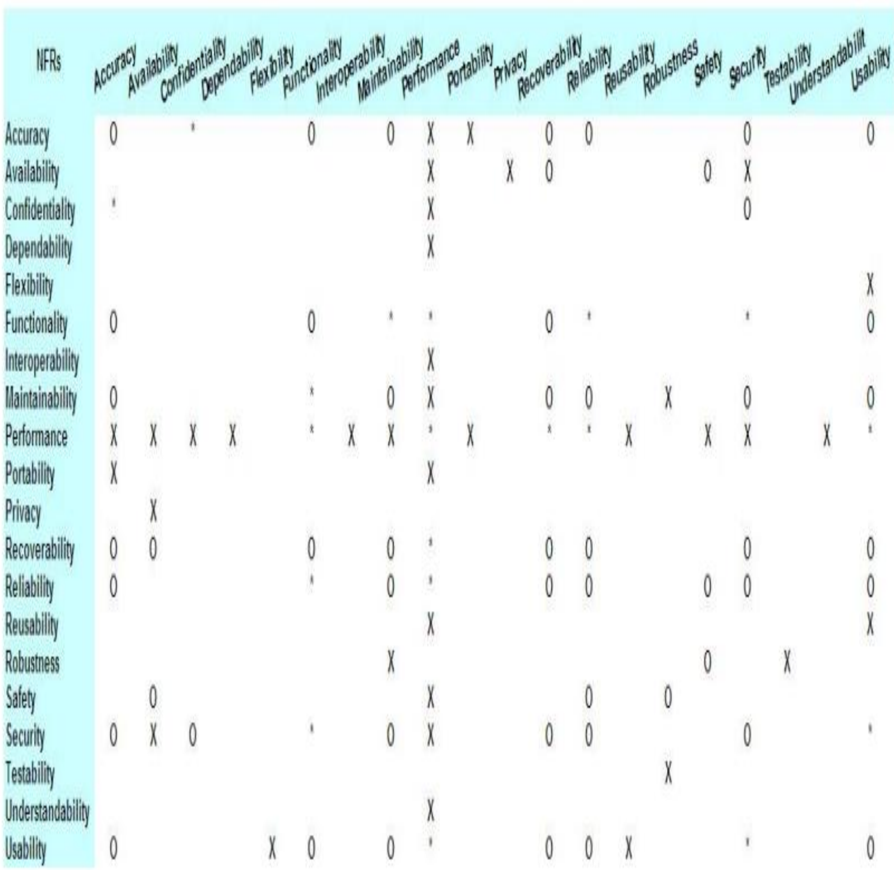
Furthermore, a method that will guide in selecting specific ICT infrastructures can be included which involves incorporating Functional requirements into the project.

Finally, a case study can be carried out to test the veracity of the techniques mentioned where the findings can be put into practice in the real world.

APPENDIX A

CATALOGUE OF CONFLICTS AMONG NFRS

The figure below is the catalogues of conflicts among NFRs developed by Mairiza et al [209]



NFRs	Accuracy	Availability	Confidentiality	Dependability	Flexibility	Functionality	Interoperability	Maintainability	Performance	Portability	Privacy	Recoverability	Reliability	Reusability	Robustness	Safety	Security	Testability	Understandabilit	Usability
Accuracy	0		*			0		0	X	X		0	0				0			0
Availability									X		X	0				0	X			
Confidentiality	*								X								0			
Dependability									X											
Flexibility																				X
Functionality	0					0		*	*			0	*				*			0
Interoperability									X											
Maintainability	0					*		0	X			0	0		X		0			0
Performance	X	X	X	X		*	X	X	*	X		*	*	X		X	X		X	*
Portability	X								X											
Privacy		X																		
Recoverability	0	0				0		0	*			0	0				0			0
Reliability	0					*		0	*			0	0			0	0			0
Reusability									X											X
Robustness								X								0		X		
Safety		0							X				0		0					
Security	0	X	0			*		0	X			0	0				0			*
Testability															X					
Understandability									X											
Usability	0				X	0		0	*			0	0	X			*			0

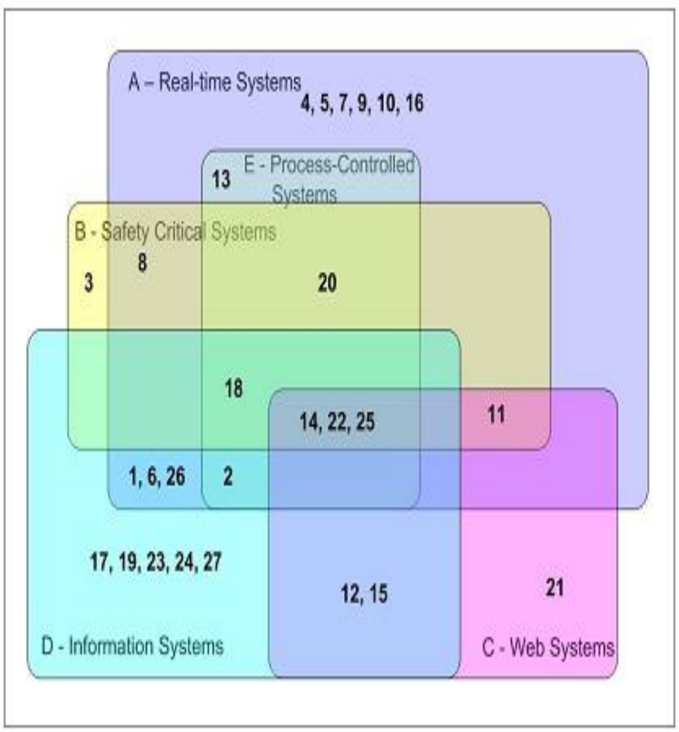
Figure A.1 Catalogue of Conflicts among NFRs

Legends: 0 =Never in Conflict, X =Absolute Conflict and * = Relative Conflict

APPENDIX B

TYPES OF SYSTEMS AND RELEVANT NFRs

The figure and tables below are the classification of relevant NFRs based on different systems and applications [210].



Legend:

1.Accuracy	10.Installability	19.Reusability
2.Availability	11.Integrity	20.Safety
3.Communicativeness	12.Interoperability	21.Scalability
4.Compatibility	13.Maintainability	22.Security
5.Completeness	14.Performance	23.Standardizability
6.Confidentiality	15.Privacy	24.Traceability
7.Conformance	16.Portability	25.Usability
8.Dependability	17.Provability	26.Verifiability
9.Extensibility	18.Reliability	27.Viability

Figure B.1 Systems and their relevant NFRs

Table B.1 Application Domains and Relevant NFRs

Application Domain	Relevant NFRs
Banking And Finance	Accuracy, Confidentiality, Performance, Security, Usability
Education	Interoperability, Performance, Reliability, Scalability, Security, Usability
Energy Resources	Availability, Performance, Reliability, Safety, Usability
Government And Military	Accuracy, Confidentiality, Performance, Privacy, Provability, Reusability, Security, Standardizability, Usability, Verifiability, Viability
Insurance	Accuracy, Confidentiality, Integrity, Interoperability, Security, Usability
Medical/Health Care	Communicativeness, Confidentiality, Integrity, Performance, Privacy, Reliability, Safety, Security, Traceability, Usability
Telecommunication Services	Compatibility, Conformance, Dependability, Installability, Maintainability, Performance, Portability, Reliability, Usability
Transportation	Accuracy, Availability, Compatibility, Completeness, Confidentiality, Dependability, Integrity, Performance, Safety, Security, Verifiability

