E-Voting: Technology Requirements Mapping

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Abstract **– Technology is the most important component in the implementation of e-voting, although technology is not the only one that contributes to the successful implementation of e-voting. However, in several countries that have successfully implemented e-voting such as India, Brazil, the Philippines and Estonia, technology plays an important role in the success of these countries in its implementation. Likewise in countries that are not successful, such as America, Brazil, the Netherlands, England and others, technology has contributed to the failure of the implementation. In this study, a mapping of the requirements and details of technology for the implementation of e-voting was made. As a result, the technology required for preparation / pre-registration, registration, voting and counting activities is divided into two models of e-voting implementation, namely kiosk (machines stored in the public room / polling station) and remote voting. These technologies must meet the aspects of security and public perception, which is: easy to use by voters and committees, as well as transparency. The contribution of this research is a map of the requirements for e-voting technology to increase the number of voters and positive perceptions / public trust in e-voting technology and the development of e-voting technology.**

Keywords **– e-voting, technology, general election.**

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1. Introduction

Technology has recently been included in the national development roadmap for most countries in the world [1], because they realize that technological progress and innovation will enter all sectors and be very beneficial for the country. Since technology as a tool is very effective in all respects, especially costs and resources, e-voting has been developed through implementation and research in the last 30 years [2]. The belief that technology is the only one that will replace conventional elections has begun to emerge [3]. It has been noted that many countries have conducted general elections using e-voting either partially or on a large scale. Although many countries failed and did not continue, many others were successful and sustainable. The main factors affecting the successful implementation of large-scale e-voting are human resources, technological resources, public trust and legal readiness.

There are four countries that were successful and sustainable in implementing e-voting when holding general elections, namely India, Brazil, the Philippines and Estonia [4], [5], [6]. The four countries, of course, use different technologies, namely machines stored in polling stations (kiosk) and software installed on voters' computers or cellphones. Three countries use machines, namely India, Philippines and Brazil [7], [8], while Estonia uses software operated on voters' gadgets [9], [10].

In the course of time, the technology used by the successful countries mentioned above has certainly changed a lot. In India, for example, there was a significant change in the last general election, in which the technology used, which previously did not issue proof papers to vote, starting from the 2014 general election, added another additional device, namely a printer for the Voter Verifiable Paper Audit Trail (VVPAT) which is integrated with an automatic ballot box. The machine automatically takes out the paper and puts it in the ballot box after the voter has made an election. This change is definitely also carried out by other countries due to the development of the technology, and to give people to trust in the e-

voting technology. Thus, in general, the factors that underlie technology design and system design are business processes and technological advances. However, in this e-voting technology, there are other factors that affect it, namely: the society and the law.

In this study, we present a mapping of technology requirements for the implementation of e-voting so that it can contribute to increasing the number of voters and positive perceptions / public trust in e-voting technology, developing e-voting technology and complementary research on the factors that influence success in bigger scale of implementation, like a general election in a country.

2. Research Methodology

In this study, we used the literature review method by taking the latest paper data and referring to the literature review method developed by Webster [11]. The literature is taken from online databases including Google Scholar, IEEEXplore, Science Direct, Proquest, Scopus and others. Some of the search keys used include:

a. "Technology"
b. "Technology mapping"
c. "e-voting technology"
d. "e-voting framework"

Furthermore, the collected literature is grouped based on the classification of writing including:

a. Papers containing reviews of technology in general election.
b. Papers containing reviews of e-voting in general election.
c. Papers containing reviews of the implementation of e-voting in a country.
d. Papers containing reviews of e-voting technology; and
e. Papers containing reviews of the e-voting framework.

After dividing the papers in groups, followed by reviewing each paper group, a matrix table containing important points is made, as well as a technology request mapping, and finally we draw a conclusion. These stages can be seen clearly in Figure 1., the research methodology.

