Virginia State Board of Elections

Advanced UOCAVA Solutions Research Project

Final Project Report

Summary provided by
Scytl USA
Election Systems and Software

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Table of Contents

1 Overview

The Advanced UOCAVA Solutions Research Project set out to further the body of knowledge and strengthen the concepts and technology of advanced UOCAVA solutions. This project was targeted at specific Virginia technology enhancements but considered application to other similar jurisdictions. Research was conducted in the following 3 categories.

Technology Category 1: Accessibility

The accessibility technology category explored solutions for providing assistive technologies to absentee voters with disability issues. Specifically, this effort looked at accessibilities technologies which can be used in conjunction with the voter's home or personal computer to interact with online absentee voting solutions. The research and proof of concept efforts focused on how to provide assistance in a reliable and private way to voters in stateside military hospitals as well as overseas locations. The technology options considered the following impairments:

- Blindness
- Visual impairment such as low vision or color blindness
- Manual dexterity disabilities
- Cognitive issues
- Hearing disabilities
- Mobility disabilities
- Speech disability
- English learned as a second language
- Dyslexia

Technology Category 2: Secure Electronic Return

The secure electronic return category explored the security and administrative requirements for technology solutions that provide for the secure electronic return of ballots. This covered the use of electronic mail, fax, secure transfer, and other electronic communication channels. This research explored how to provide electronic return such that it meets the following criteria:

- Eligibility. Only authorized voters should be able to vote.
- Privacy. Protects voter privacy, concealing the relation between voter and his/her cast vote, and ensuring that the voter's choices will remain anonymous.
- Integrity. A technology has to protect the vote against manipulation once it is cast and until it is counted.
- Voter verifiability. Voters must have the possibility to check if their ballots have been cast as intended and accurately recorded.
- Voter inclusion. Voters must have the possibility to verify the inclusion of his/her ballot in the final tally.
- Prevention of intermediate results. Prevent the disclosure of intermediate results before the election is closed.
- Ballot box accuracy. Protection against the addition of bogus ballots or the elimination of valid ballots (ballot stuffing).
- Coercion and vote buying resistance. One of the main concerns of remote voting channel is that it facilitates coercion or vote buying. Therefore, it is important to verify if the solution includes countermeasures to mitigate them.
- Channel reliability. Ability to detect delivery delays or denial of service attacks in an appropriate timeframe.

Technology Category 3: Mobile Voting Station

This technology category was to explore the idea of sending mobile voting stations with military deployments. This could be a suitcase-sized voting station which contains all the necessary provisions for a voter to conduct absentee ballot processes while deployed. There is potential for this technology to impact voters on Navy ships and those deployed into combat zones. The research would have explored the potential for this technology, the requirements surrounding its deployment, and its potential impact on the military units which would utilize it.

2 Work Completed

2.1 Accessibility

In the accessibility area, the project was concerned with improving the accessibility options offered to remote voters through electronic ballot delivery solutions. It included

- a thorough **Research Summary** which set out to understand the research that has been done (or is currently being done) with regard to accessibility in voting and/or accessibility of related internet technologies; and establish a basis for applying it to absentee and UOCAVA based scenarios.
- a review of the technological and socio-demographic constraints to consider when looking at using assistive devices to enhance electronic ballot delivery solutions.
- an analysis of the types of assistive devices which show potential for enhancing disabled voters' access to their ballots from remote locations and successfully casting them.
- a **White Paper** which prepared a the final set of principles, drivers, and constraints against which a set of 8 technology options were evaluated. The goal of the analysis was to find and select a technology solution which shows the greatest opportunity to improve accessibility options for disability voters voting under UOCAVA.
- A thorough evaluation of 8 possible accessibility solutions/scenarios based on unique combinations of interaction types, device types, and impairment types against a number of evaluation factors to produce an analysis of the best overall solutions.
- a **Prototype** of some of the advanced technology solutions evaluated. This prototype was based on the highest evaluated solution which was Scenario B: Personal computer / Standard voting / All impairments and piloted a new technology to dynamically produce an audio ballot that did not require voters to have any special software or peripherals.

2.2 Secure Electronic Return

In the secure electronic return area, the project attempted to develop a concise review of the research around the current and proposed secure electronic return options for UOCAVA voting, identifying the different technologies available and the main technological and socio-demographic constraints. This then facilitated a detailed assessment on the use of different secure electronic return options to assist UOCAVA voting.

The work completed includes:

- a **Legislative Discussion Paper** that introduced and compared the available secure electronic return technologies. This paper set out to introduce readers to the basic ballot return options and assess the risk of each one based on certain security principals. This paper further evaluated each return option for its support of accessibility requirements and which impairments each technology addressed. This paper was available along with a demonstration of some of this technology to the Virginia Legislature.
- a **Research Summary** on the current and proposed technology available for secure electronic return as well as a collection of the technological and socio-demographic constraints associated with it. This summary introduced some of the most advanced technology being proposed such as End to End Verification. Finally, the summary presented a set of principles and constraints to use when evaluating the secure electronic return options.
- a **White Paper** which provided a detailed assessment on the use of twelve different secure electronic return options based on combinations of eight return options and six means for voter authentication. The white paper scored all options against the set of evaluation criteria to produce

a ranked list of solutions that included considerations for accessibility, security, cost, complexity, and usability.

2.3 Mobile Voting Station

This mobile voting station area set out to lay the ground work research for suitcase sized voting or ballot delivery systems which could be sent with military deployments. The project began by talking with the Virginia Air National Guard and led to work on a questionnaire which would be filled out by guard members. Due to lack of time and availability of important stakeholders, this area of the project was not completed.

3 Findings and Conclusions

3.1 Accessibility

The accessibility area focused on an evaluation of scenarios based on a combination of devices, interaction methods and impairments which created a matrix of potential accessibility technology scenarios for electronic ballot delivery. The options were derived from combining the different interaction types, devices types, and impairment types listed below:

- **Interaction type:** The interaction type takes into account the different interfaces available to interact with the UOCAVA electronic ballot delivery system.
    - *Standard:* Standard interaction by using COTS electronic ballot delivery systems without any specific enhancement. The system should be compatible with the common assistive technologies.
    - *Visually enhanced:* The ballot delivery system has been visually enhanced to provide a proper voting experience to voters suffering cognitive impairments.
    - *Audio based:* The interface of the ballot delivery system is audio based, such as an Interactive Response System (IVR).
    - *Binary:* The ballot delivery system interface is binary, where the interaction is based on yes/no questions.
- **Device type**: The device type analyzes the different apparatus that could be used by voters to access the electronic ballot delivery system.
    - *Kiosk*: Assistive kiosk to be deployed in polling places/supervised voting locations with all assistive technologies and devices to be used for all kind of voters.
    - *Personal computer*: Voters' personal computer used in a remote voting process. In this case, the voters are required to have the accessibility devices they may need to operate the system.
    - *Mobile device*: Voter's mobile device (smartphone/tablet) with internet access is used in a remote voting process with a native device application.
- **Impairment type**: Voters' impairment type.
    - *Visual*: The visual impairment category includes voters suffering blindness, visual loss or visual dysfunction
    - *Mobility/dexterity*: The mobile/dexterity category includes amputation/loss of limb (upper extremities, lower extremities, both upper & lower extremities), paralysis/spinal cord injury (paraplegic, quadriplegic, other) and severe burns.
    - *Cognitive*: The cognitive impairment category includes behavioral health (PTSD, depression) and TBI (mild, moderate, severe).