Table B.2 Classification of Systems

Type of System	System Description	Example
Real-time Systems	Those systems that can support the execution of applications with time constraints on that execution (Laplante 2004)	Reactive system and embedded system
Safety Critical Systems	Those systems whose failure could result in loss of life, significant property damage, or Damage to the environment (knight 2002)	Nuclear system, medical system, air traffic control system

Table B.2 continued

Type of System	**System Description**	**Example**
Web Systems	Those systems which utilize Web technologies as an integral element of a functionally Complex system and which typically incorporates interfaces beyond the organizational boundaries (Yusop, Zowghi & Lowe 2008)	E-commerce application, learning management system, online systems
Information Systems	Those systems which consist of a set of interrelated components that collect (input), manipulate (process), and disseminate (output) data and information and provide a feedback mechanism to meet an objective (Stair & Reynolds 1999)	Laboratory information system, management information system, purchasing system
Process-Controlled Systems	Those systems that drive the operation of a hardware process (Easterbrook 2005; Leveson et al. 1994)	Light control system, fire alarm system, ship command system, space craft

APPENDIX C

ISO/IEC 25010:2011

Below is the classification and definitions of NFRs based on ISO/IEC 25010 [162], [211]

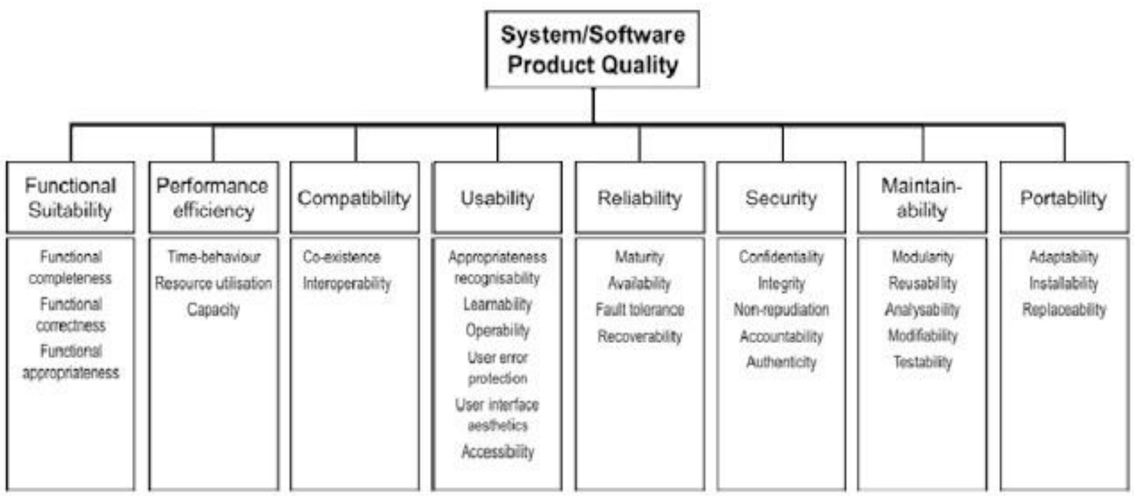


Figure C.1 Quality characteristics and sub characteristics

NFRs and their definitions

Functional suitability: degree to which a system provides functions that meet stated needs when used under specified conditions.

- Functional completeness: degree to which the set of functions covers all the specified tasks and user objectives.
- Functional correctness: system provides the correct results with the needed degree of precision.
- Functional appropriateness: the functions facilitate the accomplishment of specified tasks and objectives

Performance efficiency: performance relative to the amount of resources used under stated conditions.

- Time behaviour: response, processing times and throughput rates of a system, when performing its functions, meet requirements.
- Resource utilization: the amounts and types of resources used by a system, when performing its functions, meet requirements.
- Capacity: the maximum limits of a product or system parameter meet requirements.

Compatibility: degree to which a system can exchange information with systems, and/or perform its required functions, while sharing the same hardware or software environment.

- Co-existence: product can perform its functions efficiently while sharing environment and resources with other products.
- Interoperability: a system can exchange information with other systems and use the information that has been exchanged.

Usability: degree to which a system can be used with effectiveness, efficiency and satisfaction in a specified context of use.

- Appropriateness recognizability: users can recognize whether a system is appropriate for their needs, even before it is implemented.
- Learnability: system can be used to achieve specified goals of learning to use the system.
- Operability: system has attributes that make it easy to operate and control.
- User error protection: system protects users against making errors.
- User interface aesthetics: user interface enables pleasing and satisfying interaction for the user.
- Accessibility: system can be used by people with the widest range of characteristics and capabilities.

Reliability: degree to which a system performs specified functions under specified conditions for a specified period of time.

- Maturity: system meets needs for reliability under normal operation.
- Availability: system is operational and accessible when required for use.
- Fault tolerance: system operates as intended despite the presence of hardware or software faults.
- Recoverability: system can recover data affected and re-establish the desired state of the system is case of an interruption or a failure.

Security: degree to which a system protects information and data so that persons or other products or systems have the degree of data access appropriate to their types and levels of authorization.

- Confidentiality: system ensures that data are accessible only to those authorized to have access.
- Integrity: system prevents unauthorized access to, or modification of, computer programs or data.
- Non-repudiation: actions or events can be proven to have taken place, so that the events or actions cannot be repudiated later.
- Accountability: actions of an entity can be traced uniquely to the entity.
- Authenticity: the identity of a subject or resource can be proved to be the one claimed.

Maintainability: degree of effectiveness and efficiency with which a system can be modified by the intended maintainers.

- Modularity: system is composed of components such that a change to one component has minimal impact on other components.
- Reusability: an asset can be used in more than one system, or in building other assets.
- Analysability: effectiveness and efficiency with which it is possible to assess the impact of an intended change.
- Modifiability: system can be effectively and efficiently modified without introducing defects or degrading existing product quality.
- Testability: effectiveness and efficiency with which test criteria can be established for a system.

Portability: degree of effectiveness and efficiency with which a system can be transferred from one hardware, software or other operational or usage environment to another.

- Adaptability: system can effectively and efficiently be adapted for different or evolving hardware, software or usage environments.
- Installability: effectiveness and efficiency with which a system can be successfully installed and/or uninstalled.
- Replaceability: product can be replaced by another specified software product for the same purpose in the same environment.

APPENDIX D

EDUCATION SYSTEM AND ICT POLICIES IN NIGERIA

The body that is responsible for Education in Nigeria is the National Council of Education. The council coordinates planning, policy and finance for education. It comprises of the federal Ministers of Education, the state commissioners of education and the joint consultative committee on education [49].

The responsibility of administering education in Nigeria is shared among the three tiers of governments namely federal, state and local governments as follows:

- Primary level: Local Governments
- Secondary level: State Governments
- Tertiary/university level: Federal Government

Furthermore, there are other national bodies that are responsible for maintenance of standards in other specialized aspects of education which include The Federal Inspectorate Service, The Nigerian Educational Research and Development Council, The Science Equipment Centre and The School Broadcasting Unit.

Formal education system in Nigeria is the 9-3-4 system. Basic education normally begins at the age of six and consists of six years primary school education followed by three years of junior secondary school (JSS). Students spend three years in the senior secondary

School (SSS) and at the end of it are required to sit for the senior secondary certificate examination to enable them proceed to the tertiary institution where they normally spend four years [212].

Nigeria does not have any specific ICT policy for education. The federal ministry of education in 2007 created the ICT department. However, several private and non-governmental organizations have introduced various *ICT-driven* initiatives at different tiers of education [49].

Utilization of ICTs in Nigerian educational system as a whole is very low as most teachers are not computer literate. Furthermore, a lot of these schools do not have ICT infrastructure in place.

