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Institutional Cybersecurity from Military Perspective

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Abstract- In the time we are living in, the nonlinear increase, usage and reliability on information communication technologies (ICT) are going to move forward. In this digital environment, people, institutions and government take necessary precautions ranging from personal to strategic level and adapt themselves to live or operate in that new form of environment. When we consider a country' cybersecurity efforts as a whole, it starts with individuals at the bottom, institutions, firms and military organizations at middle and government at the top. Ensuring a robust cybersecurity policy in a country, requires all levels (individual, institution, government) to be at the same standard. While the government level cybersecurity strategy documents generally present a comprehensive approach, the institutional level cybersecurity roadmaps, action plans are generally not present or overlooked. Being one of the main elements of a country, military organizations should be prepared to operate in this new form of operational environment that is full of malwares, advanced persistent threats (APT) and cyber espionage software. In this study, institutional cybersecurity from the military perspective is analysed in the light of possible challenges, organizational structure, the military decision making process (MDMP) and cybersecurity workforce.

Keywords- Institutional Cybersecurity, military organizations, MDMP, cyber operations, cybersecurity workforce.

1. Introduction

Due to living in an interconnected world with smart devices and appliances in cyberspace, the cyber security issue has always taken the significant role and emerged as a planning factor almost in every public or private institution. Having a close relation with information security, the cybersecurity term has evolved the former as a result of the increasing number of highly cost security breaches, irreversible prestige loss. Along with the use of internet, the use of cutting edge technologies in private and military organizations, ranging from tactical to strategic level like command, control and satellite systems, has put the cybersecurity issue much more forward and entailed cybersecurity to be a more comprehensive concept over traditional information security. The concept of information security procedures has proved insufficient due to the complex nature multidimensional and strategic effects of cyber attacks, advanced persistent threats (APT) [1].

In today's security environment, most of the efforts are being done to reach the data running on systems, structured data, and the data that is not digitalized yet, unstructured data. Although not handled in this study, one of the main efforts in this context is to make the unstructured data digitalized, the structured data [2]. Whatever be the commercial, military and intelligence purpose, multiple ways to access all kinds of data, information and knowledge require that the confidentiality, integrity and availability of information are ensured. The cyber intelligence and espionage efforts are getting more and more complex sometimes igniting hard debates and conflicts between nations. How the institutions, military organizations will manage to operate in this new form of environment will be handled in this study. In section two, we discuss institutional cybersecurity and challenges will be discussed. In section three, we discuss how institutional cybersecurity becomes an integral part of cyber operations and military decision making process (MDMP). In section four, the cybersecurity workforce and military organizational structure will be discussed and finally proposals for more effective structures will be presented for a better cybersecurity approaches from military perspective.

2. Institutional Cybersecurity

Cybersecurity efforts generally start from the government or strategic level and continue to the bottom, individual level with different methods, tools and goals. In this frame, the institutional cybersecurity, taking its place between government and individual level, constitute the main body of the cybersecurity efforts. Government level cybersecurity activities generally are issuing a national cybersecurity strategy document, establishing a national cybersecurity center or national computer incidents response teams (CIRT) and nation wide coordination of cyber incidents. The institutional cybersecurity activities [3] are first of all to obey and ensure the necessary standards coming from the upper level and to form an institutional roadmap that clearly address all possible cyber incidents and also the processes during cyber incidents and all the other activities boosting up the cyber efforts. Finally, the individual level cyber activities start with situational awareness on cyber incidents, personal cybersecurity measures, obeying the procedures, rules and not overlooking cyber issues. Considering the roles and responsibilities of jobs at all three levels, our assumption is that the institutions that are most vulnerable are those that form the government and have critical infrastructures. The difficulty in envisioning the cyber threats in current times and the enlargement of cyberspace encompassing a new operational environment for military organizations, there are naturally significant challenges that need to be addressed to avert failures. National Cybersecurity Framework Manual by NATO Cooperative Cyber Defense Centre of Excellence (NATO CCD COE) has articulated important national dilemmas that should be addressed as shown in Table 1 [4].

Table 1. Main dilemmas of national cybersecurity [1] [4]

1	Stimulate the Economy vs. Improve National Security
2	Infrastructure Modernization vs. Critical Infrastructure Protection
3	Private Sector vs. Public Sector
4	Data Protection vs. Information Sharing
5	Freedom of Expression vs. Political Stability

Similar dilemmas and challenges are present more or less for institutions as well. One of the main dilemmas that institutions may face is Security vs. Privacy. The cyber attacks are happening all around the world every second. While these attacks can range from a simple code breaking to an industrial hacking and stealing from companies intellectual property assets, plans, designs and drafts etc., worth billions of dollars. The institutions may therefore wish to watch every click of their employees. In that case, the privacy of employees can be violated and overlooked. There are also some other dilemmas for institutions as well, that are shown in Table 2 [1].

Table 2. Main dilemmas of institutional cybersecurity

1	Institutional Cybersecurity vs. Privacy
2	Privacy vs. Information sharing [5]
3	Homegrown human resource vs. Outsourcing [6]
4	Open source vs. Licensed software [7]
5	IT Security Cost vs. Institutional Cybersecurity
6	Technical vs. Administrative.
7	Cooperation vs. Loss of Reputation [8]

The institutional dilemmas stated above are generic and therefore they may increase or decrease according to the type, mission, center of gravity and area of focus of institutions. The effect of social media and intelligence particularly open source intelligence (OSINT) that is cheap and easy to implement, are the key factors to be reckoned with in public and military institutions [9]. The increasing use of smart devices and the widespread use of social networks like Facebook, twitter, LinkedIn, Instagram and so on has forced the institutions to implement not only technical but also administrative precautionary measures. Especially when it comes to enforcing and sustaining the procedures, strategic awareness and leadership play a crucial role. Besides these challenges, the resiliency of command and control structure and crisis response plans in case of cyber incidents is vital for getting away with less harm.

Script kiddies, state sponsored or freelance hackers use OSINT due to its ease to access the data, information or even knowledge [10]. Actually there is limited amount of knowledge that can be found on internet, but there is a huge amount of data that hackers can simply gather and transform into information and knowledge thanks to the free tools that are accessible on the internet. Consequently the knowledge management processes of terrorists and enemy hackers enable them to attain critical information either by metadata analysis of open source data available on public websites or with the use of social networks [11].

After gathering user and system information, through various sources, and with internet of things (IoT), attackers can transform the information to form emulated versions of the organizational structure of an institution and track the personnel on social networks with masked accounts to serve their future objectives like phishing and cyber espionage attacks [12].

Uploading documents, photos and announcements to institutional websites can be seen a mundane activity within an institution if you underestimate the possible cyber risks. The prevailing use of social networks and metadata obtained from uploaded contents can reveal a quiet amount of data and information to adversaries.

While well known companies gather data from their users to provide better solutions and maximize their income, it can be wrong to assume that the terrorist organizations and the enemies do not or can't deal with the big data. The data attained from a single source can easily be cross checked with other services thanks to IoT, like social networks, online profiles or any thing taking its place in internet. Even the photos of an activity in an institution can yield about many details of the event (place, time, the make of device and so on) with their exchangeable image format (EXIF).

A metadata analysis of collected photos from various sources, can be performed using free tools available on internet. After that kind of effort, a great deal of valuable information can be attained, like relations of people and their friends, where and when they had met, which route they track etc. Seemingly unimportant and trivial things may be some invaluable information for terrorists. Taking into account these kind of challenges coming with internet and social networks, a comprehensive cyber approach should be applied balancing the security and privacy with clear and concrete procedures in institutions. In this context and in terms of our perspective, the main and growing challenges of institutional cybersecurity are as shown in Table 3 below:

Table 3. Main and growing challenges of institutional cybersecurity

1	Lack of institutional cybersecurity strategy and roadmap.
2	Cyber manpower and workforce.
3	Strategic Cyber Awareness and Leadership. (Top-Down)
4	Open Source Intelligence, metadata efforts.
5	Big Data Analytics.
6	Bring your own device (BYOD).
7	Increasing use of social networks.
8	Cyber Crisis Response Planning
9	Resilient Command and Control.
10	Interoperability of systems and subsystems among other institutions.