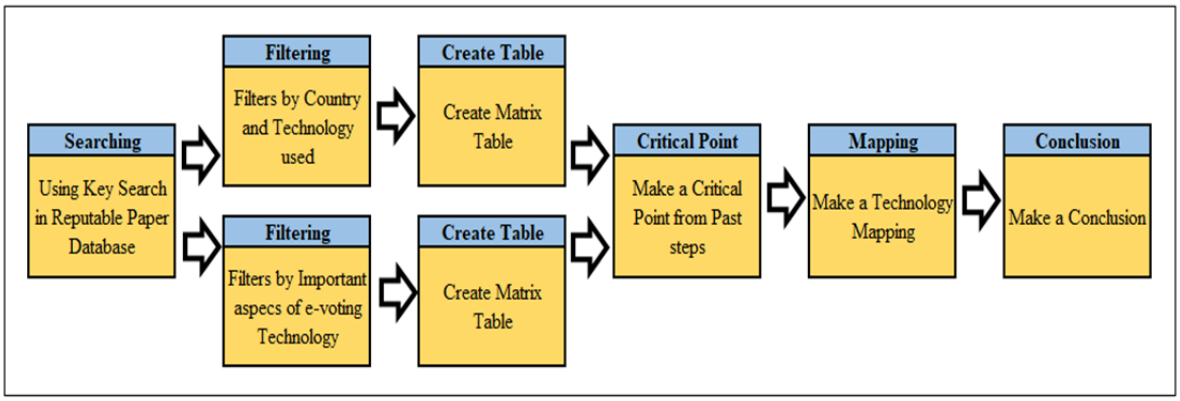

Figure 1. Research methodology

3. Literature Review

General election is an activity to elect state leaders and people's representatives for parliament which is usually carried out by countries with democratic climates [12]. The increasing use of information technology promises a revolution in both the provision of government services and the spirit of democracy [13], [14]. Since Information Technology (IT) has been applied to voting systems, understanding of the role of electronic voting systems (e-voting) and their influence on the political environment has grown dramatically. Voting technology and ballot paper design in e-voting systems can influence election results [15].

E-voting is a democratic tool that enables the involvement of individual citizens in political decision-making through electronic participation [14]. It is a voting system in which election data is recorded, stored and processed mainly as digital information [16]. Many countries are developing and trying to switch to e-voting in their democratic activities [12] and it has become a very interesting topic [4]. This is because there are many advantages generated by using e-voting rather than using conventional elections [3], [17], [18]. The advantages of e-voting over the conventional system / ballot according to Kumar [3] include:

a. Eliminating the possibility of invalid and doubtful votes, which in many cases is the root cause of controversy in elections.
b. Making the counting process much faster and more accurate than conventional systems.
c. Reducing the amount of paper used to be environmentally friendly.

d. Reducing printing, distribution and committee costs.

Meanwhile, according to Riera [19], the advantages of e-voting include:

a. Fast and accurate vote counting
b. Save on the printing and distribution of ballots
c. Providing access to persons with disabilities
d. Providing access for people who have limitations
e. Ballot papers can be made into various language versions
f. Providing access to more information regarding vote options
g. Can be used to control parties who are not entitled to vote

Some countries that carry out e-voting with their implementation and status [4], [5], [6], [18], can be described in table 1 below:

Table 1. E-voting implementation and status

No.	Status	Country
1	Countries that have implemented e-voting completely	Estonia, Norway, Switzerland, India, Brazil, and Philippines
2.	Countries that have implemented e-voting partially	Argentina, United States, Belgium, Canada, Japan. Mexico, France and Peru
3	Countries that cancelled the implementation after conducting try outs of e-voting	Australia, Costa Rica, Finland, Guatemala, United Kingdom, Ireland, Italia, Kazakhstan, and Norway
4	Countries that did not continues the implementation of e-voting	Netherland, Germany and Paraguay
5	Countries that are in the process of testing e-voting	Bangladesh, Bhutan, Ecuador, Mongolia, Nepal and Indonesia

Apart from the fact that there are many countries that have problems in implementing e-voting, technology is the only way that will replace conventional elections [20]. And future-oriented countries will choose e-voting to replace conventional voting [21], because e-voting will immediately reduce the shortcomings that exist in the process of conventional general elections [22].