Secondary schools start in most countries, Nigeria inclusive from the ages of 12 to 14 [213] Students of secondary school age make up the largest percentage of the population in Africa [214]. They have been described by the World Bank as the most important connection between primary schools and tertiary schools, eventually leading to the labour market [215]. Secondary schools is the tier of education that needs ICTs more than any other tier as UNESCO decides for cost reasons that it is not realistic to introduce ICTs in education for primary schools in most developing countries [216].

APPENDIX E

QUESTIONNAIRE

Determining an effective Information and communication Technology (ICT) Architecture for an education system

4/1/2014

Dear Sir/Madam,

I am undertaking a research project to determine the most suitable Information and communication Technology (ICT) Architecture for an education system that can be applicable in Nigeria.

Several countries around the world have introduced comprehensive nationwide ICT in education initiatives. It should be noted that ICT in education does not mean teaching students computer skills but rather using ICT infrastructure as tools to enrich the teaching and learning process.

The major components of ICT in education are: ICT policies, ICT infrastructure, and Teacher training, Digital curriculum development, Usage of ICT in teaching and learning and performance evaluation.

This survey is part of an ongoing research for selecting the most suitable architecture for the ICT infrastructure component for Nigerian Secondary schools based on the qualities selected and prioritized by the stakeholders. In other words I intend to develop a blueprint for how the hardware, software, network and all other related ICT infrastructures to be used should be selected effectively and efficiently to suit our needs. This is because each country has its peculiarities therefore what works for country A might not work for country B.

In coming up with this blueprint, all relevant stakeholders (yourself inclusive) will need to participate and give input about their expectation of how the system should be.

A perfect system where the best options are selected will not only make the system extremely expensive but might not even be achievable thus the idea is for you to choose options that you believe are enough and viable for our locality.

To this end, I kindly request you complete the following short questionnaire which will take no longer than 10 minutes of your time and return within 7 days. Your response is of utmost importance.

Should you have any question or concerns please do not hesitate to contact me by Telephone: +905078711204 or email mujiila@gmail.com

Yours sincerely,

Mujtaba Ila

Graduate Student, (Electrical and Computer Engineering department)

Meliksah University, Kayseri, Turkey

PLEASE ANSWER THE QUESTIONS BY TICKING OR CROSSING THE RELEVANT BLOCK

Section A
This section of the questionnaire refers to your background information. The information will allow me to compare groups of respondents. I assure you that your response will remain anonymous.

1. What is your gender?

Male	Female

2. What is your age?

18-29 years	30-49 years	50-64 years	Over 65 years

3. What is the highest level of education you have completed?

Secondary school	NCE/OND	University /HND	Master's Degree	PhD

4. Which if the following best describes your job?

Prinicipal / V.Principal	Teacher	ICT Professional	Education Ministry's staff	Others:

5. For how long have you been in your current job?

Less than 1 year	1-5 years	6-10 years	11-15 years	More than 15 years

6. For how many years have you been using computers and/or the internet?

Less than 1 year	Between 1 to 3 years	Between 4 to 6 years	More than 6 years

7. To what extent are you confident in the use of computers and/or the internet?

A lot	Some what	A little	Not at all

Section B
This section of the questionnaire consists of a series of statements. In the first part, you are asked to select the extent to which you disagree or agree with the statements. Select neutral, if you are unsure whether you agree or disagree with the statement.

The second part also consists of statements and options; you are to select the option you believe will suit the local needs for the proposed system.

Kindly endeavor to select only one option for each question.

	The proposed system should:	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
8.	Be able to ensure that only authorized users can temper and access any part of the system.					
9.	Be designed in such a way that users can be able to retrieve information across multiple platforms and from different gadgets.					
10.	Be able to exchange and make use of information with other existing systems already present in the ministry of education, “NECO”,”JAMB” and other related agencies.					
11.	Be designed in such a way that it will be available to as many users as possible irrespective of their disabilities.					
12.	Be able to ensure that unauthorized individuals and programs do not gain access to sensitive data and communications.					
13.	Ensure that all the technologies that will be employed during implementation of the proposed system should be consistent with each other.					

14. The proposed system should be able to respond to request made by users within:

1-3 seconds	4-6 seconds	7-10 seconds	11-13 seconds	14-16 seconds

15. The total number of students in my school (or in my locality or the school I that am supervising) is :

Less than 250	251-500	501-750	751-1000	More than1000

16. The annual (projected) increase in students in my school is :

Less than 10 %	11-20 %	21-30 %	31-40 %	More than 40 %

17. The proposed system should have annual downtime of less than____ per year :

52 minutes	3.65days	7.30 days	18.25days	36.5days

18. The proposed system should be able to store users personal and academic records for:

6 months or less	2 years	5 years	10 years	Above 10 years

19. 90 percent of users should be able to carry out major tasks with the proposed system after undergoing training for :

a few hours	a few days	a few weeks	a few months	a few years

20. The proposed system should be made in a such a way that it will be making no more than one transaction error per (eg 1 error for every 5 transactions,1 for every 50 transactions etc) :

5 Transactions	50 Transactions	500 Transactions	2500 Transactions	5000 Transactions

21. The time that should be taken to repair failed system components when the system is down should not be more than :

30 minutes	2 hours	14 hours	3 days	7 days

22. The proposed system should ensure that its components are protected from intentional corruption and damage at least :

10% of the time	30 % of the time	50% of the time	70% of the time	99% of the time

Section C

The qualities listed and defined below are adjudged by experts to be important in all ICT systems. From your own point of view, kindly rank them in order of importance by allocating a **1** to the most important quality, a **2** to the second-most important,3 to the next most important and continue in this way until you allocate a **12** to the least important issue. Use each number only once.

a) **Accessibility:** The ability of a system to accommodate users of different capabilities.
b) **Accuracy:** The ability of a system to ensure precision of the computations and control.
c) **Coherence:** The ability of the components of a system to work together seamlessly in order to fit the overall strategy of the system.
d) **Data retention:** The ability of a system to store data over a given period of time.
e) **Interoperability:** The ability of two or more systems to exchange and use information.
f) **Maintainability:** The ability to modify a system to deal with new technologies or fix defects. **Performance:** This concern the speed a system responds to re quest.
g) **Portability:** The ease with which a system or its component can be transferred from one location to another.
h) **Reliability:** The ability of a system to perform its required functions under certain conditions for a specified period of time.
i) **Security:** The ability of a system to prevent unauthorized access and at the same time allow access to legitimate users.
j) **Scalability:** The ability of a system to perform under increased workload.
k) **Usability:** This concerns the ease with which users can carry out any task with a system

	Qualities	Ranking
	Accessibility	
	Accuracy	
	Coherence	
	Data retention	
	Interoperability	
	Maintainability	
	Performance	
	Portability	
	Reliability	
	Security	
	Scalability	
	Usability	

Section D

This is an optional part where you are given an opportunity to add any information or suggestions that you think can be of use to the project. If you need to clarify your choice of any answer, please do so here.

Your Name: (Optional)

Telephone and email Contact: (Optional)

Thank you for your co-operation in completing this questionnaire.