3. Cyberspace Operations (CO) and Military Decision Making Process (MDMP)

According to Joint Publication 3-12, Cyberspace Operations (CO), there are several cyberspace capabilities whose main purpose is to attain the objectives in or through cyberspace [13]. The commanders, whether in battlefield or in headquarters should be aware of the cyber use, its advantages and risks, in military operations. Today's and tomorrow's security environment could not be thought apart from information communication technologies (ICT) which is supposed to ensure confidentiality, integrity and availability of information when and where it is needed [14]. In order to succeed in cyberspace and attain the cyber superiority, armies should effectively implement cyberspace operations. In some military organizations, cyber capabilities are managed together or under the frame of electronic warfare units [15].

For instance, the leading countries in the world handle cyber and electronic in a same context and merge these two activities like cyber electronic warfare activities (CEWA) [16] due to the close relations of these two areas in military operations. When we analyze the cyberspace operation, it is divided in three parts; offensive cyberspace operations, defensive cyberspace operations and DOD information network operations [16].

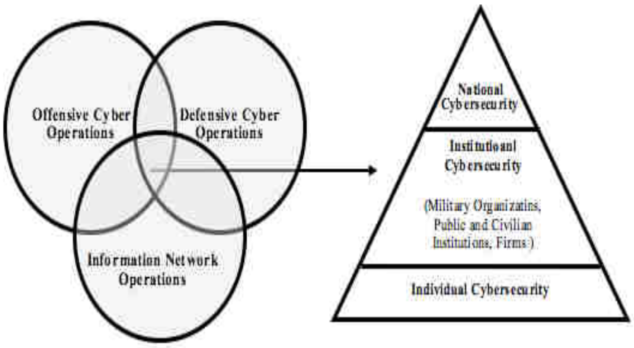
Offensive Cyber Operations
Defensive Cyber Operations
Information Network Operations
National Cybersecurity
Institutioanl Cybersecurity
(Military Organizatins, Public and Civilian Institutions, Firms)
Individual Cybersecurity

Fig. 1. Three Interdependent Functions [FM 3-38] interaction with cybersecurity hierarchy model.

In the operation's process, planning is handled with art and first understanding and then visualizing a fact and putting forward the ways to reach the target [17]. Operational planning can be divided in two areas, conceptual and detailed planning [17], [18], [19]. The conceptual planning deals with a more comprehensive, creative and critical thinking approach in order to put the operational environment in a framework applying an appropriate operational design. The detailed planning is the execution of military decision making process (MDMP) after getting the commander's initial planning guidance [20].

MDMP is a continuous and recurrent system that facilitates the leaders to understand the situation, analyse the mission and develop course of actions [20]. Planning cyberspace operations whether within electronic warfare concept or stand alone, requires detailed planning leading to specific MDMP. Cyberspace or cybersecurity is a functional area of battlefield supporting operations, regardless of an operation ongoing, alone, or as a sole tool or solution achieving military objectives. We argue that, in future, the integration of conventional operations and cyberspace operations becomes a *sine-qua-non* for military success.

By following the steps of MDMP [21], starting from the defining and accepting the mission and preliminary examination of it, CO should be analysed through all the steps and finally put forward just like other battlefield functional areas detailing how it can support the operations. When an operational design is prepared by a group of staff before planning, or simultaneously, operational cyber effects should also be considered under the name of "*Cyber Operational Design*." The need for operational design from cyber perspective stems from the complex nature and strategic effects of cyber threats. Therefore, before or along with the MDMP, cyber operational design should be prepared in order to support commander's decision and help the MDMP to be aligned in terms of cyber. An awareness of the strategic effects of enemy's information systems and critical infrastructures, CO can be the commander's main method to operate in the battlefield before deploying any of its units.

3. Cybersecurity Workforce, Manpower and Organizational Structure

In order to provide talented and qualified cyber manpower for military organizations there should be a cybersecurity workforce strategy section within an institutional cybersecurity roadmap. Considering the sources of manpower, the eligible workforce should be secured at the very beginning from military high schools, from military academies and civilian cybersecurity dedicated personnel. However, it is not easy to work with talented hackers in a military organization, the flexible working hours and other facilities should be provided in that environment. It must be also ensured that a clear definition of roles, job descriptions and duties should be communicated in order to classify the areas of responsibilities and to abide by the rule of law.

The distribution of responsibilities of cyber workforce can be information assurance, cyber intelligence, operations (offensive and defensive), and maintenance in general. As a result of cyberspace operational planning in MDMP, intelligence requirements are going to help identify the adversary's efforts, activities and even center of gravity. Therefore, cyber intelligence gathering from multiple sources with multiple tools will have an important role in cyberspace operations planning [22]. However, to find and recruit the talented, dedicated hackers, programmers and systems administrators to work for your institutions is not an easy job. But if institutions demonstrate that they have a high level of cyber situational awareness and a special interest in cyber security and also promise a good salary, it may attract those people to apply to your institutions. In this context, cybersecurity recruitment exercises such as "*capture the flag*," are of great importance in order to attract and identify potential and skilled cyber patriots [23].

One more important factor in attracting talented cybersecurity workforce in military institutions is coming together with universities and having a close collaboration and coordination in cyber events like conferences, cyber camps, workshops and cybersecurity exercises across nation-wide. These kinds of events are going to boost cyber situational awareness and bring together the talented people and provide a social environment where people can share their know-how and tacit and explicit knowledge. Whether these kinds of events can be organized by public institutions or private ones, military high school or academy students should be encouraged to participate in those activities personally or with designated teams. For instance, in U.S military academy, WestPoint, and some other institutions like National Security Agency (NSA) and Department of Homeland Security (DHS) are organizing such cyber events [24]. In order to form a robust and effective cybersecurity workforce for military organizations those initial steps should be be taken into account as follows:

- ➢Having a cyber workforce planning section in the institutional cybersecurity roadmap or document,
- ➢Job descriptions for cyberspace activities should be clearly specified and documented, no ambiguous areas should be left,
- ➢Civilian contractors meeting the required military standards, having the necessary international certificates in their fields, should be recruited and assigned in cyberspace operations' positions.
- ➢Talented civilian contractors should especially be used on job and master-apprentice trainings,
- ➢Resilient cyber workforce planning should be envisaged and necessary adjustments for service time of contractors should be implemented carefully.

Many countries have established their cybersecurity organizations both in government level and institutional (military) level. From military perspective, when we think of an operation, we also think of several main elements like intelligence and logistics. Particularly the intelligence activities precede the operation in order to provide all the necessary information and knowledge, putting forth the action, about the enemy then a suitable reaction can be given to a situation. In this context, in the MDMP process supporting the commander's decision and operations order, intelligence becomes one of the core elements of operational plan.

Therefore, in military cyber organizations there should be a close interaction and interoperability between cyber and intelligence units. The same issue is also valid for electronic support (ES) activities that support all three main elements: (Electronic Attack (EA), Electronic Protection (EP) and Electronic Support (ES)) of electronic warfare (EW). Electronic support activities require close collaboration with intelligence measures since they focus on searching for radiated electromagnetic energy for threat analysis [25].

In Fig.2, a proposed cyber command and its relation to intelligence command is shown. Due to the strategic nature of cybersecurity, the cyber command should be able to respond to the needs of the army rapidly and with little or no bureaucratic inertia. Therefore, it should be as proximate as possible to the commander of the army. Here, cyber and electronic units can be separate or integrated as a single command too. The costs and benefits of single command of cyber and electronic units can be analysed in terms of operability, efficiency, effectiveness, bureaucracy and cost.

It should be remembered that before arranging the organizational structure of the cybersecurity units, following action items should be prepared, executed and sustained:

- Clearly stated national and institutional cybersecurity strategy document [26] or a roadmap,

- Government or military level cybersecurity end states,

- Legal frame of cyberspace operations and electronic warfare activities

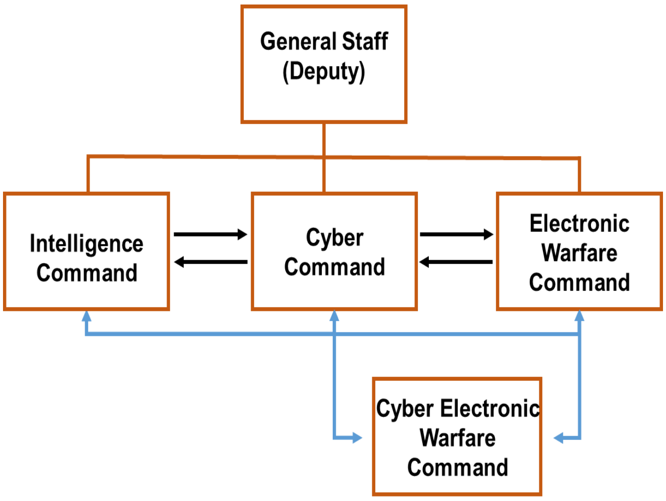

Fig. 2. The proposed organization of cyber command in military organizations that has close relation with electronic warfare and intelligence units.