  Note: Voters suffering sensory hearing impairments (deafness, partial loss, tinnitus) have been excluded as they should be able to interact with a standard electronic ballot delivery system without problems.

The matrix diagram (table) below illustrates all of the possible combinations by using the identified variables. This is a comprehensive table, where all the combinations that are not possible in a real

environment are marked as N/A (not applicable) and combinations that may not be feasible for implementation in Virginia have been marked as OOS (out of scope).

		Device								
		Kiosk			Personal computer			Mobile device		
	Impairment	Visual	Mobility/ Dexterity	Cognitive	Visual	Mobility/ Dexterity	Cognitive	Visual	Mobility/ Dexterity	Cognitive
Interaction	Standard	A	A	A	B	B	B	N/A	N/A	N/A
	Visually enhanced	N/A	C.1	C.1	N/A	C.2	C.2	N/A	D	D
	Audio based	E.1	OOS	OOS	E.2	OOS	OOS	F	N/A	N/A
	Binary	OOS	G.1	G.1	OOS	G.2	G.2	OOS	H	H

The remaining feasible scenarios are numbered A through H, and were evaluated in detail based on their support for the evaluation factors presented. The following Scenarios were analyzed in detail:

A. Kiosk / Standard voting / All impairments: In this scenario, the kiosk will provide all kind of assistive devices to be used by voters suffering any type of impairments.

B. Personal computer / Standard voting / All impairments: In this scenario, as the system is a remote computer-based system, all the accessibility devices and technologies should be supported.

C. Personal computer (& Kiosk) / Visually enhanced / Cognitive (& Mobility/Dexterity) [1]: In this scenario, the system is visually enhanced for a proper use of voters suffering cognitive impairments.

D. Mobile / Visually enhanced / Cognitive: In this scenario, the electronic delivery system is accessed from a mobile device by voters suffering Mobility, Dexterity or Cognitive impairments.

E. Personal computer (& Kiosk) / Audio based / Visual[2]: In this scenario, a totally audio based ballot delivery platform is used by the visual impaired voters.

F. Mobile / Audio based / Visual: In this scenario, a totally audio based ballot delivery platform is used by the visual impaired voters with their mobile devices.

G. Kiosk & Personal Computer / Binary / Cognitive (& Mobility/Dexterity) [3]: In this scenario, the kiosk and the Personal computer access to the ballot delivery that implements a binary interface.

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[1] When differentiation is required between the on-site scenario (kiosk) and the remote scenario (personal computer), the following sub-scenario will be referenced:

- C.1. Kiosk / Visually enhanced / Cognitive (& Mobility/Dexterity).
- C.2. Personal computer / Visual.

[2] When differentiation is required between the on-site scenario (kiosk) and the remote scenario (personal computer), the following sub-scenario will be referenced:

- E.1. Kiosk / Audio based / Visual.
- E.2. Personal computer (& Kiosk) / Audio based / Visual.

[3] When differentiation is required between the on-site scenario (kiosk) and the remote scenario (personal computer), the following sub-scenario will be referenced:

- G.1. Kiosk / Binary / Cognitive (& Mobility/Dexterity).

H. Mobile / Binary / Cognitive: In this scenario, the mobile ballot delivery platform is a binary interface.

Each of these scenarios was discussed in detail in the White Paper, with emphasis on the pros and cons of each. Each scenario is then scored against the evaluation factors listed below. Scores were assigned from 1 to 5, with 1 being the lowest, 5 the highest, and 3 the minimum acceptable.

Category	#	Factor	Definition
Accessibility	1	Full Ballot usability	Provides voters with the capability to interact with the entire ballot (all contests, candidates, and referendum). This includes the ability for the voter to receive, mark, and return the full ballot and the ability to engage and operate all possible voting methods (i.e. write-in, straight party, cross over voting, etc.).
	2	Completion of Return Material	Appropriately provides an interaction which allows voters to complete the required return material according to state law with the greatest ease and intuitiveness. This includes the ability to retrieve, complete, and assembled return material with the ballot for the correct return of the ballot.
	3	Time	Voting interaction should facilitate a complete but efficient interaction. Voters should be provided a mechanism to vote that does not require extensive amounts of time which make voting prohibitive.
	4	Familiarity to voter	Provides a familiar interaction to the voter with clear and informative instructions which increase the voter's confidence and familiarity with the system. Where possible, the voting interaction should use mechanisms which are familiar and accessible to the voter of certain impairments or – as much as possible – to traditional voting concepts which may be familiar to voters.
	5	Independence	The voter must be able to vote independently. This factor measures how likely the voter is to receive, mark, and return the ballot without requesting assistance from another person. The voting interaction should be designed to remove barriers which force disabled voters from seeking assistance.
	6	Ease of Use	The voter should be able to operate the system and assistive devices in an easy manner. Use of assistive devices to receive, mark, and return the ballot must be possible by voters with minimal education and technology background. The device interface must be appropriate both for the voter's impairment and the voting process.

- G.2. Personal Computer / Binary / Cognitive (& Mobility/Dexterity).

Category	#	Factor	Definition
	7	Cross impairment support	Voting platforms should be capable of assisting voters of different impairments. This factor measures the ability of a scenario to meet the needs of voters with varying impairments without additional devices, software, or voting channel.
	8	Setup difficulty	Voters should be able to setup the system and the assistive devices without undue difficulty. If voters need assistance, the setup process should be easy to setup for someone with minimal technology knowledge or education. The setup process should be such that it is difficult or impossible to introduce error or unreliability into the performance of the assistive device such that the voter's interaction is harmed.
Security	9	Security	General security evaluation (including voter privacy, voter eligibility, ballot integrity, verifiability and auditability, among other factors). The assistive voting platform must continue to maintain the security and integrity of the ballot process for all voters.
Implementation cost	10	Implementation Cost	The cost for the Election Authorities related to the implementation of the accessible voting scenario (infrastructure and service cost).
Voters' cost	11	Voters' cost	Cost for the voters (accessible devices, software, etc.) related to the accessible voting scenario.