APPENDIX F

SURVEY DATA

Demographic Characteristics of the respondents if given below:

Table F.1 Demographic characteristics of the respondents

Demographic Characteristics		**Number**	**%**
Gender	Male	90	91%
	Female	9	9%
Age	18-29 years old	34	35%
	30-49 years old	54	55%
	50-64 years old	10	10%
	Over 65 years	0	0%
Educational Background	Secondary school	2	2%
	NCE/OND	11	11%
	University /HND	63	64%
	Master's Degree	23	23%
	PhD	0	0%
Job Profile	Principal/Vice Principal	13	13%
	Teacher	31	32%
	ICT Professional	22	22%
	Education ministry or related agencies employee	32	33%
Years of experience	Less than 1 year	19	20%
	Between 1-5 years	32	34%
	Between 6-10 years	19	20%
	Between 11-15 years	9	9%
	More than 15 years	16	17%
Experience with ICT	Less than 1 year	6	6%
	Between 1 to 3 years	12	12%
	Between 4 to 6 years	24	24%
	More than 6 years	57	58%
Confidence in the use of ICT	A lot	76	77%
	Some what	6	6%
	A little	15	15%
	Not at all	2	2%

RATING SCALE DATA

Table F.2 Rating by entire stakeholders

S/No.	Non Functional Requirement	N	n	Very High	High	Medium	Low	Very Low	Total
1	Accessibility	99	94	31%	39%	15%	7%	7%	100%
2	Accuracy	99	97	18%	4%	20%	36%	23%	100%
3	Coherence	99	96	33%	52%	6%	6%	2%	100%
4	Data retention	99	98	61%	14%	11%	5%	8%	100%
5	Interoperability	99	98	27%	50%	15%	5%	3%	100%
6	Performance	99	97	41%	28%	23%	4%	4%	100%
7	Portability	99	97	27%	62%	5%	4%	2%	100%
8	Reliability	99	98	38%	28%	18%	14%	2%	100%
9	Scalability	99	91	14%	10%	20%	35%	21%	100%
10	Security	99	91	33%	46%	9%	7%	5%	100%
11	Usability	99	98	14%	30%	24%	24%	7%	100%

Table F.3 Ratings by Regulators (Staff of Education ministry)

S/No.	Non Functional Requirement	N	n	Very High	High	Medium	Low	Very Low	Total
1	Accessibility	99	32	38%	34%	13%	9%	6%	100%
2	Accuracy	99	31	23%	0%	16%	26%	35%	100%
3	Coherence	99	31	42%	45%	3%	6%	3%	100%
4	Data retention	99	31	61%	13%	13%	3%	10%	100%
5	Interoperability	99	32	22%	59%	6%	6%	6%	100%
6	Performance	99	30	47%	43%	10%	0%	0%	100%
7	Portability	99	31	32%	58%	3%	3%	3%	100%
8	Reliability	99	32	31%	38%	9%	22%	0%	100%
9	Scalability	99	30	17%	7%	13%	40%	23%	100%
10	Security	99	32	28%	47%	6%	9%	9%	100%
11	Usability	99	31	19%	32%	26%	16%	6%	100%

Table F.4 Ratings by Developers (ICT Professionals)

S/No.	Non Functional Requirement	N	n	Very High	High	Medium	Low	Very Low	Total
1	Accessibility	99	21	33%	38%	14%	5%	10%	100%
2	Accuracy	99	22	18%	9%	18%	32%	23%	100%
3	Coherence	99	22	45%	41%	9%	5%	0%	100%
4	Data retention	99	22	68%	5%	18%	0%	9%	100%
5	Interoperability	99	22	36%	41%	23%	0%	0%	100%
6	Performance	99	22	50%	18%	18%	9%	5%	100%
7	Portability	99	22	27%	59%	9%	5%	0%	100%

Table F.4 continued

S/No.	Non Functional Requirement	N	n	Very High	High	Medium	Low	Very Low	Total
8	Reliability	99	22	50%	14%	23%	14%	0%	100%
9	Scalability	99	20	10%	20%	0%	55%	15%	100%
10	Security	99	18	33%	39%	17%	11%	0%	100%
11	Usability	99	22	5%	23%	32%	32%	9%	100%

Table F.5 Ratings by Users (Teachers)

S/No.	Non Functional Requirement	N	n	Very High	High	Medium	Low	Very Low	Total
1	Security	99	27	30%	56%	4%	4%	7%	100%
2	Portability	99	30	23%	67%	0%	7%	3%	100%
3	Interoperability	99	30	20%	47%	23%	7%	3%	100%
4	Accessibility	99	27	19%	48%	19%	4%	11%	100%
5	Coherence	99	29	21%	55%	10%	10%	3%	100%
6	Performance	99	31	39%	16%	35%	6%	3%	100%
7	Scalability	99	27	15%	7%	26%	22%	30%	100%
8	Data retention	99	31	52%	29%	10%	6%	3%	100%
9	Usability	99	31	10%	29%	29%	29%	3%	100%
10	Accuracy	99	30	13%	3%	20%	43%	20%	100%
11	Reliability	99	30	30%	27%	27%	10%	7%	100%

Table F.6 Ratings by Managers (Principals/Vice Principals)

S/No.	Non Functional Requirement	N	n	Very High	High	Medium	Low	Very Low	Total
1	Accessibility	99	14	36%	36%	14%	14%	0%	100%
2	Accuracy	99	14	14%	7%	29%	50%	0%	100%
3	Coherence	99	14	21%	79%	0%	0%	0%	100%
4	Data retention	99	14	71%	0%	0%	14%	14%	100%
5	Interoperability	99	14	36%	50%	7%	7%	0%	100%
6	Performance	99	14	21%	36%	29%	0%	14%	100%
7	Portability	99	14	21%	64%	14%	0%	0%	100%
8	Reliability	99	14	50%	29%	14%	7%	0%	100%
9	Scalability	99	14	14%	7%	50%	21%	7%	100%
10	Security	99	14	50%	36%	14%	0%	0%	100%
11	Usability	99	14	29%	36%	0%	21%	14%	100%

APPENDIX G

COMPUTATION OF TOPSIS AND SAW

TOPSIS Analysis

Below is the complete computation carried out for the TOPSIS analysis in Chapter 4.

The first step is to standardize the decision matrix which commences by computing the root of sum of square as shown in the table below:

Table G.1 Computation of Root of sum of squares

S/No.	**NFRs**	**Architectures**				**Root of sum of square**	
		Distributed	**Integrated**	**Pooled**	**Converged**		
1	Accessibility	2	3	3	3	$\surd(2^2+3^2+3^2+3^2)$	5.57
2	Accuracy	2	3	2	3	$\surd(2^2+3^2+2^2+3^2)$	5.10
3	Coherence	2	3	3	3	$\surd(2^2+3^2+3^2+3^2)$	5.57
4	Data retention	3	1	3	3	$\surd(2^2+1^2+3^2+3^2)$	5.29
5	Interoperability	3	1	3	1	$\surd(3^2+1^2+3^2+1^2)$	4.47
6	Maintainability	1	3	2	3	$\surd(1^2+3^2+2^2+3^2)$	4.80
7	Performance	2	3	3	3	$\surd(2^2+3^2+3^2+3^2)$	5.57
8	Portability	3	3	3	2	$\surd(3^2+3^2+3^2+2^2)$	5.57
9	Reliability	2	2	3	3	$\surd(2^2+2^2+3^2+3^2)$	5.10
10	Scalability	3	1	3	3	$\surd(3^2+1^2+3^2+3^2)$	5.29
11	Security	1	3	1	3	$\surd(1^2+3^2+1^2+3^2)$	4.47
12	Usability	3	3	3	3	$\surd(3^2+3^2+3^2+3^2)$	6.00

Each column is then divided by respective root of sum of square obtained from Table G.1