3. Conclusion

The understanding and handling of the cyberspace, cybersecurity efforts vary from country to country. Some countries see the picture more comprehensively [4] including national critical infrastructures, electromagnetic spectrum, electronic warfare and cyber intelligence activities in the big picture. Therefore, those countries see the cyberspace and cyber activities as a strategic means or a new domain within the operations environment [27]. On the other hand, some other countries perceive cyberspace as equal to internet and therefore, they simply see the cybersecurity as equal to information security.

The complex and destabilizing cyber attacks, whether a denial of service attack, a cyber espionage or an advanced persistent threat (APT), have shown that the level of risk is high and no one is immune to being a subject of cyber threats. In public or civil organizations, the institutional cybersecurity can be achieved by having and sustaining a comprehensive approach like envisioning challenges, dilemmas, cyber risks especially emanating from social networks, preparing an institutional cybersecurity roadmap or action plan, updating information security procedures to compose cyber issues, balancing between privacy and security in institutions.

However, from a military perspective the things that civilian institutions should do forms the tier one in military organizations. In addition to these, tier one, military organizations should be prepared to operate in cyberspace whether cyber is a supportive of a full operation (conventional, urban warfare, peace support etc.) or an operation on its own. Regarding the destructive effects, collateral damage and killings of both civilians and military personnel, cyber wars can play an important role in preventing the killings and casualties in battlefield.

In such a chaotic era, the military organizations need to prepare for the worst by establishing resilient and cyber command structure, interoperable and synchronized planning efforts with electronic warfare command. Due to the changing character of wars from conventional to unconventional, symmetric to asymmetric and hybrid wars, cyber operations need to be designed to defense and sustain the military assets.

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A Model for Optimising Security in Public Key Infrastructure Solutions for eGovernment

A case study of Kenya

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Abstract-Public Key Infrastructure (PKI) quality attributes like security, availability, integrity, interoperability etc. are latent in nature meaning they cannot be measured or observed directly. This presents a problem on how they can be optimized since as Drucker's maxim goes, if you can't measure it, you can't manage it. We are cognizant of the fact that in most governments, the planners, implementers and assessors of PKI rely on quality management systems like ISO to qualitatively measure compliance to best practices through quarterly audits. Such strategies are paperwork intensive and try to ensure process adherence but lack the capacity to quantitatively measure non-functional quality properties. eGovernments and their cyber security strategies, face massive threats from a knowledge society that has easy access to hacking tools, and also well-funded hacker groups, some sponsored by foreign governments.In this work,we derive a conceptual framework from existing frameworks then model a quantitative decision support tool using path analysis techniques, specifically Partial Least Square Structural Equation Modeling.The data used to initialize the model is real data collected from an ongoing PKI implementation. We opine that if key decisions are optimized during planning, implementation and auditing, then the security of the a PKI solution will also be optimized. We also provide an eGovernment arrangement that relies on PKI security for identification, authentication and authorization. It is worthwhile to note that although PKI is a universal concept, its design and implementation in different contexts means that each context offers emergent challenges that require unique security solutions.

Keywords-Public Key Infrastructure; Digital Certificate; eGovernment; Cyber Security; Structural Equation Modelling.

1. Introduction

Governments are adopting new ways of doing business through the digital platform and are embracing online and mobile applications not only to improve internal efficiencies but offer their citizens delightful service.The security of eGovernment relies on secure identification and authentication of all stakeholders during transactions to make sure that only authorized parties get access to the relevant resources at the right time [1,2]. One reliable method of ensuring this in such complex environments is the use of public key infrastructure solutions to register all players, issue them with digital certificates and ensure that all communications are signed with digital signatures [3]. However, there is no best fit formula for optimizing all PKI solutions globally since each PKI operates in different contexts and each context offers emergent challenges that require to be addressed in a unique way [4].

In this paper, we shall contribute to knowledge by developing a quantitative model for rational decision optimization when reasoning about PKI security in developing economies. We are cognizant of the fact that in most governments, PKI regulators, planners, implementers and assessors rely on quality management systems like ISO and standards such as x.50x in their PKI quarterly audits or reviews. In fact ISO 9126-(1-4) and later ISO 25030 (which is part of the Software Quality and Requirements Evaluation (SQuaRE) the ISO 25000 series) forms the basis of identifying security as a worthwhile topic worth researching. Audits based on the standards above are paperwork intensive and try toensure process and requirements compliance mainly through checklists but lack the capacity to measure latent quality properties like security, interoperability, availability, privacy, reliability, performance etc. which are not explicit hence cannot be observed directly. We demonstrate how security can be modeled using multivariate assessment of factors that have causal relationships using partial least squares structural equation models. After collecting data using questionnaires and interview methods, we use regression analysis in the form of Partial Least Squares Structural Equation Modeling to model and perform measurements in SmartPLS Version 3 [5]. The output is a generic but extensible quantitative PKI security rational decision optimization model. The model shall display variable relationships and their quantitative weights in such a manner that decision makers can use them to prioritize resources and or take corrective actions where needed during audits or when predicting scenarios [6].

2. Materials Theories and Methods

2.1. Software Quality Optimisation

In this section we briefly review other software quality optimization approaches presented in other works before justifying why we chose to utilize Partial Least Squares, Structural Equation Modeling (PLS-SEM). The term optimization is not new when talking about software systems. Reference [7] presents software cost optimization using linear COCOMO equations. As is well known, COCOMO concentrates on effort and cost and ignores other important software quality properties like security. Reference [8] and [9] propose Enterprise Architecture Analysis (EAA) techniques to optimize non-functional quality attributes like security, availability, interoperability, integrity etc. This is good and in line with this paper. However EAA tools are derived from Unified Modeling Language (UML) and modeling follows Open Group's ArchiMate. Enforcing quality attribute constraints using Object Constraint Language (OCL) requires considerable programming effort that many researchers would find difficult to learn. Reference [10] also presents the Architecture Tradeoff Analysis methodology (ATAM) initially developed by the Software Engineering Institute as a software architecture quality optimization framework. ATAM performs architecture analysis and design tradeoff decisions in order to achieve desired quality attributes such as security, performance, availability etc. in the final solutions. ATAM is good but its results depend on the quality of the architecture. It concentrates more on tradeoffs but lacks an inference or predictive capability based on quantitative assessments of the latent quality variables. Besides, PKI security is so critical that such pareto optimal [11] techniques may compromise the entire system (tradeoffs may introduce loopholes which can be used to commit exploits). Reference [12] also presents a comparative study on software quality optimization either using case-based or parametric methods. However, they view optimization from the point of view of the discovery and removal of defects only and ignore other important quality attributes. Reference [13] discusses how to optimize the quality of e-learning systems components using multi-criteria evaluation, and specifically mention security as one of the key criteria that must be optimized. However, their model is too broad and does not give the security aspect the in-depth treatment it deserves.

Other works like [14] suggest search based software engineering (SBSE) techniques as a means of searching for optimal solutions when faced by a large search space of potential solutions. SBSE strategies include automated tools that utilize simulated annealing and genetic algorithms to optimize activities such as requirements engineering, costing, project management, maintenance, quality assessment etc. (ibid). However, SBSE techniques use meta-heuristic algorithms to search large solution spaces to arrive at optimal solutions. This is computationally intensive and requires significant execution time that may render such techniques infeasible[15]. Lastly but not least, [6] presents the partial least square structural equation modeling (PLS-SEM) technique which is a multivariate data analysis method that can test theoretically supported linear and additive causal models. In our case, we adopt PLS-SEM to model software quality properties like security, performance etc. and the multi-variables that influence them in a user friendly and easy to understand environment. Other factors that influenced our choice for this framework are the ability to represent causal relationships in path models and perform predictive quantitative assessments on them even with small sample sizes.