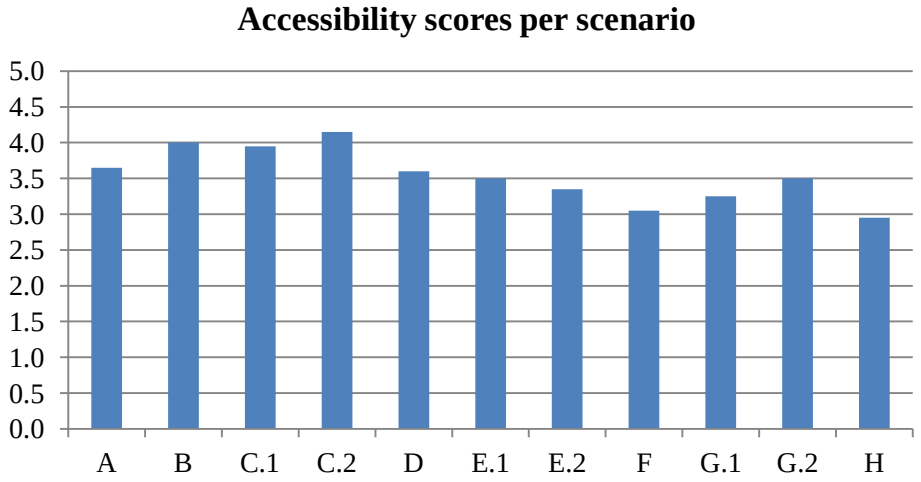
3.1.1 Results Analysis per category

3.1.1.1 Accessibility

Regarding the accessibility category, the remote ballot delivery scenarios using personal computers represent the most convenient options in general. The first and the second scenarios represent the most adequate voting options for voters suffering different impairments. Among the top ranked scenarios, on-site scenarios (kiosk based) are also included, because they use the same voting platform as in the first and second scenario.

The following are the top ranked scenarios for accessibility:

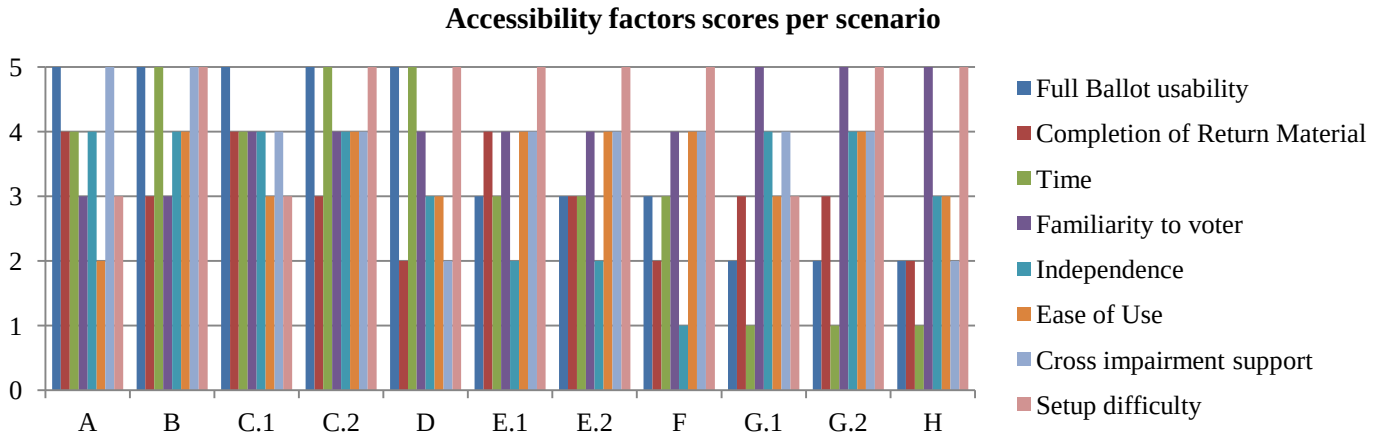
- ✓ Scenario C.2: Personal computer / Visually enhanced / Cognitive (& Mobility/Dexterity).
- ✓ Scenario B: Personal computer / Standard voting / All impairments.
- ✓ Scenario C.1: Kiosk / Visually enhanced / Cognitive (& Mobility/Dexterity).
- ✓ Scenario A: Kiosk / Standard voting / All impairments.
- ✓ Scenario D: Mobile / Visually enhanced / Cognitive.
- ✓ Scenario G.2: Personal Computer / Binary / Cognitive (& Mobility/Dexterity).
- ✓ Scenario E.2: Personal Computer / Audio based / Visual.



In regard to each accessibility factor:

- *Full ballot usability:* The scenarios A, B, C and D support all possible voting methods (i.e. write-in, straight party, cross over voting, etc.). On the other hand, the scenarios E, F, G and H do not support the write-in voting method.
- *Completion of return material:* The kiosk-based scenarios A, C.1 and E.1 provide the best interaction that allows voters to complete the required return material. As they are onsite scenarios, they offer the possibility to provide assistance to print and assemble everything (when required).
- *Time:* In regard to the required time to complete the voting process, the standard voting interface (scenarios A and B) and the visually enhanced interface (scenarios C and D) are the most convenient scenarios. The required time by the audio based voting interface (scenarios E and F) could be acceptable, but the binary voting interface (scenarios G and H) would require a substantial amount of time to complete the voting process.
- *Familiarity to voter:* The binary voting interface (scenarios G and H) provides the most familiar interaction to the voter, which increase the voter's confidence and familiarity with the system. The audio based voting interface (scenarios C and D) and the visually enhanced interface (scenarios E and F) also provide a reasonably familiar interface to voters.
- *Independence:* The scenarios A, B, C and G are the scenarios where the voter more likely will be able to vote independently. However, it should be noted that in some cases, assistance from another person may be required, as this paper assesses the accessibility of an electronic ballot delivery system, but the postal return requires printing and assembling the ballot and the return material.
- *Ease of use:* The remote voting options (scenarios B, C.2 and G.2) and the audio based options (scenarios E.1, E.2 and F) represent the most convenient options for voters in order to operate the system in an easy manner, as they, respectively, allow using the voters' computer (a known environment) or a telephone-like interaction.
- *Cross impairment support:* In general, all scenarios, except for scenarios D and H, are capable of assisting voters of different impairments. The scenarios D and H (Mobile / Visually enhanced / Cognitive, and Mobile / Binary / Cognitive, respectively) cannot be successfully used by visual impaired voters, as there are not mature enough assistive devices for mobile devices.

- *Setup difficulty:* The remote voting options, either computer-based (scenarios B, C.2, E.2 and G.2) or mobile based(scenarios D, F and H), represent the most convenient option for voters, as no specific setup is required, as they are used to the assistive devices they use (if any) and know how to operate them.