3.1. E-voting Technology in Countries that Carry out E-voting

India is a democratic country that uses e-voting in its general elections, with a population of more than one billion. In 2014 in the last general election, there were 814 million voters spread across 930 polling stations. E-voting in India began in 1989 in several states, and starting in 2003, e voting began to be used throughout the country. They use an e-voting machine called the Electronic Voting Machine (EVM). Initially, the EVM consisted of two main engines, namely a control unit and a voting board. This machine is battery powered, there is no outgoing data connection such as Wi-Fi / internet connection or USB [23]. In the 2014 general election, the main engine of the EVM became three, namely the control unit, voting board and the Voter Verifiable Paper Audit Trail printer integrated with the ballot box. The functions of the 3 machines are [7]:

a. The control unit has a function to process and store ballot data
b. The voting board has a function to elect candidates by voters
c. The Voter Verifiable Paper Audit Trail (VVPAT) printer has a function to print ballot papers, used for the audit process when there is a lawsuit in automatic calculation.

Similar to India, Brazil started implementing e-voting in 2006 using a machine similar to India's, namely the Control Unit which is integrated with the keyboard and the Voter Verifiable Paper Audit Trail (VVPAT) engine [8].

The United States started e-voting in the 2004 presidential election, and it only takes place in the ten percent of the states. And with their 100,000 citizens abroad, they use DRE machines (Direct-Recording Electronic voting systems) equipped with a Voter Verifiable Paper Audit Trail (VVPAT) [17]. For expatriates, they use a remote voting machine called the Secure Electronic Registration and Voting Experiment (SERVE). Meanwhile, Norway and Estonia use the same e-voting method, namely remote voting. The machines used are voter gadgets such as computers, laptops and cellphones, and it use SMS for verification. Estonia first used it in 2005, while Norway used it in 2011 [10], [24].

The following table 2, is a list of countries along with the e-voting technology they use [23], [25].

Table 2. E-Voting technology

Country	E-voting machine	E-voting Type	Election Type	Machine Problem
India	Electronic Voting Machine (EVM)	Kiosk	State	None
The Philippines	PCOS	kiosk	State	None
Brazil	GX-1 Integrated Processor	Kiosk	State	None
Belgium	DEVS	Kiosk	Local / Partial	Power and Computer Failure
Australia	PC's	Remote Voting	Partial / Military in abroad	None
United Kingdom	Direct Recording Equipment (DRE)	Kiosk and Remote Voting	Local / Partial	Remote Voting Problem
Estonia	PC's / Gadget	Remote Voting	State	None
Norway	PC's / Gadget	Remote Voting	State	None
Indonesia	Direct Recording Equipment (DRE) + VVPAT	Kiosk	Local / Partial	None
Italy	NEDAP	Kiosk	Local/Partial	None
Netherland	NEDAP ES3B	Kiosk	Local / partial	Security Problem
Spain	IrishStyle Electronic Voting System	Remote Voting	Local / Partial	None
United States	Direct Recording Equipment (DRE) + VVPAT + SERVE	Kiosk and Remote Voting	Local / Partial	None

3.2. Previous Studies

There are several studies on the use of e-voting technology which generally suggest that e-voting technology is not only a tool for counting votes so that it is faster and cheaper in its implementation, but there are many factors that must be considered, such as ease of use by operators and voters, confidentiality and its accuracy and safety [3], [10], [26], [27]. According to Avgerou and Alzarrah, [28], [29], there are many aspects that need to be considered when designing e-voting technology including authentication, uniqueness, accuracy, integrity, verifiability, auditability, reliability, confidentiality, flexibility, and transparency.

According to Inuwa [25], the most important thing in e-voting technology is security and encryption which is divided into 6 phases of activity, namely Registration, Authentication, Voting and saving the votes, Managing the votes, Counting the votes, and Auditing. In a research conducted by Chiang in Taiwan in 2019, e-voting technology must meet the requirements, namely convenience for users and security [15]. Whereas in the research conducted by Choi, perceived usefulness, perceived ease of use, accuracy, transparency and confidentiality are the fields of e-voting technology that can directly increase public trust [19], [30], [31], [32], [33].