2.2. EGovernment Security and PKI

Developing economies are both at an advantage and disadvantage when it comes to technology adoption in Government. They are advantaged because they adopt technologies that have already been tested live in the first world and hence most bugs and teething problems would have been removed or understood. However, they are disadvantaged because developing economies have their own unique socio-economic, socio-cultural and socio-political contexts which require solutions that are customized for them. When reasoning about PKI for instance, each country solution requires a unique technical, policy , legal and regulatory framework developed and customized in the country of implementation [3,16]. The poor ICT infrastructure, low incomes, low literacy on e-business, low trust levels, insecure transaction services, high costs of connectivity etc. present enormous challenges [17]. One big context challenge in developing economies for instance is the entrenched culture of corruption as detailed in the Transparency International (TI) report 2014 showing Nigeria, Kenya etc. ranking very poorly at positions 136 and 145 respectively [18]. Fig. 1 presents an extensible model for eGovernment demonstrating Estonia [20], Australia [21], Kenya [22] etc. we conclude that the PKI solution should act as the secure gate keeper that identifies and authenticates all parties transacting online by providing an environment that is secure, trustworthy and supports non-repudiation [23]. A PKI enabled gateway makes sure that access to the secure government intranet is only allowed for parties that successfully authenticate using digital certificates. In so doing all government information resources across board are secured. The UK model also has a similar gateway but some of its information resources like for local authorities lie external to the secure intranet [19]. The Estonian model does not have a secure gateway but each agency connects to the common internet called the X-ROAD via a security server. Now that means it is possible to insecurely access the X-ROAD but be kept at bay by individual agency security servers. We propose that an amalgamation of the two though expensive would provide several layers of security that would be difficult to break. This would also enhance user privacy since different agencies require different identity information and a context sensitive smartcard based identity management system running on the intranet and agency servers would enforce it. More recent developments point to the fact that eGovernment is quickly moving towards the cloud [24].

In Kenya, eGovernment and hence cyber security initiatives like PKI rest on a host of development, legal and regulatory frameworks namely:

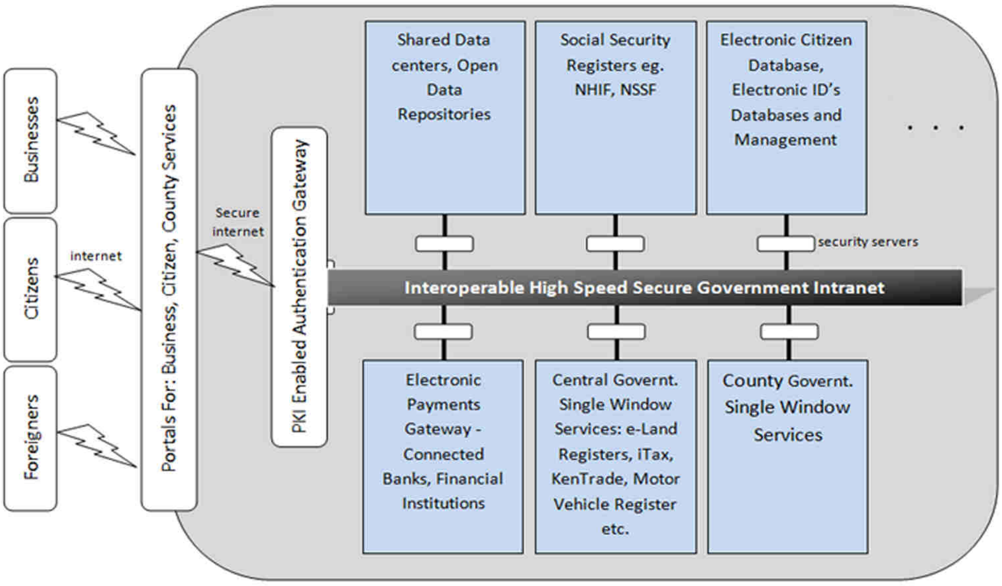

Businesses
Citizens
Foreigners
internet
Portals For: Business, Citizen, County Services
Secure internet
PKI Enabled Authentication Gateway
Shared Data centers, Open Data Repositories
Social Security Registers eg. NHIF, NSSF
Electronic Citizen Database, Electronic ID's Databases and Management
. . .
security servers
Interoperable High Speed Secure Government Intranet
Electronic Payments Gateway - Connected Banks, Financial Institutions
Central Governt. Single Window Services: e-Land Registers, iTax, KenTrade, Motor Vehicle Register etc.
County Governt. Single Window Services

Fig. 1. PKI Enabled e-Government Model.

1. The Kenyan Constitution 2010 which recognizes electronic transactions.
2. The Kenya Vision 2030 which identifies ICT as one of the important foundations for economic development bearing the theme “strengthening the foundation for a knowledge economy” and therefore achieving transformation in the government to make it responsive to the citizen [22].

Under this, the Kenya Transparency & Communications Infrastructure Project (KTCIP) sponsored by the World Bank helped set up Kenya’s PKI.

3. The National Cyber Security Management Framework which incorporated the
4. Information and Communications Act 1998 and specifically Cap 411A which sets up a legal framework for eCommerce in Kenya. It also amalgamated the Electronic Certification and Domain Name Administration Regulations 2010 which sets relevant conditions that must be met for electronic communications to be authentic and provides for a national PKI.
5. The National Computer Incident Report (NCIR) team.

The Kenyan PKI model closely shadows that of South Korea since the company that won the tender to implement it (Samsung SDS) is from there. The project architecture is as captured in Fig. 2.

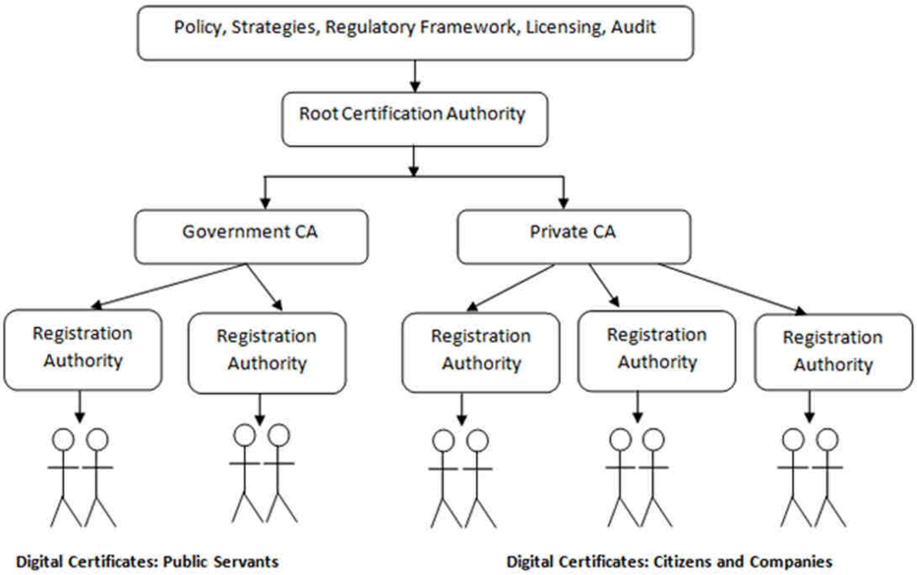

Policy, Strategies, Regulatory Framework, Licensing, Audit
Root Certification Authority
Government CA
Private CA
Registration Authority
Registration Authority
Registration Authority
Registration Authority
Registration Authority
Digital Certificates: Public Servants
Digital Certificates: Citizens and Companies

Fig. 2. National PKI Infrastrure, Kenya; Source Communications Authority of Kenya, 2014.

2.3. Assessing Security in PKI Solutions

Some generic security threats in PKI as identified by the Australian Government include but are not limited to inappropriate evidence of identity, accidental/deliberate submission of wrong identity documents during initial registration, failure of necessary checks during registration, staff collusion, corrupt CA staff, poor record keeping, data entry mistakes, interception, database corruptions, social engineering attacks on certificate/registration authority (C/RA) staff/help desk, revocation failures, RA spoofing, compromised private key, private key media failure, Relying Party (RP) fails to check revocation status /certificate path, poor infrastructure security [25] etc. The document also gives mitigation measures for the identified threats andvulnerabilities.

Reference [4] presents an assessment model when assessing PKI solutions to ensure interoperable and trustworthy systems as shown in Fig. 3. The model envisions a highly interdependent environment in which the policy body, assessor, assessors accreditation body and PKI accreditation body work in tandem to make sure that the CP, CPS, Standards etc. are applied to the CA’s Information Technology (IT) infrastructure and its procedures and operations to ensure qualitative systems. This paper draws most of its assessment criteria from [4] only that we provide a quantitative way of assessing the key attributes identified other than relying purely on checklists. The ISO 9126 standards [26] and SEI standards[26] identify general attributes when assessing software quality.