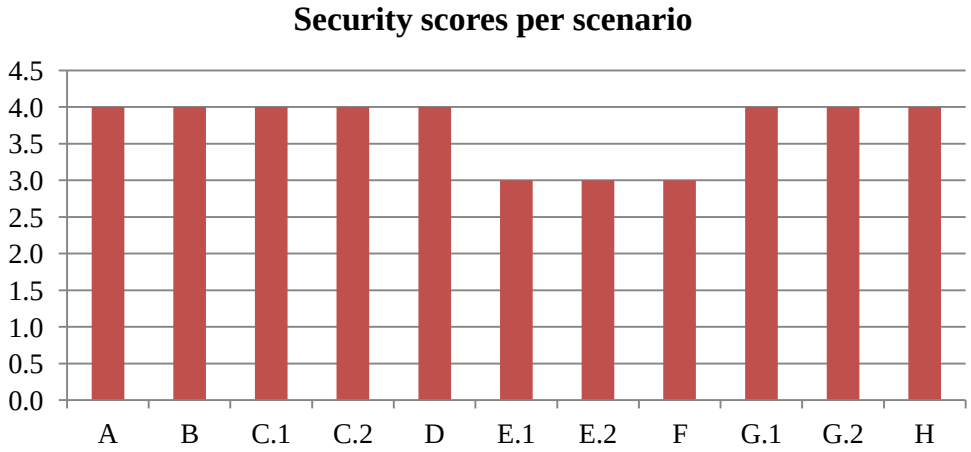


3.1.1.2 Security

Regarding the security category, it is important to note that the White Paper did not fully assess the security of the systems, but established the desired security level. However, in some scenarios, the voting system has to interact with a third party system (IVR) and, therefore, the security level scores are lower due to the third party integration. In that case, the IVR system must be protected also from external attacks and IVR administrators must behave honestly.

The following are the top ranked scenarios for security:

- ✓ Scenario A: Kiosk / Standard voting / All impairments.
- ✓ Scenario B: Personal computer / Standard voting / All impairments.
- ✓ Scenario C.1: Kiosk / Visually enhanced / Cognitive (& Mobility/Dexterity).
- ✓ Scenario C.2: Personal computer / Visually enhanced / Cognitive (& Mobility/Dexterity).
- ✓ Scenario D: Mobile / Visually enhanced / Cognitive.
- ✓ Scenario G.1: Kiosk / Binary / Cognitive (& Mobility/Dexterity).
- ✓ Scenario G.2: Personal Computer / Binary / Cognitive (& Mobility/Dexterity).
- ✓ Scenario H: Mobile / Binary / Cognitive.

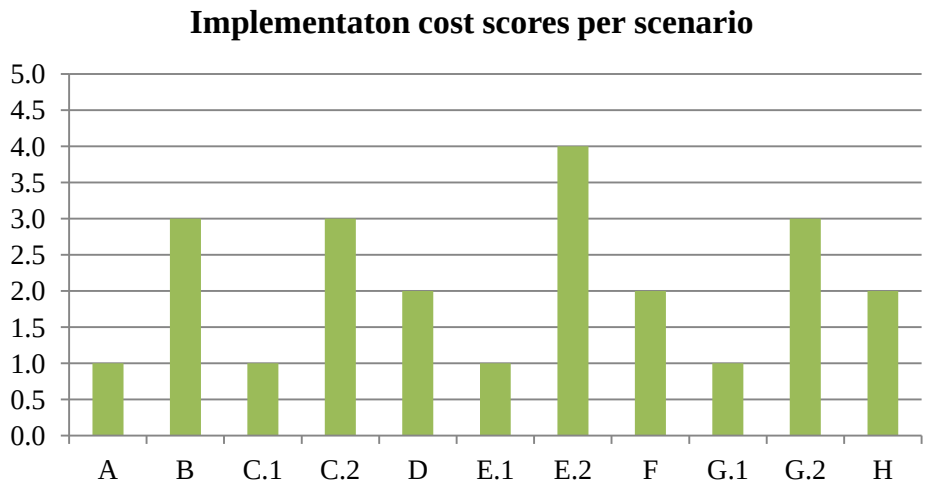


3.1.1.3 Implementation cost

Regarding the implementation cost category, the scenarios that require a simple central infrastructure without on-site deployment (remote scenarios; E.2, B, C.2 and G.2) represent the most economic options for the Election Authorities. The mobile scenarios (D, F and H), although they are also remote, are not included in the top ranked ones because it is necessary to develop a system that is supported on a wide range of device/platform combinations.

The following are the top ranked scenarios for implementation cost:

- ✓ Scenario E.2: Personal Computer / Audio based / Visual.
- ✓ Scenario B: Personal computer / Standard voting / All impairments.
- ✓ Scenario C.2: Personal computer / Visually enhanced / Cognitive (& Mobility/Dexterity).
- ✓ Scenario G.2: Personal Computer / Binary / Cognitive (& Mobility/Dexterity).



3.1.1.4 Voters' cost

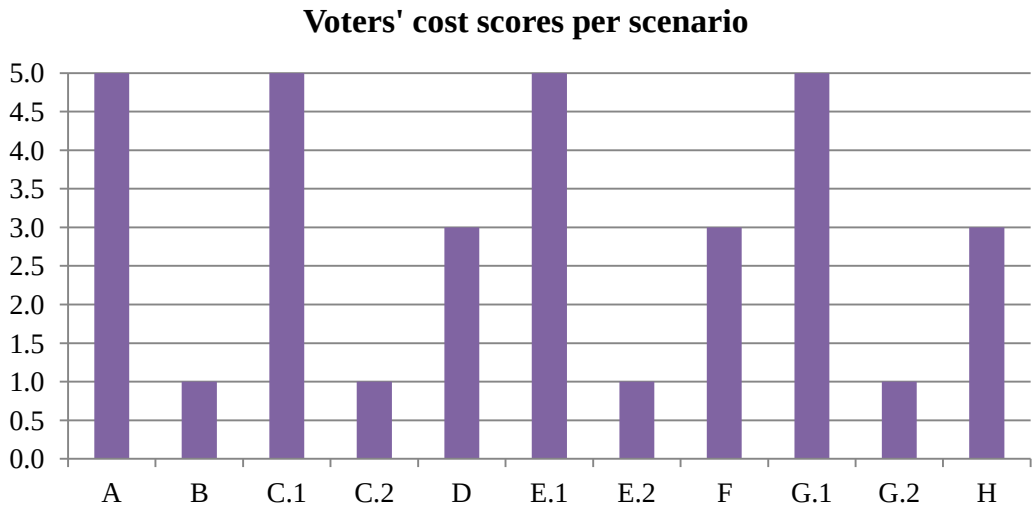
Regarding the voters' cost category, the onsite scenarios (A, C.1, E.1 and G.1) represent the most convenient option for voters, as Election Authorities have to provide all the necessary assistive peripherals and software to operate the system. The mobile voting scenarios (D, F and H) obtain a score of 3 (the minimum acceptable) because it has been assumed that there are not currently specific assistive technologies for the mobile platform and the mobile application all the assistive features (therefore, voters do not have to provide these technologies).