In the research conducted by Cetinkaya [34], and Cranor [35], e-voting technology must fulfill the following criteria:

a. Privacy. Voters can only vote for themselves; other people cannot have access to other people's choices and will be guarded for a long time.
b. Eligibility. Only voters who meet the requirements can vote.
c. Uniqueness. Voters can vote and will be counted only once.
d. Uncoercibility. No one can impose a choice in any way
e. Receipt Freeness. Voters cannot get a sign that they have selected certain options
f. Fairness. There is no partial calculation, all candidates are given a fair decision
g. Transparency. All voting processes must be transparent, the results must be published
h. Accuracy. All election results must be counted and cannot be deleted, canceled or duplicated
i. Robustness. Nothing can influence the process and the results of the election.

In the following Table 3., we summarize the aspects of the above studies into a table of critical aspects for the implementation of e-voting by adopting structure by Jane Webster and Richard T. Watson [11].

Table 3. Critical aspects for e-voting implementation

Aspect	Security				Public	
Authors	Privacy / Confidentiality	Authentication	Availability	Integrity	Easy to use	Transparency
Kumar	√	√	√	√	√	
Mpekoa	√	√	√	√	√	
Adeshina	√	√	√	√	√	
Shuaibu	√	√	√	√	√	
Hapsara	√	√	√	√	√	√
Avgerou	√	√	√	√	√	√
Aljarrah	√	√	√	√	√	√
Inuwa	√	√	√	√		
Choi	√				√	√
Chiang	√	√	√	√	√	
Cetinkaya	√	√	√	√		√
Fuzioka	√	√	√	√		√
Cranor	√	√	√	√		√
Gilbert	√				√	√
Litle	√					√

4. Discussion And Findings

From the results of the literature review above, the explanation of the technology used by countries that have implemented e-voting, and from the previous studies, we can generally draw a map of the technology requirements for successful e-voting implementation, including:

a. The technology used is in the form of kiosk machines stored at polling stations and in the form of remote voting.
b. The technology used must meet the security aspects.
c. The technology used must be easy to use both by the election committee and voters and be transparent in the process.

From the above mapping, it can be described in Figure 2. below:

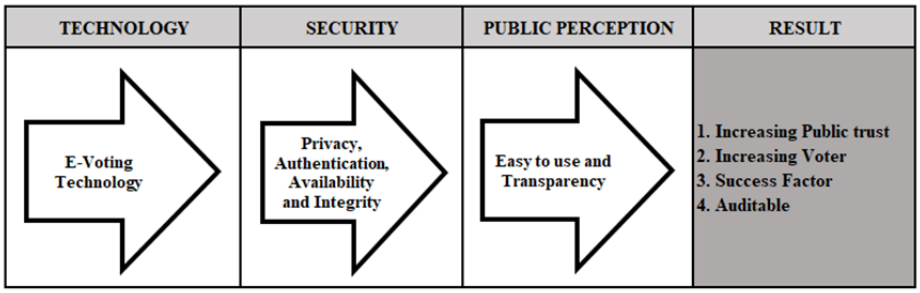

Figure 2. Technology requirement and result

4.1. Partial Requirements Mapping

Of all the countries that implement e-voting, there are generally two models of e-voting technology, namely kiosk-shaped machines stored in polling stations and remote voting / mobile voting that uses voters' gadgets in the election process. Meanwhile, technology mapping that must be used for general election activities is divided into [25]:

a. Preparation / preregistration
b. Registration
c. Voting
d. Counting
e. Auditing

These five phases are activities that need to be supported by technology. The fact is, that the 5th phase is to complete these phases. Auditing activity is optional because it is usually used when there is a lawsuit by the candidates who are not satisfied with the results of the vote count. However, auditing is no less important and the technology for it also needs to be prepared.