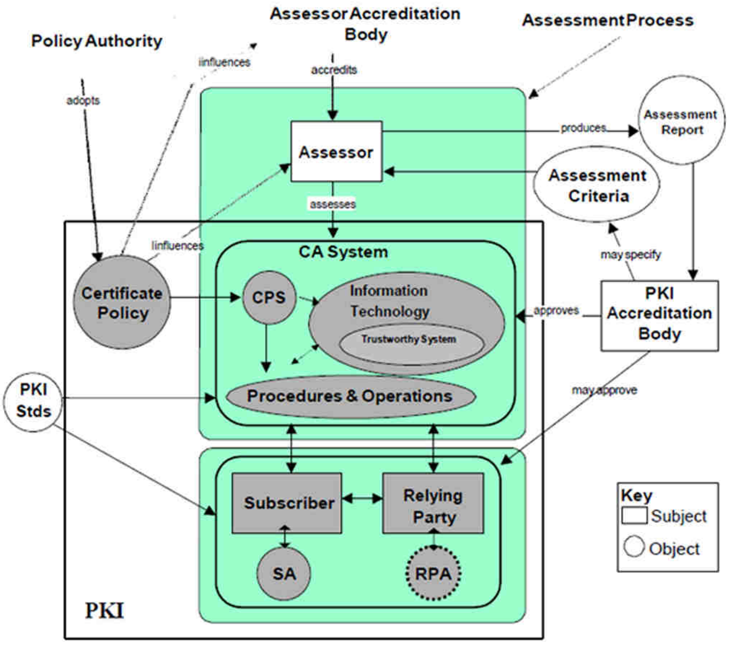


Fig. 3.PKI Assessment Model: Adopted from [4].

PKI security is intrinsic to the quality of the Certificate Policy (CP) and the resultant Certificate Practice Statement (CPS) and how strictly they are enforced during planning, implementation and daily management [4]. We now briefly look at each of the variables identified in the CF before moving on to methodology. We recognize the fact that the variables and indicators selected for this model may not be the only ones available, hence the CF is extensible as indicated. Some had to be left out in order to make the study manageable. The major works from which these are drawn include [4,27,25].

Each quality property is a latent variable that has measurement indicators/ attributes. However, when assessing a quality property say security, it becomes necessary to studywhat variables influence it and how they can be measured. To measure the latent variable, indicators are used and they have to be sourced from literature, from current industry practice or empirically where they do not exist [28]. Table 1 identifies the exogenous variables that influence security in the model and some of their indicators mainly drawn from the

PKI x.509 standards [29] and the PKI assessment guidelines [4] and other literature. This forms the basis for coming up with the conceptual framework shown in Fig. 4 from which the PLS-SEM model was drawn.

Just like in [4] we divide our security assessment based on seven key areas:

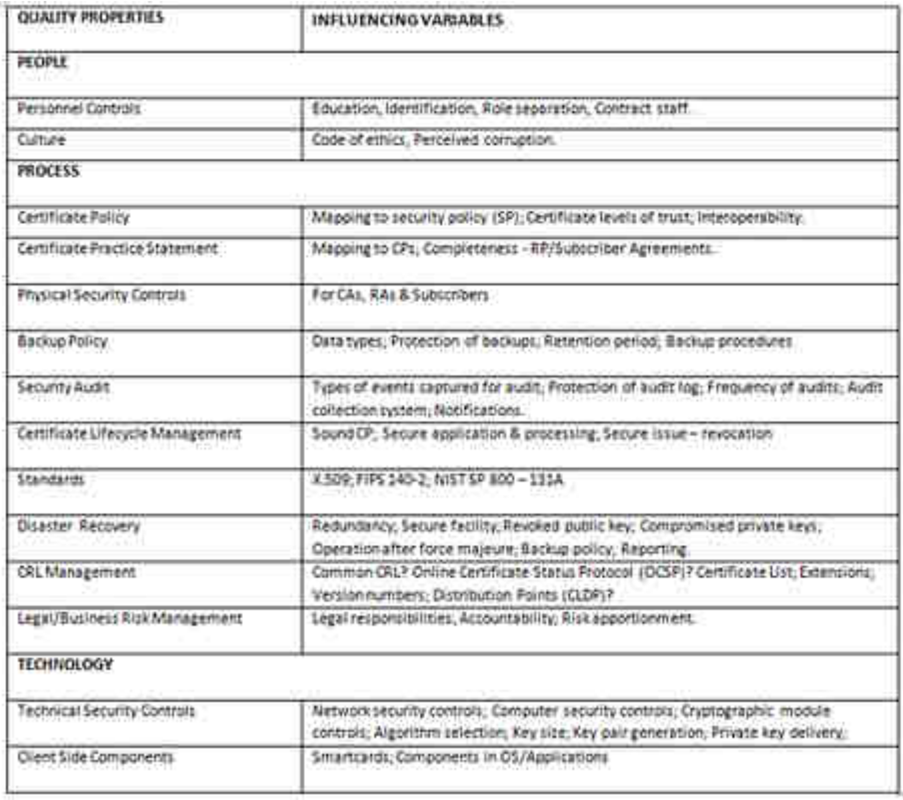
- Policy, legal and regulatory assessments
- Initial registration controls
- Certificate lifecycle controls
- Management, operation and physical controls
- Technical security controls
- Certificate, CRL and OCSP profiles
- Specification administration.

However, when modeling, we do not specifically structure the model as such because we are more interested in the relevant security variables regardless of from which segment they come from and how they affect the four cornerstones of PKI security, namely confidentiality, integrity, availability and accountability [30]. The identified variables and theirindicators are tabulated in Table 1. Notice however that in the table, we try to capture where a particular variable falls in the People, Process and Technology model (PPT) since this model has been widely applied in eGovernment studies. However we pitch for the CPPT model with C standing for Culture [31]. The culture variable is very important in developing economies because we argue that however well all the other variables are met, a culture of corruption for example can totally wipe out any gains and totally compromise security of PKI systems. The table translates to Fig. 6, the Conceptual Framework (CS).

A. Personnel Controls

We investigate whether key personnel have the right qualifications to handle their jobs in a trustworthy manner. Other controls include role separation for sensitive tasks and the trustworthinessof the process of engaging contract staff.

Table 1. Exogenous variables and their indicators



QUALITY PROPERTIES	INFLUENCING VARIABLES
PEOPLE	
Personnel Controls	Education, Identification, Role seperation, Contract staff.
Culture	Code of ethics, Perceived corruption.
PROCESS	
Certificate Policy	Mapping to security policy (SP); Certificate levels of trust; Interoperability.
Certificate Practice Statement	Mapping to CPs; Completeness - RP/Subscriber Agreements.
Physical Security Controls	For CAs, RAs & Subscribers
Backup Policy	Data types; Protection of backups; Retention period; Backup procedures
Security Audit	Types of events captured for audit; Protection of audit log; Frequency of audits; Audit collection system; Notifications.
Certificate Lifecycle Management	Sound CP; Secure application & processing; Secure issue – revocation
Standards	X.509; FIPS 140-2; NIST SP 800 – 131A
Disaster Recovery	Redundancy; Secure facility; Revoked public key; Compromised private keys; Operation after force majeure; Backup policy; Reporting.
CRL Management	Common CRL? Online Certificate Status Protocol (OCSP)? Certificate List; Extensions; Version numbers; Distribution Points (CLDP)?
Legal/Business Risk Management	Legal responsibilities; Accountability; Risk apportionment.
TECHNOLOGY	
Technical Security Controls	Network security controls; Computer security controls; Cryptographic module controls; Algorithm selection; Key size; Key pair generation; Private key delivery.
Client Side Components	Smartcards; Components in OS/Applications

B. Culture

The research would investigate if there is a professional code of ethics and whether it is strictly enforced. We shall also find out the perception in terms corruption/nepotism on how tenders, contracts are issued and how staff are employed.

C. Certificate Policy (CP)

A CP is the cornerstone of a PKI. It is usually owned by the root certification authority and is usually drawn from the eGovernment security policy.

A CP is a set of rules which govern the requirements that any PKI participant must meet in order to operate within the PKI and it lays the ground for various CA interoperability.

D. Certificate Practice Statement (CPS)

Derived from a CP, a CPS states the practices and procedures that a single CA would use in all its operations.