Table G.2 Standardized decision matrix computation

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	2/5.57	3/5.57	3/5.57	3/5.57
2	Accuracy	2/5.10	3/5.10	2/5.10	3/5.10
3	Coherence	2/5.57	3/5.57	3/5.57	3/5.57
4	Data retention	3/5.29	1/5.29	3/5.29	3/5.29
5	Interoperability	3/4.47	1/4.47	3/4.47	1/4.47
6	Maintainability	1/4.80	3/4.80	2/4.80	3/4.80
7	Performance	2/5.57	3/5.57	3/5.57	3/5.57
8	Portability	3/5.57	3/5.57	3/5.57	2/5.57
9	Reliability	2/5.10	2/5.10	3/5.10	3/5.10
10	Scalability	3/5.29	1/5.29	3/5.29	3/5.29
11	Security	1/4.47	3/4.47	1/4.47	3/4.47
12	Usability	3/6.00	3/6.00	3/6.00	3/6.00

The resulting table is a standardized decision matrix. The idea behind normalizing the matrix is to transform all the values into common measurable units to allow comparison of different criteria. The standardized matrix is shown below:

Table G.3 Standardized decision matrix

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	0.36	0.54	0.54	0.54
2	Accuracy	0.39	0.59	0.39	0.59
3	Coherence	0.36	0.54	0.54	0.54
4	Data retention	0.57	0.19	0.57	0.57
5	Interoperability	0.67	0.22	0.67	0.22
6	Maintainability	0.21	0.63	0.42	0.63
7	Performance	0.36	0.54	0.54	0.54
8	Portability	0.54	0.54	0.54	0.36
9	Reliability	0.39	0.39	0.59	0.59
10	Scalability	0.57	0.19	0.57	0.57
11	Security	0.22	0.67	0.22	0.67
12	Usability	0.50	0.50	0.50	0.50

The second step in TOPSIS is to construct the weighted standardized decision matrix where the quality attributes of the Architecture are multiplied by the weighted ratings of the NFRs obtained from Table 4.20 as shown below:

Table G.4 Weighted Standardized decision matrix computation

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	0.36 x 3.6	0.54 x 3.6	0.54 x 3.6	0.54 x 3.6
2	Accuracy	0.39 x 1.1	0.59 x 1.1	0.39 x 1.1	0.59 x 1.1
3	Coherence	0.36 x 1.5	0.54 x 1.5	0.54 x 1.5	0.54 x 1.5
4	Data retention	0.57 x 2.4	0.19 x 2.4	0.57 x 2.4	0.57 x 2.4
5	Interoperability	0.67 x 0.3	0.22 x 0.3	0.67 x 0.3	0.22 x 0.3
6	Maintainability	0.21 x 0.3	0.63 x 0.3	0.42 x 0.3	0.63 x 0.3
7	Performance	0.36 x 1.8	0.54 x 1.8	0.54 x 1.8	0.54 x 1.8
8	Portability	0.54 x 2.1	0.54 x 2.1	0.54 x 2.1	0.36 x 2.1
9	Reliability	0.39 x 2.7	0.39 x 2.7	0.59 x 2.7	0.59 x 2.7
10	Scalability	0.57 x 0.4	0.19 x 0.4	0.57 x 0.4	0.57 x 0.4
11	Security	0.22 x 0.6	0.67 x 0.6	0.22 x 0.6	0.67 x 0.6
12	Usability	0.50 x 3	0.50 x 3	0.50 x 3	0.50 x 3

The table below displays the weighted standardized decision matrix.

Table G.5 Weighted Standardized decision matrix

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	1.29	1.94	1.94	1.94
2	Accuracy	0.43	0.65	0.43	0.65
3	Coherence	0.54	0.81	0.81	0.81
4	Data retention	1.36	0.45	1.36	1.36
5	Interoperability	0.20	0.07	0.20	0.07
6	Maintainability	0.06	0.19	0.13	0.19
7	Performance	0.65	0.97	0.97	0.97
8	Portability	1.13	1.13	1.13	0.75
9	Reliability	1.06	1.06	1.59	1.59
10	Scalability	0.23	0.08	0.23	0.23
11	Security	0.13	0.40	0.13	0.40
12	Usability	1.50	1.50	1.50	1.50

The third step in TOPSIS is to determine the Ideal solution and the negative ideal solution from the weighted standardized decision matrix. The ideal solution (Is) is the set of maximum values for each NFR obtained from the Table G.5. This is given in the table below

Table G.6 Ideal Solutions

S/No.	NFRs	Ideal Solution (Is)
1	Accessibility	1.94
2	Accuracy	0.65
3	Coherence	0.81
4	Data retention	1.36
5	Interoperability	0.20
6	Maintainability	0.19

Table G.6 continued

S/No.	NFRs	Ideal Solution (Is)
7	Performance	0.97
8	Portability	1.13
9	Reliability	1.59
10	Scalability	0.23
11	Security	0.40
12	Usability	1.50

The negative ideal solution (Ns) is the set of minimum values for each NFR obtained from Table G.5. This is given in the table below

Table G.7 Negative ideal solutions

S/No.	NFRs	Negative Ideal Solution (Ns)
1	Accessibility	1.29
2	Accuracy	0.43
3	Coherence	0.54
4	Data retention	0.45
5	Interoperability	0.07
6	Maintainability	0.06
7	Performance	0.65
8	Portability	0.75
9	Reliability	1.06
10	Scalability	0.08
11	Security	0.13
12	Usability	1.50

The fourth step is to determine the separation from the ideal solutions and the negative ideal solutions.

The ideal solution value for each NFR from Table G.6 is subtracted from the Weighted Standardized decision matrix to obtain the separation from the ideal solution as shown below:

Table G.8 Separation from ideal solution computation

S/No.	NFRs	Architectures			
		Distributed	Integrated	Pooled	Converged
1	Accessibility	$(1.29 - 1.94)^2$	$(1.94 - 1.94)^2$	$(1.94 - 1.94)^2$	$(1.94 - 1.94)^2$
2	Accuracy	$(0.43 - 0.65)^2$	$(0.65 - 0.65)^2$	$(0.43 - 0.65)^2$	$(0.65 - 0.65)^2$
3	Coherence	$(0.54 - 0.81)^2$	$(0.81 - 0.81)^2$	$(0.81 - 0.81)^2$	$(0.81 - 0.81)^2$
4	Data retention	$(1.36 - 1.36)^2$	$(0.45 - 1.36)^2$	$(1.36 - 1.36)^2$	$(1.36 - 1.36)^2$
5	Interoperability	$(0.20 - 0.20)^2$	$(0.07 - 0.20)^2$	$(0.20 - 0.20)^2$	$(0.07 - 0.20)^2$
6	Maintainability	$(0.06 - 0.19)^2$	$(0.19 - 0.19)^2$	$(0.13 - 0.19)^2$	$(0.19 - 0.19)^2$
7	Performance	$(0.65 - 0.97)^2$	$(0.97 - 0.97)^2$	$(0.97 - 0.97)^2$	$(0.97 - 0.97)^2$

Table G.8 continued

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
8	Portability	$(1.13 - 1.13)^2$	$(1.13 - 1.13)^2$	$(1.13 - 1.13)^2$	$(0.75 - 1.13)^2$
9	Reliability	$(1.06 - 1.59)^2$	$(1.06 - 1.59)^2$	$(1.59 - 1.59)^2$	$(1.59 - 1.59)^2$
10	Scalability	$(0.23 - 0.23)^2$	$(0.08 - 0.23)^2$	$(0.23 - 0.23)^2$	$(0.23 - 0.23)^2$
11	Security	$(0.13 - 0.40)^2$	$(0.40 - 0.40)^2$	$(0.13 - 0.40)^2$	$(0.40 - 0.40)^2$
12	Usability	$(1.50 - 1.50)^2$	$(1.50 - 1.50)^2$	$(1.50 - 1.50)^2$	$(1.50 - 1.50)^2$

The result of the computation of the Euclidean distance is displayed in the table below:

Table G.9 Separation from ideal solution

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	0.42	0.00	0.00	0.00
2	Accuracy	0.05	0.00	0.05	0.00
3	Coherence	0.07	0.00	0.00	0.00
4	Data retention	0.00	0.82	0.00	0.00
5	Interoperability	0.00	0.02	0.00	0.02
6	Maintainability	0.02	0.00	0.00	0.00
7	Performance	0.10	0.00	0.00	0.00
8	Portability	0.00	0.00	0.00	0.14
9	Reliability	0.28	0.28	0.00	0.00
10	Scalability	0.00	0.02	0.00	0.00
11	Security	0.07	0.00	0.07	0.00
12	Usability	0.00	0.00	0.00	0.00
	Sum Total	1.01	1.14	0.12	0.16
Is	**(Sum Total)$^{1/2}$**	1.00	1.07	0.35	0.40

Where Is = Ideal Solution.