The following are the top ranked scenarios for voters' cost:

- ✓ Scenario A: Kiosk / Standard voting / All impairments.
- ✓ Scenario C.1: Kiosk / Visually enhanced / Cognitive (& Mobility/Dexterity).
- ✓ Scenario E.1: Kiosk / Audio based / Visual.
- ✓ Scenario G.1: Kiosk / Binary / Cognitive (& Mobility/Dexterity).

The following are the next top ranked scenarios that obtain a score of 3:

- ✓ Scenario D: Mobile / Visually enhanced / Cognitive.
- ✓ Scenario F: Mobile / Audio based / Visual.
- ✓ Scenario H: Mobile / Binary / Cognitive.



3.1.2 Global results analysis

The following table sorts each scenario according to the final score obtained.

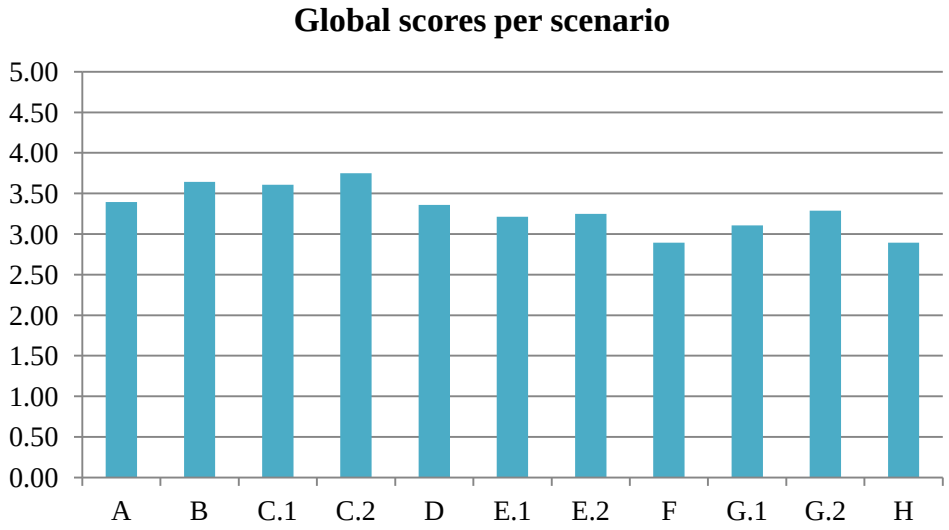
Ranking	Scenario		Score
1st	C.2	Personal computer / Visually enhanced / Cognitive (& Mobility/Dexterity)	3.75
2nd	B	Personal computer / Standard voting / All impairments	3.64
3rd	C.1	Kiosk / Visually enhanced / Cognitive (& Mobility/Dexterity)	3.61
4th	A	Kiosk / Standard voting / All impairments	3.39
5th	D	Mobile / Visually enhanced / Cognitive	3.36
6th	G.2	Personal Computer / Binary / Cognitive (& Mobility/Dexterity)	3.29
7th	E.2	Personal Computer / Audio based / Visual	3.25
8th	E.1	Kiosk / Audio based / Visual	3.21
9th	G.1	Kiosk / Binary / Cognitive (& Mobility/Dexterity)	3.11
10th	F	Mobile / Audio based / Visual	2.89
11th	H	Mobile / Binary / Cognitive	2.89

The Scenario C.2 (Personal computer / Visually enhanced / Cognitive (& Mobility/Dexterity)) is the scenario that obtains the best score against the full set of identified evaluation factors, as it scores well against the accessibility and security factors. The implementation cost is reasonably acceptable and the main limitation is the voters' cost factor (as in any remote scenario, it is required to the voter to provide the required infrastructure on the voter's side). The on-site (kiosk) version of this scenario (C.1) is the 3rd scenario in the ranking and the mobile version of this scenario (D) is the 5th scenario, as they represent the most convenient option (kiosk/ mobile) for voters suffering cognitive and mobility/dexterity impairments.

The standard voting interface in the remote scenario (B) and the onsite scenario (A) are the 2nd and 4th, respectively, scenarios in the ranking, because they obtain reasonably good scores in the accessibility and security factors and, the first one, also in the implementation cost factor.

The Scenarios G.2 and E.2, the 6th and 7th, are the remote computer-based scenarios of the binary interface and the audio based interface, respectively. As a result of the analysis, the remote computer-

based options represent usually the most convenient option for Election Authorities, because the cost is considerably low compared to other options (onsite scenarios or remote mobile scenarios). The Scenarios E.1 and G.1, the 8th and 9th, and F and H, the 10th and 11th, in that order, are the onsite scenarios and mobile scenarios of the audio based interface and binary interface (which score lower than the remote computer-based scenario as per the rationale described before).



3.2 Secure Electronic Return

This area focused on the research around the current and proposed secure electronic return options for UOCAVA voting, identifying the different technologies available to address the main technological and socio-demographic constraints. This effort included a detailed assessment on the use of secure electronic return to assist UOCAVA voting, which was then used to assess the most viable secure electronic return options to meet Virginia's needs.

The research presented eight basic secure electronic return options and six means for voter authentication. The options were then assessed for their basic applicability to the Virginia context. The combination of the eight voting options with the six authentication methods created a matrix of potential secure electronic return scenarios. Combinations that are not possible or that are not feasible for implementation in Virginia were eliminated leaving 12 feasible scenarios are numbered 1 through 12. These were evaluated in detail based on their support for the defined principles and constraints. This detailed analysis includes also a discussion of the pros, cons, and risks of each Scenario. The following Scenarios were analyzed in detail:

1. On-site, computer-based voting with authentication based on physical ID.
2. On-site telephone-based voting with authentication based on physical ID.
3. On-site computer-based voting through the internet with password-based authentication.
4. On-site telephone voting with password-based authentication.
5. Remote telephone voting with password based authentication.
6. Remote fax voting.
7. Remote computer voting through the internet with password-based authentication.
8. Remote e-mail voting through the Internet.
9. Remote SFTP voting through the Internet with password-based authentication.
10. Remote mobile phone voting through the internet with password-based authentication.

11. Remote computer-based voting through the internet with third party authentication.
12. Remote mobile phone-based voting through the internet with third party authentication.

These principles and constraints were used to score each secure electronic return option.