E. Physical Security Controls

These measures for CAs/RAs/Subscribers try to minimize the risk of key compromise through break-ins, theft, force marjorie, power failures etc.

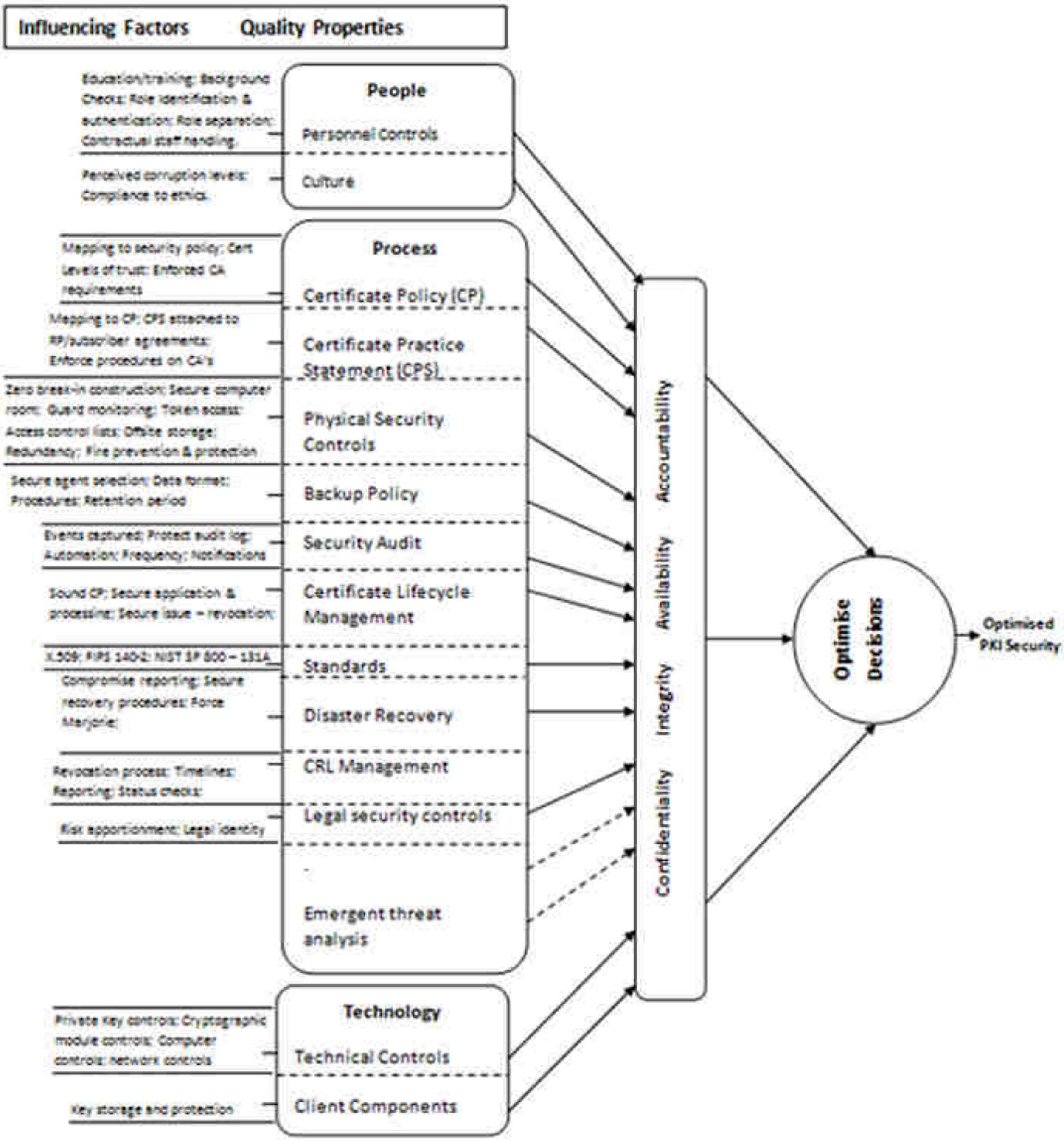

Influencing Factors
Quality Properties
Education/training: Background Checks: Role identification & authentication: Role seperation: Contractual staff handling.
Perceived corruption levels: Compliance to ethics.
People
Personnel Controls
Culture
Mapping to security policy: Cert Levels of trust: Enforced CA requirements
Mapping to CP: CPS attached to RP/subscriber agreements: Enforce procedures on CA's
Zero break-in construction: Secure computer room: Guard monitoring: Token access: Access control lists: Offsite storage: Redundancy: Fire prevention & protection
Secure agent selection: Data format: Procedures: Retention period
Events captured: Protect audit log: Automation: Frequency: Notifications
Sound CP: Secure application & processing: Secure issue – revocation:
X.509: FIPS 140-2: NIST SP 800 – 131A
Compromise reporting: Secure recovery procedures: Force Marjorie:
Revocation process: Timelines: Reporting: Status checks:
Risk apportionment: Legal identity
Process
Certificate Policy (CP)
Certificate Practice Statement (CPS)
Physical Security Controls
Backup Policy
Security Audit
Certificate Lifecycle Management
Standards
Disaster Recovery
CRL Management
Legal security controls
-
Emergent threat analysis
Private Key controls: Cryptographic module controls: Computer controls: network controls
Key storage and protection
Technology
Technical Controls
Client Components
Confidentiality
Integrity
Availability
Accountability
Optimise Decisions
Optimised PKI Security

Fig. 4.PKI Security Decision Optimisation Conceptual Framework.

F. Backup Policy

The backup policy is a very sensitive area. If a backup agent is engaged, it is important to have a secure selection process. Also the format in which the data (and especially the keys) are stored is important i.e. plaintext or encrypted. Also, data retention periods, redundancy requirements etc. have to be met.

G. Security Audit

One important consideration is whether the assessors will be in-house or contracted. External auditors are likely to do an unbiased job. Other measurements include protection of the audit log against alteration or destruction since it may have important evidence.

H. Certificate Lifecycle Management

All the processes starting with initial registration, processing, issue, activation, deactivation, revocation etc. of certificates should be done in a secure and trustworthy manner.

İ. Standards

These are very important to any PKI solution. A checklist of the relevant standards will be used to assess adherence to best practice.

J. Disaster Recovery

Readiness to deal with disastrous events that can bring the PKI to its knees is very important. Good provisions forcompromise reporting tested and tried recovery procedures after disasters etc. need to be assessed.

K. CRL Management

Certificate Revocation Lists (CRL) management is very important and can prove very costly if not handled properly. The reporting process when revocation is required should be secure e.g. who requests for a revocation and does the revocation messages have to be digitally signed? Also, strict reporting timelines are important.

L. Legal Security Controls

The legal, policy and regulatory framework should be sufficient in order to deal with difficult scenarios like risk apportionment, potential liability management, indemnity, legal responsibilities etc. for all players like CA, RA, RP, Subscriber, repositories etc.

M. Technical Controls

These are a raft of assessments that would touch on a wide range of technical concerns like the logical security of the private key, security of the cryptographic module, computer and network controls.

N. Client Components

The term client here mainly refers to relying parties and citizens. The concern here is mainly on how the private key is stored, is it on the client computer or in a smartcard? How is the private key generated and or passed to the client after generation? Is the process secure? This is important sincemost cases of key loss and or compromise may emanate from this end.

2.4. Partial Least Squares Structural Equation Modeling (PLS-SEM)

Partial Least Squares Structural Equation Modeling (PLS-SEM) is an extension of the multiple linear regression analysis technique [32]. A linear regression model helps a researcher to study the causal relationship that one variable (called the independent variable say *X*) has on a dependent variable say *Y*. Suppose for example we wish to observe the relationship between education E and salaries of information security experts S based on the two variables only and ignoring all the others that could have an effect on *S*. Let *S* be the earnings and *E* the independent variable influencing *S* based on number of years spent at school. Assuming that data about the salaries and education levels of the experts were collected and plotted in a chart as shown in Fig. 2 then it would indeed appear that the more the number of years in education a person has the higher the income. This hypothesized relationship can be captured as follows in a simple regression model (1):

$$S= C_0+\beta E+\varepsilon \qquad (1)$$

Where: S = salary of the expert (called the dependent or endogenous variable); C_0 is baseline/constant earning with zero education; $\beta$is the positive effect on earnings for every year spent in school (called the regression coefficient) and E is the independent/exogenous/explanatory variable. However, a careful study of the scatter chart may lead the researcher to conclude that it is not education alone that may influenceearnings since there is no strict linearity displayed. Other unaccounted for factored like experience, productivity etc. could have a significant impact. The researcher therefore includes an error term ε which represents all those variables that have a causal relationship on the income but are not directly observable at times referred to as noise [33]. If we set $\varepsilon = 0$ as in most cases, then the regression equation becomes the equation of a straight line in a 2-dimensinal plane with C0 becoming the y-intercept and (E, S) being arbitrary points (x, y) that lie on the line and β the slope of the line as shown in (2).

$$S = C_0+ \beta E \qquad (2)$$

Now this means that somewhere on the scatter chart we can find a line which satisfies (2) and this can be found by estimating (predicting) the values of C_0 and βa task which requires considerable effort because many lines fit the bill. Hence the task is to find the *best fit* – a line *L* which best generalizes the data as shown in Fig. 5.