To determine the separation from the Negative ideal solutions, the same steps carried out above are repeated. The Negative ideal solution value for each NFR from Table G.7 is subtracted from the Weighted Standardized decision matrix as shown below:

Table G.10 Separation from negative ideal solution computation

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	$(1.29 - 1.29)^2$	$(1.94 - 1.29)^2$	$(1.94 - 1.29)^2$	$(1.94 - 1.29)^2$
2	Accuracy	$(0.43 - 0.43)^2$	$(0.65 - 0.43)^2$	$(0.43 - 0.43)^2$	$(0.65 - 0.43)^2$
3	Coherence	$(0.54 - 0.54)^2$	$(0.81- 0.54)^2$	$(0.81 - 0.54)^2$	$(0.81 - 0.54)^2$
4	Data retention	$(1.36 - 0.45)^2$	$(0.45 - 0.45)^2$	$(1.36 - 0.45)^2$	$(1.36 - 0.45)^2$
5	Interoperability	$(0.20 - 0.07)^2$	$(0.07 - 0.07)^2$	$(0.20 - 0.07)^2$	$(0.07 - 0.07)^2$
6	Maintainability	$(0.06 - 0.06)^2$	$(0.19 - 0.06)^2$	$(0.13 - 0.06)^2$	$(0.19 - 0.06)^2$
7	Performance	$(0.65 - 0.65)^2$	$(0.97 - 0.65)^2$	$(0.97 - 0.65)^2$	$(0.97 - 0.65)^2$
8	Portability	$(1.13 - 0.75)^2$	$(1.13 - 0.75)^2$	$(1.13 - 0.75)^2$	$(0.75 - 0.75)^2$

Table G.10 continued

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
9	Reliability	$(1.06 - 1.06)^2$	$(1.06 - 1.06)^2$	$(1.59 - 1.06)^2$	$(1.59 - 1.06)^2$
10	Scalability	$(0.23 - 0.08)^2$	$(0.08 - 0.08)^2$	$(0.23 - 0.08)^2$	$(0.23 - 0.08)^2$
11	Security	$(0.13 - 0.13)^2$	$(0.40 - 0.13)^2$	$(0.13 - 0.13)^2$	$(0.40 - 0.13)^2$
12	Usability	$(1.50 - 1.50)^2$	$(1.50 - 1.50)^2$	$(1.50 - 1.50)^2$	$(1.50 - 1.50)^2$

The result from the computation is displayed below:

Table G.11 Separation from negative ideal solution

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	0.00	0.42	0.42	0.42
2	Accuracy	0.00	0.05	0.00	0.05
3	Coherence	0.00	0.07	0.07	0.07
4	Data retention	0.82	0.00	0.82	0.82
5	Interoperability	0.02	0.00	0.02	0.00
6	Maintainability	0.00	0.02	0.00	0.02
7	Performance	0.00	0.10	0.10	0.10
8	Portability	0.14	0.14	0.14	0.00
9	Reliability	0.00	0.00	0.28	0.28
10	Scalability	0.02	0.00	0.02	0.02
11	Security	0.00	0.07	0.00	0.07
12	Usability	0.00	0.00	0.00	0.00
	Sum Total	1.01	0.87	1.89	1.86
Ns	**(Sum Total)$^{1/2}$**	1.00	0.93	1.37	1.36

Where Ns is the negative ideal solution.

The fifth step in TOPSIS is the calculation of the relative closeness to the ideal solutions. The alternative that has the highest value is deemed to be closest to the ideal solution. The computation is shown in the table below.

Table G.12 Relative closeness to ideal solution

NFRs	Architectures			
	Distributed	**Integrated**	**Pooled**	**Converged**
Is	1.00	1.07	0.35	0.40
Ns	1.00	0.93	1.37	1.36
Is + Ns	2.01	2.00	1.72	1.76
Ns/(Is + Ns)	0.50	0.47	**0.80**	0.77

SAW Analysis

Below is the complete computation carried out for the SAW analysis in Chapter 4.

Table G.13 Quality attributes of Architectures with assigned values

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	2	3	3	3
2	Accuracy	2	3	2	3
3	Coherence	2	3	3	3
4	Data retention	3	1	3	3
5	Interoperability	3	1	3	1
6	Maintainability	1	3	2	3
7	Performance	2	3	3	3
8	Portability	3	3	3	2
9	Reliability	2	2	3	3
10	Scalability	3	1	3	3
11	Security	1	3	1	3
12	Usability	3	3	3	3

The first step in SAW involves normalising the quality attributes of the system architectures obtained from the table above as shown below:

Table G.14 Normalization of quality attributes of the architectures

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	2/3	3/3	3/3	3/3
2	Accuracy	2/3	3/3	2/3	3/3
3	Coherence	2/3	3/3	3/3	3/3
4	Data retention	3/3	1/3	3/3	3/3
5	Interoperability	3/3	1/3	3/3	1/3
6	Maintainability	1/3	3/3	2/3	3/3
7	Performance	2/3	3/3	3/3	3/3
8	Portability	3/3	3/3	3/3	2/3
9	Reliability	2/3	2/3	3/3	3/3
10	Scalability	3/3	1/3	3/3	3/3
11	Security	1/3	3/3	1/3	3/3
12	Usability	3/3	3/3	3/3	3/3

The result of the normalization is given below:

Table G.15 Normalised quality attributes

S/No.	NFRs	Architectures			
		Distributed	Integrated	Pooled	Converged
1	Accessibility	0.67	1.00	1.00	1.00
2	Accuracy	0.67	1.00	0.67	1.00
3	Coherence	0.67	1.00	1.00	1.00
4	Data retention	1.00	0.33	1.00	1.00
5	Interoperability	1.00	0.33	1.00	0.33
6	Maintainability	0.33	1.00	0.67	1.00
7	Performance	0.67	1.00	1.00	1.00
8	Portability	1.00	1.00	1.00	0.67
9	Reliability	0.67	0.67	1.00	1.00
10	Scalability	1.00	0.33	1.00	1.00
11	Security	0.33	1.00	0.33	1.00
12	Usability	1.00	1.00	1.00	1.00

The second step is to evaluate the score for each architecture by multiplying the normalized values with weighted ratings of the NFRs obtained from Table 4.20.