Principle/ Constraint	Definition
Accessibility	The voting process is equally accessible to all eligible voters, including voters with disabilities. In any case, the voting process shall be performed by the voter without requiring any assistance for making their selections.
One vote per voter	Only one vote per voter is counted for obtaining the election results. This shall be fulfilled even in the case the voter is allowed to cast multiple votes.
Voter authentication	The election process shall ensure before allowing a voter to cast a vote, that the identity of the voter is the same as claimed, that the voter is eligible to vote, and that she has not exceeded the allowed voting intents.
Administrative Authentication	Election authorities, system administrators, or other individuals with administrative access to voting systems, are uniquely identified and authenticated by the voting system before they are allowed to perform any actions, as authorized, on the system components.
Only count votes from valid voters	The election process shall ensure that the votes used in the counting process are the ones cast by valid eligible voters.
Individual verifiability	The voting process shall provide means to the voters for verifying that their votes have been properly deposited inside the ballot box (vote recorded as cast).
Privileged Verifiability	The voting system provides evidence that allows the election auditors to independently check the outcome of the election. The voting system must also provide evidence to auditors that the system functioned in the way it was supposed to. The evidence could include system event logs, public voting system reports, voter-verified records, and, in some cases, mathematical proofs. In addition, the voting system and its supporting election procedures must provide assurances that the evidence provided by the system is trustworthy.
Public Verifiability	The voting system provides evidence that allows the general public to independently check the outcome of the election. Public verifiability is a property offered by emerging cryptographic voting protocols. In this case, sufficient evidence is made publically available by the voting system so any individual can verify the outcome of the election. Generally this

Principle/ Constraint	Definition
	requires some assumptions about the behavior of other entities (e.g., other voters, poll workers, administrators, etc.).
Voter privacy	The voting process shall prevent at any stage of the election the correlation between voters and the contents of the ballots cast by such voters.
Ballot Integrity	The election outcome properly reflects the choices of participating voters. The voting system must: (a) record votes consistent with voters' selections, (b) accurately store the collection of cast ballots, (c) protect the cast ballots from unauthorized modification, deletion or insertion, and (d) accurately count the votes.
Results validation	The voting process shall provide means for verifying if the results clearly represent the intention of the voters that participated in the voting process. This verification shall also ensure that only votes from valid voters have been used in the counting process to prevent fraudulent practices that could compromise the election accuracy.
Service availability	The election process and any of its critical components or entities (e.g., voters' roll information, cast votes, voting channel…) shall be available during the whole election period to voters, election managers, observers or any other actor involved in the process.
Cost	The cost related to the introduction of the secure electronic return option (infrastructure and service cost).
Complexity	Difficulty level of the process for implementing the secure electronic return scenario.
Convenience for voters	Simplicity level of the overall voting process (the process voters must follow to cast their ballots).
Socio-Demographic Constraints	This constraint comprises the characteristics of the voting population, which may include: • Geographical dissemination • Citizenship perception on introducing new voting technologies • The resistance of any group against such introduction • Computers per citizen, mobiles per citizen, PSTN telephones per citizen, smart-phones in the area, Internet usage. Although the assessment of the human elements may be non-quantifiable, they have to be taken into account when evaluating

Principle/ Constraint	Definition
	the feasibility of the different secure electronic return scenarios.

After evaluating principles/constraints presented above for each secure electronic return scenario, an assessment summary of the different secure electronic return scenarios was obtained by evaluating them against the following criteria groups:

- complexity;
- usability and convenience;
- accessibility;
- security; and
- cost.

The following table summarizes the relation introduced before:

Summarized factor	Principle/ Constraint
Accessibility	Accessibility
Security	One vote per voter
	Voter authentication
	Administrative Authentication
	Only count votes from valid voters
	Individual verifiability
	Privileged Verifiability
	Public Verifiability
	Voter privacy
	Ballot Integrity
	Results validation
	Service availability
Cost	Cost
Complexity	Complexity
Usability and convenience	Convenience for voters
	Socio-Demographic Constraints

3.2.1 Methodology

Each scenario was scored against the set of factors defined above. Scores are assigned from 1 to 5, with 1 being the lowest, 5 the highest, and 3 the minimum acceptable.

A weight was assigned to each of the principle constraints. With the assigned weight, a summarized factor has been obtained by grouping the scored principle/constraints.

Summarized factor	Principle/ Constraint	Weight
Accessibility	Accessibility	20
Security	One vote per voter	20
	Voter authentication	20

	Administrative Authentication	10
	Only count votes from valid voters	20
	Individual verifiability	10
	Privileged Verifiability	10
	Public Verifiability	10
	Voter privacy	20
	Ballot Integrity	20
	Results validation	10
	Service availability	10
Cost	Cost	25
Complexity	Complexity	20
Usability and convenience	Convenience for voters	20
	Socio-Demographic Constraints	10

The formulas below have been used to obtain the score of the summarized factor and the score of the scenario.

$$Score_{summarized\_factor} = \frac{\sum(Score_{principle\_constraint} * Weight_{principle\_constraint})}{\sum(Weight_{principle\_constraint})}$$

$$Score_{scenario} = \frac{\sum(Score_{principle\_constraint} * Weight_{principle\_constraint})}{\sum(Weight_{principle\_constraint})}$$

3.2.2 Results

As seen in the table below, which summarizes all of the scores, each scenario has the potential to be acceptable in the Virginia context. The following sections further analyzed the scenarios and the obtained scores.

Principle/ Constraint	S.1	S.2	S.3	S.4	S.5	S.6	S.7	S.8	S.9	S.10	S.11	S.12
Accessibility	5	4	4	4	3	1	4	3	2	2	3	2
One vote per voter	5	5	5	5	5	4	5	4	4	5	5	5
Voter authentication	5	5	4	4	4	2	4	2	4	4	3	3
Administrative Authentication	5	5	5	5	5	2	5	2	3	5	5	5
Only count votes from valid voters	5	5	5	5	5	2	5	2	3	5	4	4
Individual verifiability	5	4	5	4	4	1	5	2	2	5	5	5
Privileged Verifiability	5	4	5	4	4	1	5	2	3	5	5	5
Public Verifiability	5	5	5	5	5	2	5	2	2	5	5	5
Voter privacy	5	4	5	4	3	1	5	1	2	5	5	3

Ballot Integrity	5	5	5	5	4	1	5	1	2	5	5	5
Results validation	5	4	5	4	4	2	5	2	3	5	5	5
Service availability	4	4	4	4	5	4	5	5	5	5	4	4
Cost	1	2	1	2	4	5	3	5	5	2	3	2
Complexity	1	2	2	3	3	5	3	4	4	3	3	3
Convenience for voters	4	4	3	3	3	4	5	5	5	2	3	2
Socio-Demographic Constraints	5	5	5	5	4	3	4	4	4	2	4	2

The following table shows the aggregated score per summarized factor and the final score of each scenario, by applying the formula described above.