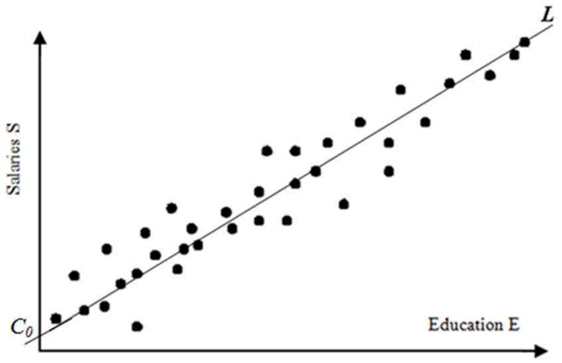


Fig. 5. Scatter chart of S/E

One way of achieving this is selecting the line that has the minimum sum of square errors. We now move on to PLS-SEM.

Structural Equation Models, also called simultaneous equation models are multivariate or multiple linear regression analysis models [34]. Unlike equation 1 where we only have a single influencing variable, we can model more variables say we add experience X to the model (1) resulting in (3). $\gamma$is modeled to be positive.

$$S = C_0 + \beta E + \gamma X + \varepsilon \qquad (3)$$

Equation 3 now has become a multi-regression and multivariate in nature. It now has two regression coefficients. It means that *S* is influenced by *E* and X and the task of estimating (predicting) values of C_0, β and $\gamma$is nolonger within 2-D space but 3-D, and on a plane rather than a simple straight line and relies purely on observable variables *S, E* and *X*. Unlike humans who find it challenging to reason in more than 3-D, the computer can perform analysis of many variables in *n*-D space [35]. Each factor enters the analysis independently and its causal impact can also be assessed independently e.g. possibility of answering questions like“Holding education constant, how does experience influence earnings?”

Partial Least Square (PLS) is an extension of multiple linear regression analysis equations [6]. The O observations described by D dependent variables are stored in an O×Dmatrix denoted by I. The values of P predictors on the observations are stored in an O×P matrix F. PLS does not aim to find hyper planes of minimum variance between responses and independent variables, but to predict I from F by finding a linear regression model through creation of new spaces where observed and predicted variables can be plotted [36].

Structural Equation Modeling is a technique for depicting relationships between variables with the aim of quantitatively testing the theory hypothesized by the researcher e.g. whether an independent variable influences the dependent one or not. In our case we use PLS-SEM tool that helps a person to model and do Analysis of Variance (ANOVA). A PLS-SEM model would have:

Exogenous variables: independent variables. All causal relationship arrows point away from it.

Endogenous variables: dependent variables. Path arrows point to it showing causal effects.

Indicators: observed measures or variables used to infer the value of the latent variable.

Diagrammatically, a model takes the form of Fig. 6 [6].

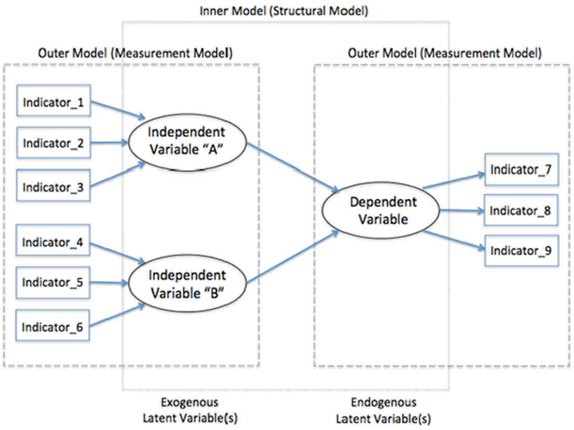


Fig. 6. Structural Equation Model

2.5. **Methodology**

Literature review was done using the structure case strategy [37]. This helped the research to distill key PKI security quality attributes and develop the CF. The CF was then directly modeled in SmartPLS as shown in Fig. 7. Each quality property in the CF becomes a latent variable in SmartPLS. The influencing factors become indicators in a reflective relationship. Intermediate variables of confidentiality, integrity, availability and accountability become endogenous variables to which all arrows from exogenous variables point, representing various influences. The last endogenous variable in the chain OPTIMAL_DECISION_FIT represents the collective state of PKI security after assessment.

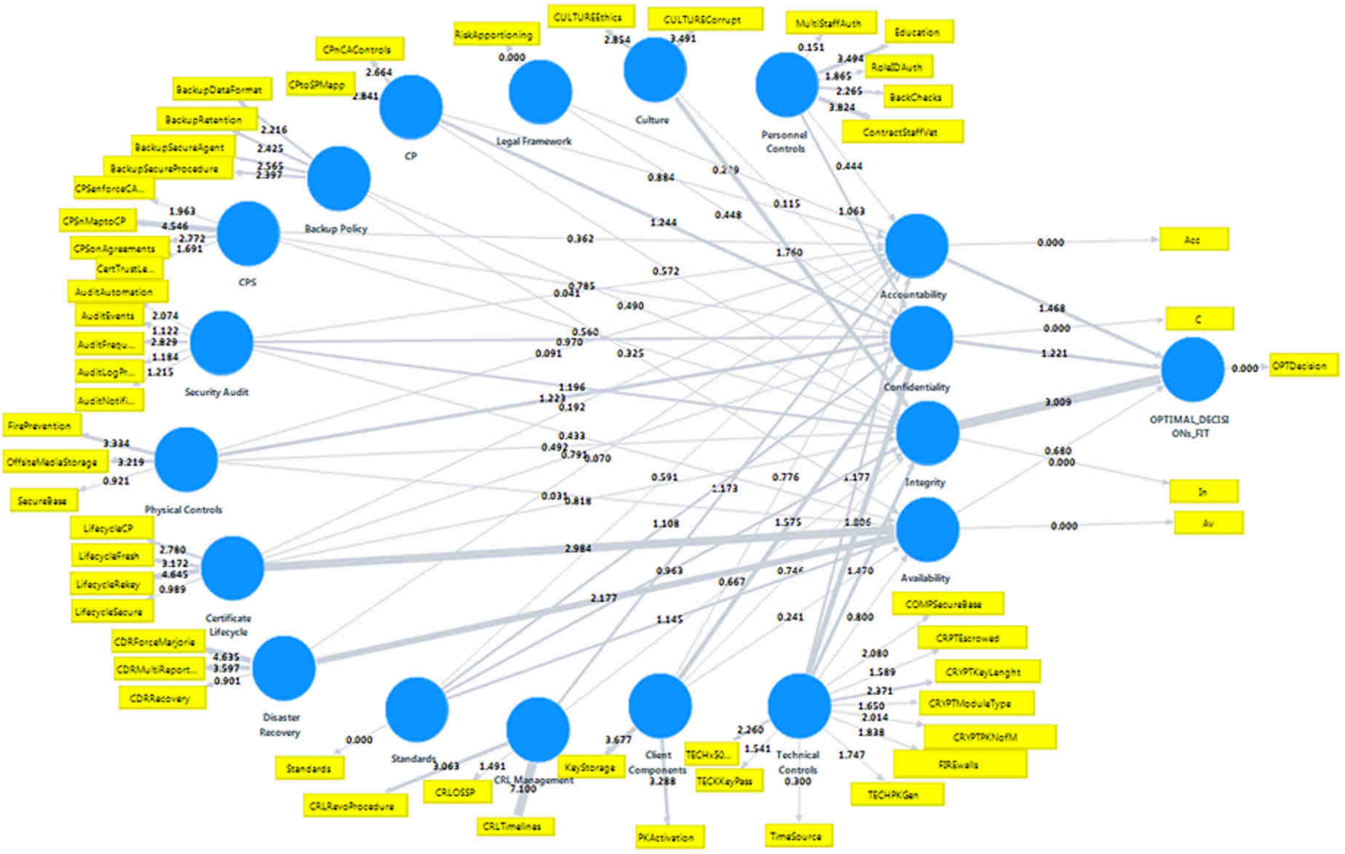


Fig. 7. Model in SmartPLS: results of post study bootstrapping after 300 iterations