4.1.1. Preparation / Pre-registration

The preparation / pre-registration activity phase is an activity that is usually carried out by the government or the general election commission to prepare voters, elect the residents who according to

the law can vote and then are separated / marked to participate in the general election. The technology mapping for the implementation of e-voting is as follows:

a. The technology for storing and processing centralized population data, accompanied by its security support that can be accessed by the public and the general election commission.
b. The technology for storing and processing voter data along with its security support that can be accessed by the public / voters, and the e-voting technology which can be used after this activity

4.1.2. Registration

The registration phase is an activity carried out by voters just before voting. This activity is commonly used for verification and data validation. The activity in this phase is different between the voting method using machine kiosks stored at the polling station, and the remote voting. The technology mapping in the registration activities is as follows:

a. For the voting method using a machine kiosk stored in the polling station, there is a machine that can access the voter database according to the polling station code. The registration can use a personal digital ID card that is scanned by the registration machine. This technology must also be able to detect voters who have voted even in other places and must be safe in the data communication.
b. As for the voting method using the remote voting method, the machine used is of course the voter's gadget. The technology that must be prepared is registration software / application that can access the voters' database. In this registration activity, the function of this technology is to register the voter's telephone number and the International Mobile Equipment Identity (IMEI) / Media Access Control (MAC address) [9], [5], [36] on the voter's gadget to be used in election activities, as well as for the security in communication data.

4.1.3. Voting

The voting phase is the most critical activity during the general election. The technology used must really meet all aspects such as security and user perceptions. The technology mapping required is as follows:

a. For voting methods that use a machine kiosks stored in polling stations, the kiosk machines must meet requirements such as: voters cannot vote more than once, there is no ballot error, the election result cannot be changed, encrypted ballot, easy to use by both normal or disabled voters, issues a receipt as a sign that the results of the choice cannot be detected, and issues a Voter Verifiable Paper Audit Trail (VVPAT).
b. As for the voting methods that use remote voting, the software must meet requirements such as: voters cannot vote more than once, there are no ballot errors, the election results cannot be changed, the ballot is encrypted, easy to use for both normal and disabled voters, and high level of security in data communications.

4.1.4. Counting

The counting phase is an activity that requires technology that is simpler than other activities. This is because the ballots are stored in digital form, so it only remains to be counted and it doesn't take a long time. However, this activity is very critical because it involves the results of the candidates. The required technology mapping is as follows:

a. For the voting method using a machine kiosk stored in the polling station, of course the polling station chairman only needs to press a button and the activity is over. However, if the ballot is sent directly to the election center, of course the data communication must have a high level of security, the ballot should be only counted once, easy to use, the calculation results are easily accessible by the public, and the process is transparent.
b. As for the voting method using remote voting, usually the calculation authority is at the national tabulation center. Of course, data communication must have a high level of security, ballot is only counted once, easy to use, the results of calculations are easily accessible by the public, and the process is transparent.

4.1.5. Auditing

As previously explained, the auditing phase is an activity that is not so important to put in the technology mapping. If the technology of the four previous activities meet the requirements, of course the auditing process will run smoothly and there will be no negative findings on the technology performance [37].

4.2. Technology Requirement Mapping

As the result of partial requirement mapping, the technology requirement mapping can be developed. The mapping is prepared based on activities, consisting of preparation / pre-registration, registration, voting and counting. This technology is divided into two voting methods, namely kiosk and

remote voting. This technology must have a positive public perception, namely easy to use and transparency. Thus, if the technology mapping is implemented as expected, it will generate public trust in this technology and then increase the number of voters [38]. An overview of the technology requirement mapping can be seen in Figure 3. below:

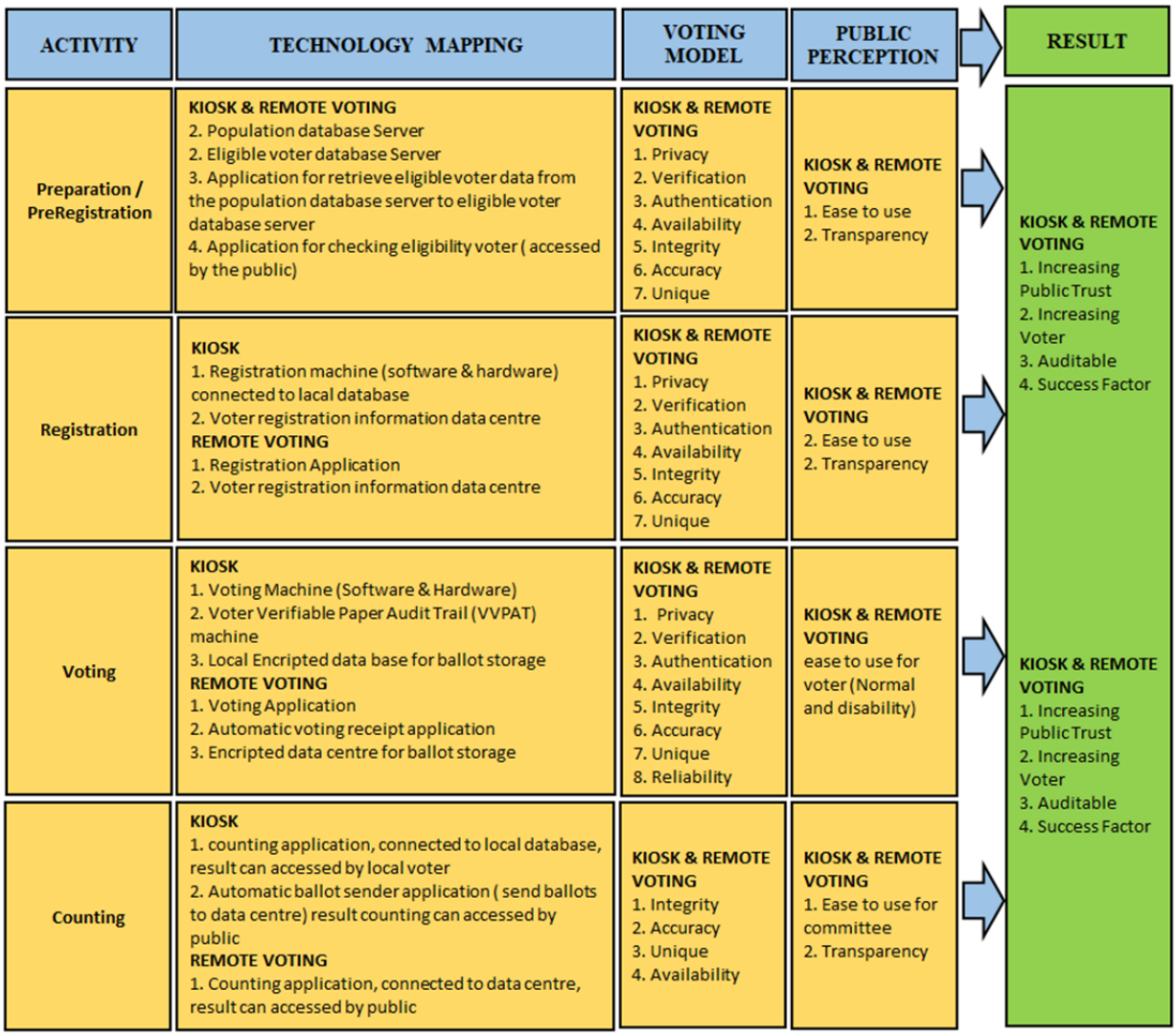

Figure 3. Technology requirements mapping

5. Conclusion

One of the factors that influence the successful implementation of e-voting and increase the number of voters is the public's trust in technology. In this study, a technology requirement mapping is presented where the technology needs of each phase of the general election activity from preparation to the end are mapped. From the results of this study, technology is needed in the preparation / preregistration, the registration, the voting, and the counting activities which are divided into two models of e-voting implementation, namely the kiosk (machines stored in the public room / polling station) and the remote voting. These technologies must meet the aspects of security and public perception, namely easy to use by voters and committees, as well as transparency in the process.

For further research, it is suggested to have deeper mapping in each phase or activity, specific mapping in the security sector, e-voting technology framework, and e-voting implementation framework.

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