Summarized factor	S.1	S.2	S.3	S.4	S.5	S.6	S.7	S.8	S.9	S.10	S.11	S.12
Accessibility	5	4	4	4	3	1	4	3	2	2	3	2
Security	4.9	4.6	4.8	4.5	4.3	2	4.9	2.2	3	4.9	4.6	4.3
Cost	1	2	1	2	4	5	3	5	5	2	3	2
Complexity	1	2	2	3	3	5	3	4	4	3	3	3
Usability and convenience	4.3	4.3	3.7	3.7	3.3	3.7	4.7	4.7	4.7	2	3.3	2
Total	4.18	4.08	4.02	4.00	3.96	2.65	4.45	2.96	3.39	3.88	4.02	3.53
Ranking	2nd	3rd	4th	6th	7th	12th	1st	11th	10th	8th	5th	9th

3.2.3 Results analysis per summarized factor

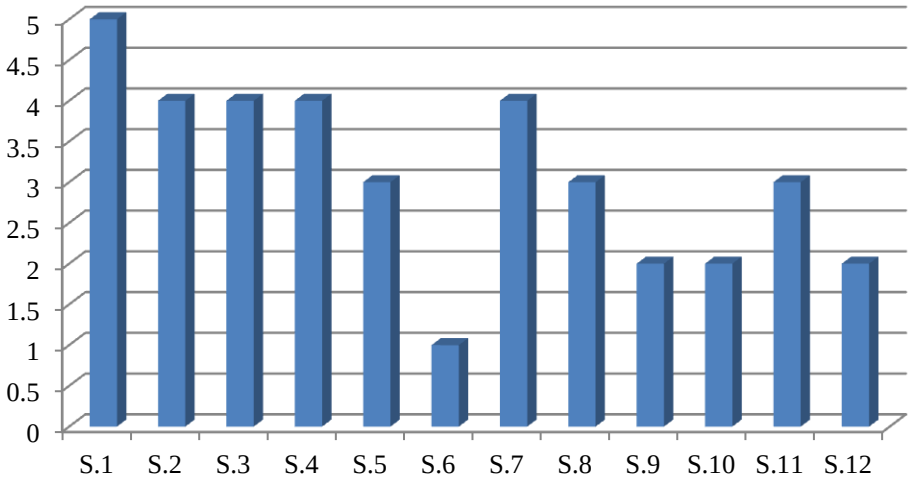
3.2.3.1 Accessibility

Regarding the accessibility factor, the on-site scenarios represent the best options. Among the top ranked scenarios, the remote computer voting scenario is also included as long as it has been designed to conform to accessibility standards and, more importantly, to be compatible with most common assistive technologies and devices.

The following are the top ranked scenarios:

- ✓ Scenario 1: On-site computer voting / Physical ID.
- ✓ Scenario 2: On-site telephone voting / Physical ID.
- ✓ Scenario 3: On-site computer voting / Passwords.
- ✓ Scenario 4: On-site telephone voting / Passwords.
- ✓ Scenario 7: Remote computer voting through the Internet / Passwords.

Accessibility scores per scenario



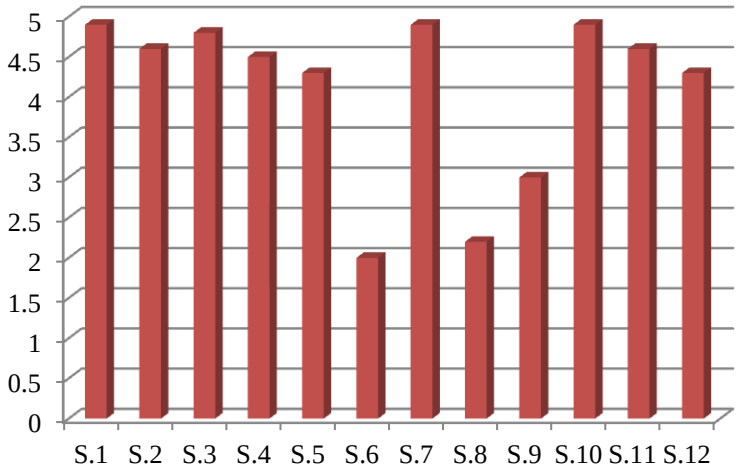
3.2.3.2 Security

Regarding the security factor, the scenarios that provide advanced electronic voting features (voter privacy, ballot integrity, strong voter authentication mechanisms and voting verifiability) are the ones that obtain the best scores according to the established criteria.

The following are the top ranked scenarios for security:

- ✓ Scenario 1: On-site computer voting / Physical ID.
- ✓ Scenario 7: Remote computer voting through the Internet / Passwords.
- ✓ Scenario 10: Remote mobile phone voting through the Internet / Passwords.
- ✓ Scenario 3: On-site computer voting / Passwords.
- ✓ Scenario 2: On-site telephone voting / Physical ID.
- ✓ Scenario 11: Remote computer voting through the Internet / Third –party systems.
- ✓ Scenario 4: On-site telephone voting / Passwords.
- ✓ Scenario 12: Remote mobile phone voting through the Internet / Third –party systems.
- ✓ Scenario 5: Remote telephone voting / Passwords.

Security scores per scenario



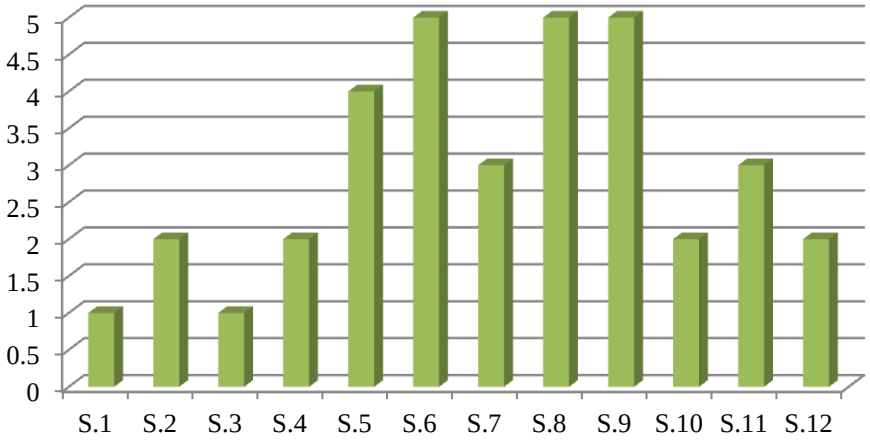
3.2.3.3 Cost

Regarding the cost factor, the scenarios that require a simple central infrastructure without on-site deployment (remote return scenarios) represent the most economic option for the Election Authorities. As expected, all scenarios that involve deployment of a secure electronic return system to polling places have the highest associated costs and complexity (due to equipment deployment, logistics, and operational expenses). Conversely, scenarios employing remote voting display the lowest costs and complexity, although the password delivery mechanism could increase both factors.

The following are the top ranked scenarios for cost:

- ✓ Scenario 6: Remote fax voting.
- ✓ Scenario 8: Remote e-mail voting through the Internet.
- ✓ Scenario 9: Remote SFTP voting through the Internet / Passwords.
- ✓ Scenario 5: Remote telephone voting / Passwords.