All indicators are ideally translated into a questionnaire or interview question with interval measures on the responses. We use a seven level Likart scale system with the worst case scenario scoring the least (1) while the best the most (7). Where we have used No/Yes field, the No is scored as 1 and the Yes as a 7. For example, under technical controls on the CF, to measure the attribute Cryptographic Module Controls, one of the indicators is the key length (CRPTKeyLenght) as modelled in SmartPLS. The questionnaire question was presented as follows:-

We use the following key lengths to generate private and public keys:

□ 64 bits □ 128 bits □ 512 bits □ 256 bits
□ 1024 bits □ 2048 bits ▣ >2048 bits

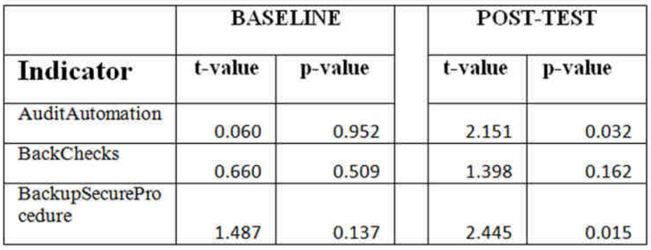
In this case we assume 64 bits to be the worst case scenario while >2048 bits the best. The responses were coded into interval values 1 – 7 and captured in an Excel file which was used to populate the model. Initially, we carry out a baseline survey to establish the level of attainment of various attributes. We initially use a sample size of 30 to collect data about the various attributes. Then after three months, we collect data again in a post study to see whether the weaknesses identified earlier have been improved by comparing various statistical measures generated. We use a reflective measurement scale because we assume the indicators have correlations among themselves.

3. Calculations

A. Bootstrapping Algorithm

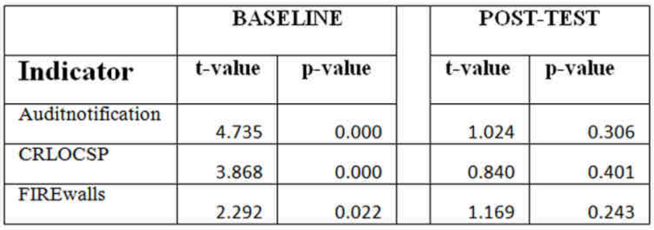
Figure 7 shows the results of the bootstrapping algorithm after 300 iterations and the significance level set at 0.05. The values on the causal lines between variables in the inner model represent the t-values. Looking at the model, we can say for example that integrity, accountability and confidentialityare very significant factors when coming up with optimized decisions due to their high t-values. However, Availability-> Optimal Decisions Fit has the lowest t-value among the three (0.680). Table 2a and 2b below shows a comparison between the p and t-values of some of the indicators during the baseline and post study. We could not fit the entire table because of the limited space. In Table 2a, there was an improvement in the indicator values while in Table 2b there was a decline.

Table 2a. Examples of indicators that showed improvement.



	BASELINE			POST-TEST	
Indicator	t-value	p-value		t-value	p-value
AuditAutomation	0.060	0.952		2.151	0.032
BackChecks	0.660	0.509		1.398	0.162
BackupSecureProcedure	1.487	0.137		2.445	0.015

Table 2b. Examples of indicators that showed decline.



	BASELINE			POST-TEST	
Indicator	t-value	p-value		t-value	p-value
Auditnotification	4.735	0.000		1.024	0.306
CRLOCSP	3.868	0.000		0.840	0.401
FIREwalls	2.292	0.022		1.169	0.243

Explanations for improvement of the **t** values of indicators can be found in the fact that in some cases e.g. AuditAutomation (the level of automation in collection of system audit data); the baseline data was scanty and incomplete. Although the improvement may be argued to be a false impact, it is worthwhile to note that at least the model was able to capture and measure any anomalies and represent the true position when complete data was entered. In Table 2b, the CRLOCSP (whether checking CRLs uses the online certificate status protocol) declined because although the baseline established that OCSP is implemented in the PKI, the post study detected that it is OCSP without stapling. The study therefore provided a recommendation for the managers to consider implementing stapling for a more efficient PKI.

B. Composite Reliability

After running the PLS algorithm, Figure 8a shows the composite reliability of the data collected during the baseline survey while 8b shows that of the post study data. Notice that it is easy to notice the improvement in the data's reliability indicating more consistency in the positive responses of the respondents regarding the state of implementation of the various security attributes. In Figure 8b, all the attributes have attained the target value 0.7 and above hence we can conclude that the PKI is in a healthy state.

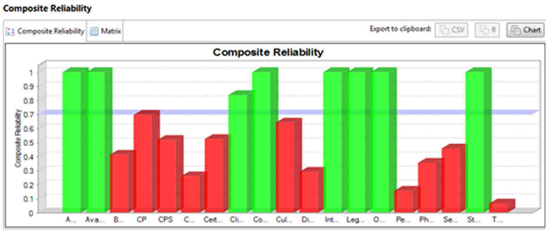


Fig. 8a. Composite reliability pre-study

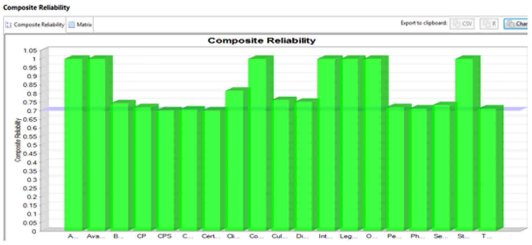


Fig. 8b. Composite reliability post study

C. R^2 Value

The R square (R^2) value shows how closely the data fits the regression line. In PLS, it is also called the coefficient of multiple regressions. We can say a model fits the data well if the differences between the observations and predicted values are small and unbiased. R^2 therefore indicates the percentage of the target variable variance explained by the linear model.

$$R^2 = \text{Explained Variation} / \text{Total Variation(4)}$$

The R^2 value of the OPTIMAL_DECISION_FIT post study (30.4%) is higher than that of the baseline study (24.6%) as shown in Figure 9a and 9b respectively. This indicates some improvement in the total security of the PKI solution since the exogenous variables have increased their total effects on the optimal decisions.

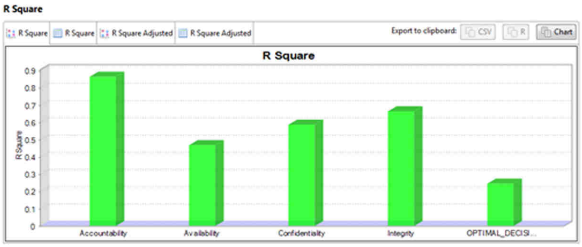


Fig. 9a. R^2 of OPTIMAL_DECISION_FIT baseline

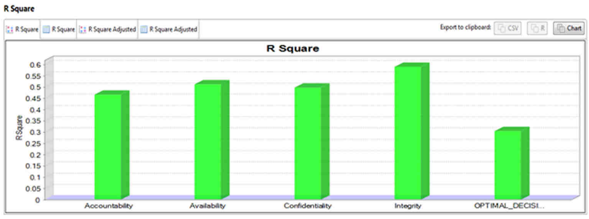


Fig. 9b. R^2 of OPTIMAL_DECISION_FIT post study

4. Conclusions

PLS-SEM is a flexible method for modeling variables, their relationships and performing predictions. When used in assessing and optimising PKI security, it can be used to capture all relevant latent variables together with their indicators to come up with a structural model which can be used to optimise rational decision making. Ideally, the analysis of variance leads the assessor to answer important questions that help to enhance variables that seem to fall below expected values.

PLS-SEM is a flexible method for modeling variables, their relationships and performing predictions. When used in assessing and optimising PKI security, it can be used to capture all relevant latent variables together with their indicators to come up with a structural model which can be used to optimise rational decision making. Ideally, the analysis of variance leads the assessor to answer important questions that help to enhance variables that seem to fall below expected values.

5. Acknowledgements

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