Table G.16 Computation of Weighted normalized decision matrix

S/No.	NFRs	Architectures			
		Distributed	Integrated	Pooled	Converged
1	Accessibility	0.67 x 3.6	1.00 x 3.6	1.00 x 3.6	1.00 x 3.6
2	Accuracy	0.67 x 1.1	1.00 x 1.1	0.67 x 1.1	1.00 x 1.1
3	Coherence	0.67 x 1.5	1.00 x 1.5	1.00 x 1.5	1.00 x 1.5
4	Data retention	1.00 x 2.4	0.33 x 2.4	1.00 x 2.4	1.00 x 2.4
5	Interoperability	1.00 x 0.3	0.33 x 0.3	1.00 x 0.3	0.33 x 0.3
6	Maintainability	0.33 x 0.3	1.00 x 0.3	0.67 x 0.3	1.00 x 0.3
7	Performance	0.67 x 1.8	1.00 x 1.8	1.00 x 1.8	1.00 x 1.8
8	Portability	1.00 x 2.1	1.00 x 2.1	1.00 x 2.1	0.67 x 2.1
9	Reliability	0.67 x 2.7	0.67 x 2.7	1.00 x 2.7	1.00 x 2.7
10	Scalability	1.00 x 0.4	0.33 x 0.4	1.00 x 0.4	1.00 x 0.4
11	Security	0.33 x 0.6	1.00 x 0.6	0.33 x 0.6	1.00 x 0.6
12	Usability	1.00 x 3	1.00 x 3	1.00 x 3	1.00 x 3

The result of the evaluation is shown in the table below:

Table G.17 Weighted normalized decision matrix

S/No.	NFRs	Architectures			
		Distributed	Integrated	Pooled	Converged
1	Accessibility	2.40	3.60	3.60	3.60
2	Accuracy	0.73	1.10	0.73	1.10
3	Coherence	1.00	1.50	1.50	1.50
4	Data retention	2.40	0.80	2.40	2.40
5	Interoperability	0.30	0.10	0.30	0.10

Table G.17 continued

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
6	Maintainability	0.10	0.30	0.20	0.30
7	Performance	1.20	1.80	1.80	1.80
8	Portability	2.10	2.10	2.10	1.40
9	Reliability	1.80	1.80	2.70	2.70
10	Scalability	0.40	0.13	0.40	0.40
11	Security	0.20	0.60	0.20	0.60
12	Usability	3.00	3.00	3.00	3.00

The last step was carried out by evaluating the score for each architecture where the values under each architecture column were summed up. The alternative that has the highest score is deemed the alternative the matches the criteria the best.

Table G.18 Evaluation score for each architecture using SAW

S/No.	NFRs	Architectures			
		Distributed	**Integrated**	**Pooled**	**Converged**
1	Accessibility	2.40	3.60	3.60	3.60
2	Accuracy	0.73	1.10	0.73	1.10
3	Coherence	1.00	1.50	1.50	1.50
4	Data retention	2.40	0.80	2.40	2.40
5	Interoperability	0.30	0.10	0.30	0.10
6	Maintainability	0.10	0.30	0.20	0.30
7	Performance	1.20	1.80	1.80	1.80
8	Portability	2.10	2.10	2.10	1.40
9	Reliability	1.80	1.80	2.70	2.70
10	Scalability	0.40	0.13	0.40	0.40
11	Security	0.20	0.60	0.20	0.60
12	Usability	3.00	3.00	3.00	3.00
	Summation	**15.63**	**16.83**	**18.93**	**18.90**

APPENDIX H

RANKING ANALYSIS OF DIFFERENT STAKEHOLDER GROUPS

Regulators' ranking of the elicited NFRs

The table below represents the raw data of the ranking of the elicited NFRs from the Regulators point of view

Table H.1 Raw ranking data of elicited NFRs by the Regulators

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**
Accessibility	11	5	4	2	1	0	0	0	0	0	0	0
Accuracy	6	8	3	2	0	0	0	0	1	1	1	1
Coherence	1	3	2	3	1	1	1	3	3	3	1	1
Data retention	0	2	4	6	3	2	0	1	2	0	2	1
Interoperability	0	0	1	2	4	2	3	3	1	4	1	2
Maintainability	0	0	2	2	2	5	4	3	5	0	0	0
Performance	1	0	2	1	4	6	4	2	0	1	1	1
Portability	0	0	0	0	2	2	3	2	5	5	0	4
Reliability	4	1	2	3	2	2	1	3	2	0	3	0
Security	0	2	2	2	3	2	2	3	1	3	1	2
Scalability	0	0	0	0	1	1	1	1	2	4	11	2
Usability	0	2	1	0	0	0	4	2	1	2	2	9
Total	23	23	23	23	23	23	23	23	23	23	23	23

In order to determine the respective ranks of the NFRs, each rank column is multiplied by its rank order i.e. all the values that fall under the 1st column are multiplied by 1, all those that fall under 2nd column are multiplied by 2 and so on until we reach the 12th column were the values are multiplied by 12.

The values that corresponds to each NFR row are then added up. The NFR whose total is the lowest is deemed to be ranked 1st, the NR with the second lowest total is 2nd and so on.

Table H.2 Computation of ranking order from Regulators point of view

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**Total**
Accessibility	11	10	12	8	5	0	0	0	0	0	0	0	46
Accuracy	6	16	9	8	0	0	0	0	9	10	11	12	69
Coherence	1	6	6	12	5	6	7	24	27	30	11	12	135
Data retention	0	4	12	24	15	12	0	8	18	0	22	12	115
Interoperability	0	0	3	8	20	12	21	24	9	40	11	24	148
Maintainability	0	0	6	8	10	30	28	24	45	0	0	0	151
Performance	1	0	6	4	20	36	28	16	0	10	11	12	132
Portability	0	0	0	0	10	12	21	16	45	50	0	48	154
Reliability	4	2	6	12	10	12	7	24	18	0	33	0	128
Security	0	4	6	8	15	12	14	24	9	30	11	24	133
Scalability	0	0	0	0	5	6	7	8	18	40	121	24	205
Usability	0	4	3	0	0	0	28	16	9	20	22	108	102

From the Total row of Table H.2, the NFRs were ranked by the Regulators as shown below:

Table H.3 Regulators' ranking of the elicited NFRs

Rank	Total	NFR
1	46	Accessibility
2	69	Accuracy
3	102	Usability
4	115	Data retention
5	128	Reliability
6	132	Performance
7	133	Security
8	135	Coherence
9	148	Interoperability
10	151	Maintainability
11	154	Portability
12	205	Scalability

In summary, Accessibility, Accuracy, Usability are most important while Portability, Maintainability and Interoperability are least important from the regulators point of view.

Developers' ranking of the elicited NFRs

The table below represents the raw data of the ranking of the NFRs from the Developers point of view

Table H.4 Raw ranking data of elicited NFRs by the Developers

NFRs	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Accessibility	6	5	6	1	1	1	1	0	0	1	0	0
Accuracy	8	6	0	1	1	2	0	1	0	2	0	1
Coherence	1	0	1	2	3	5	1	3	1	0	2	3
Data retention	0	1	4	4	2	2	1	2	2	2	0	2

Table H.4 continued

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**
Interoperability	1	0	1	1	0	1	7	2	0	2	5	2
Maintainability	1	0	2	2	2	0	2	3	6	2	2	0
Performance	3	3	1	1	2	2	2	1	0	5	1	1
Portability	0	1	0	1	1	1	1	3	2	3	3	6
Reliability	2	5	3	4	0	2	1	0	2	0	2	1
Security	0	1	2	1	3	2	1	3	5	1	1	2
Scalability	0	0	1	1	3	1	3	2	2	1	5	3
Usability	0	0	1	3	4	3	2	2	2	3	1	1
Total	22	22	22	22	22	22	22	22	22	22	22	22

Following the steps for computation above, we have:

Table H.5 Computation of ranking order from Developers point of view

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**Total**
Accessibility	6	10	18	4	5	6	7	0	0	10	0	0	66
Accuracy	8	12	0	4	5	12	0	8	0	20	0	12	69
Coherence	1	0	3	8	15	30	7	24	9	0	22	36	119
Data retention	0	2	12	16	10	12	7	16	18	20	0	24	113
Interoperability	1	0	3	4	0	6	49	16	0	20	55	24	154
Maintainability	1	0	6	8	10	0	14	24	54	20	22	0	159
Performance	3	6	3	4	10	12	14	8	0	50	11	12	121
Portability	0	2	0	4	5	6	7	24	18	30	33	72	129
Reliability	2	10	9	16	0	12	7	0	18	0	22	12	96
Security	0	2	6	4	15	12	7	24	45	10	11	24	136
Scalability	0	0	3	4	15	6	21	16	18	10	55	36	148
Usability	0	0	3	12	20	18	14	16	18	30	11	12	142

From the Total row of Table H.5, the NFRs were ranked by the Developers as shown below:

Table H.6 Developers' ranking of NFRs

Rank	**Total**	**NFR**
1	66	Accessibility
2	69	Accuracy
3	96	Reliability
4	113	Data retention
5	119	Coherence
6	121	Performance
7	129	Portability
8	136	Security
9	142	Usability
10	148	Scalability
11	154	Interoperability
12	159	Maintainability

Accessibility, Accuracy and reliability are ranked most important while interoperability, Scalability and Usability are least important to the developers.

Users' ranking of the elicited NFRs

The table below represents the raw data of the ranking of the NFRs from the Users point of view

Table H.7 Raw ranking data of elicited NFRs by the Users

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**
Accessibility	*3*	*7*	*1*	*3*	*0*	*1*	*1*	*1*	*2*	*0*	*1*	*0*
Accuracy	*6*	*3*	*3*	*3*	*3*	*0*	*0*	*1*	*0*	*1*	*0*	*0*
Coherence	*0*	*1*	*2*	*1*	*1*	*4*	*1*	*3*	*0*	*4*	*3*	*0*
Data retention	*1*	*0*	*5*	*0*	*3*	*0*	*2*	*1*	*5*	*1*	*2*	*0*

Table H.7 continued

NFRs	***1st***	***2nd***	***3rd***	***4th***	***5th***	***6th***	***7th***	***8th***	***9th***	***10th***	***11th***	***12th***
Interoperability	*0*	*0*	*1*	*2*	*3*	*1*	*1*	*3*	*3*	*3*	*3*	*0*
Maintainability	*1*	*0*	*0*	*2*	*1*	*4*	*3*	*1*	*1*	*3*	*1*	*3*
Performance	*0*	*0*	*5*	*2*	*1*	*5*	*0*	*1*	*2*	*3*	*1*	*0*
Portability	*0*	*0*	*0*	*0*	*2*	*2*	*2*	*2*	*2*	*0*	*3*	*7*
Reliability	*3*	*3*	*0*	*2*	*2*	*1*	*6*	*2*	*0*	*1*	*0*	*0*
Security	*5*	*1*	*1*	*2*	*2*	*0*	*1*	*2*	*2*	*1*	*3*	*0*
Scalability	*0*	*1*	*0*	*1*	*1*	*1*	*1*	*0*	*3*	*2*	*3*	*7*
Usability	*1*	*4*	*2*	*2*	*1*	*1*	*2*	*3*	*0*	*1*	*0*	*3*
Total	20	20	20	20	20	20	20	20	20	20	20	20

Following the steps for computation above, we have:

Table H.8 Computation of ranking order from Users point of view

NFRs	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**Total**
Accessibility	3	14	3	12	0	6	7	8	18	0	11	0	82
Accuracy	6	6	9	12	15	0	0	8	0	10	0	0	66
Coherence	0	2	6	4	5	24	7	24	0	40	33	0	145
Data retention	1	0	15	0	15	0	14	8	45	10	22	0	130
Interoperability	0	0	3	8	15	6	7	24	27	30	33	0	153
Maintainability	1	0	0	8	5	24	21	8	9	30	11	36	117
Performance	0	0	15	8	5	30	0	8	18	30	11	0	125
Portability	0	0	0	0	10	12	14	16	18	0	33	84	103
Reliability	3	6	0	8	10	6	42	16	0	10	0	0	101
Security	5	2	3	8	10	0	7	16	18	10	33	0	112
Scalability	0	2	0	4	5	6	7	0	27	20	33	84	104
Usability	1	8	6	8	5	6	14	24	0	10	0	36	82

From the Total row of Table H.8, the NFRs were ranked by the Users as shown below:

Table H.9 Users' ranking of NFRs

Rank	Total	NFR
1	66	Accuracy
2	82	Accessibility
2	82	Usability
4	101	Reliability
5	103	Portability
6	104	Scalability
7	112	Security
8	117	Maintainability
9	125	Performance
10	130	Data retention
11	145	Coherence
12	153	Interoperability

The users ranked Accuracy, Accessibility and Usability as very important but Coherence, Data retention and Performance are the least important.

Managers' ranking of the elicited NFRs

The table below represents the raw data of the ranking of the NFRs from the Managers point of view

Table H.10 Raw ranking data of elicited NFRs by the Managers

NFRs	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Accessibility	3	2	3	3	0	0	0	0	0	0	0	0
Accuracy	1	5	0	0	4	1	0	0	0	0	0	0
Coherence	1	2	1	1	1	0	0	1	2	0	2	0
Data retention	0	0	2	4	0	1	0	2	1	0	0	1
Interoperability	1	0	1	0	4	0	1	0	2	1	1	0
Maintainability	2	0	0	1	0	3	2	0	0	2	1	0

Table H.10 continued

NFRs	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Performance	0	0	2	0	0	2	3	3	1	0	0	0
Portability	0	2	1	0	0	3	1	2	0	0	0	2
Reliability	0	0	1	1	2	0	4	1	2	0	0	0
Security	1	0	0	0	0	0	0	0	0	7	3	0
Scalability	0	0	0	1	0	0	0	2	0	1	2	5
Usability	2	0	0	0	0	1	0	0	3	0	2	3
Total	11	11	11	11	11	11	11	11	11	11	11	11

Following the steps for computation above, we have:

Table H.11 Computation of ranking order from Managers point of view

NFRs	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	Total
Accessibility	3	4	9	12	0	0	0	0	0	0	0	0	28
Accuracy	1	10	0	0	20	6	0	0	0	0	0	0	37
Coherence	1	4	3	4	5	0	0	8	18	0	22	0	65
Data retention	0	0	6	16	0	6	0	16	9	0	0	12	53
Interoperability	1	0	3	0	20	0	7	0	18	10	11	0	70
Maintainability	2	0	0	4	0	18	14	0	0	20	11	0	69
Performance	0	0	6	0	0	12	21	24	9	0	0	0	72
Portability	0	4	3	0	0	18	7	16	0	0	0	24	48
Reliability	0	0	3	4	10	0	28	8	18	0	0	0	71
Security	1	0	0	0	0	0	0	0	0	70	33	0	104
Scalability	0	0	0	4	0	0	0	16	0	10	22	60	52
Usability	2	0	0	0	0	6	0	0	27	0	22	36	57

From the Total row of Table H.11, the NFRs were ranked by the Managers as shown below:

Table H.12 Managers' ranking of NFRs

Rank	**Total**	**NFR**
1	28	Accessibility
2	37	Accuracy
3	48	Portability
4	52	Scalability
5	53	Data retention
6	57	Usability
7	65	Coherence
8	69	Maintainability
9	70	Interoperability
10	71	Reliability
11	72	Performance
12	104	Security

The Managers are of the opinion that Accessibility, Accuracy and Portability are the top most important NFRs while Reliability, Performance and Security are the least important NFRs.

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