Cost scores per scenario

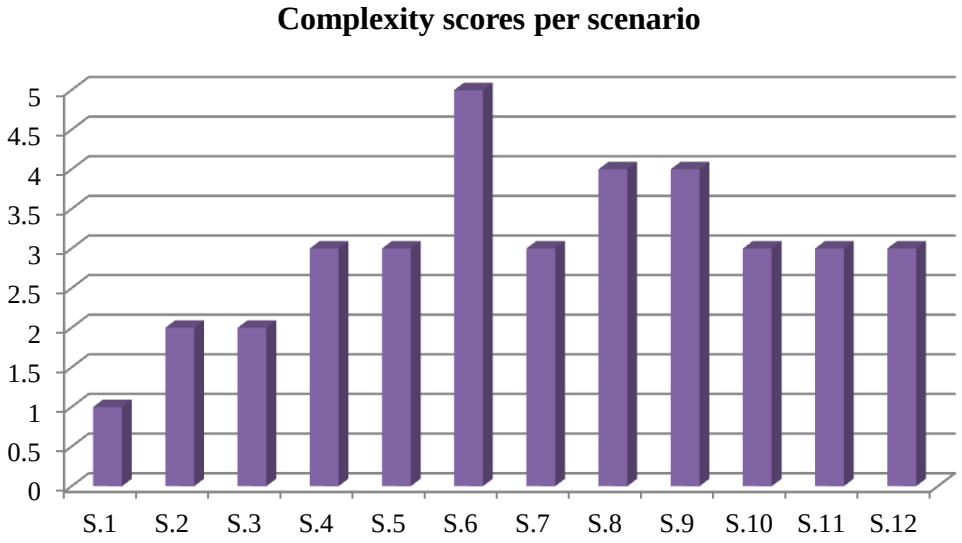


3.2.3.4 Complexity

Regarding the complexity factor, the scenarios that require a simple central infrastructure without on-site deployment (remote return scenarios) represent the less complex option for the Election Authorities. As expected, this factor is highly correlated with the cost factor.

The following are the top ranked scenarios for complexity:

- ✓ Scenario 6: Remote fax voting.
- ✓ Scenario 8: Remote e-mail voting through the Internet.
- ✓ Scenario 9: Remote SFTP voting through the Internet / Passwords.



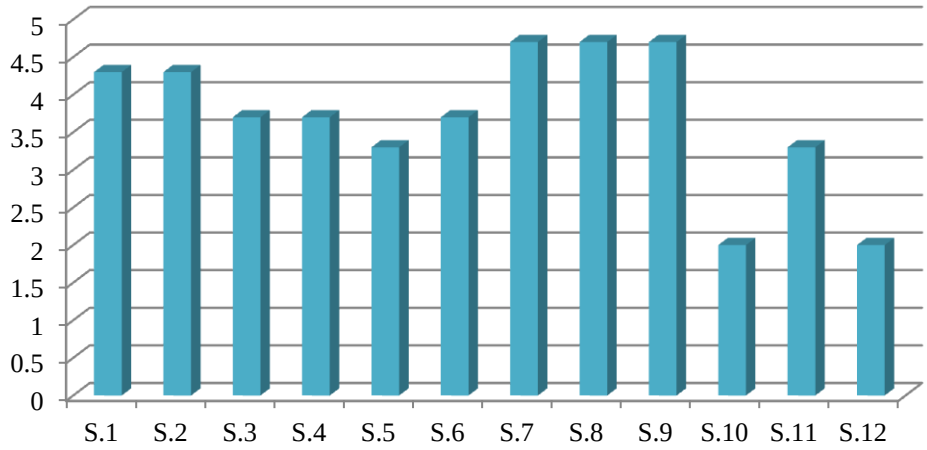
3.2.3.5 Usability and convenience

Regarding the usability and convenience factor, there are two types of scenarios in the top ranked ones: the scenarios that provide a voting interface that is highly usable (on-site scenarios) and the scenarios that allow voters to vote from almost anywhere (remote computer-based voting scenarios).

The following are top ranked scenarios for usability and convenience:

- ✓ Scenario 7: Remote computer voting through the Internet / Passwords.
- ✓ Scenario 8: Remote e-mail voting through the Internet.
- ✓ Scenario 9: Remote SFTP voting through the Internet / Passwords.
- ✓ Scenario 1: On-site computer voting / Physical ID.
- ✓ Scenario 2: On-site telephone voting / Physical ID.

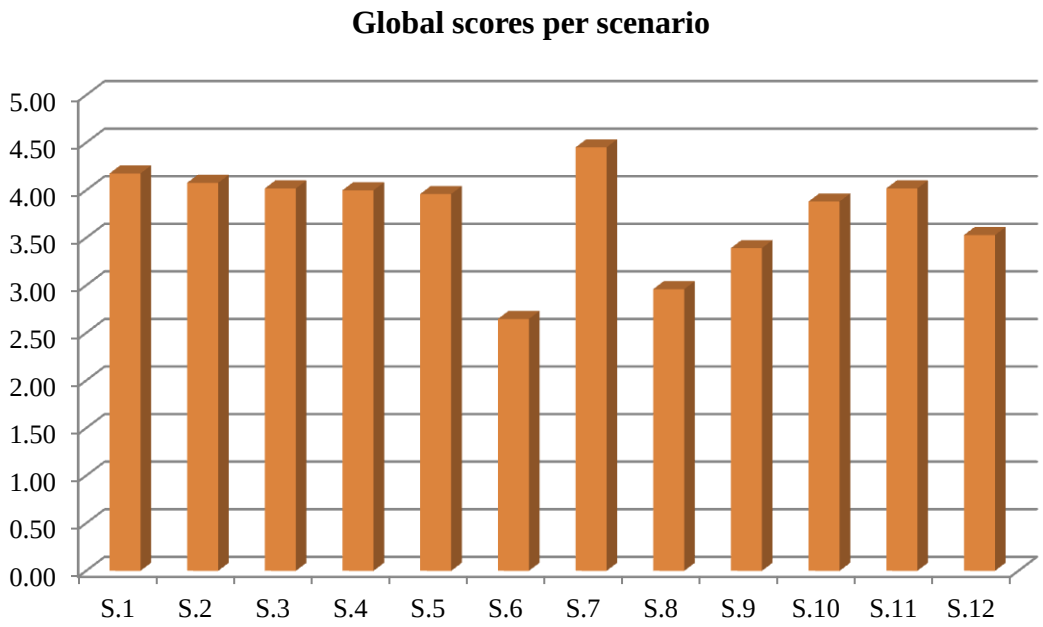
Usability and convenience scores per scenario



3.2.4 Global results analysis

The following table sorts each scenario according to the final score obtained.

Position	Scenario	Score
1st	Scenario 7: Remote computer voting through the Internet / Passwords	4.45
2nd	Scenario 1: On-site computer voting / Physical ID	4.18
3rd	Scenario 2: On-site telephone voting / Physical ID	4.08
4th	Scenario 3: On-site computer voting / Passwords	4.02
5th	Scenario 11: Remote computer voting through the Internet / Third –party systems	4.02
6th	Scenario 4: On-site telephone voting / Passwords	4.00
7th	Scenario 5: Remote telephone voting / Passwords	3.96
8th	Scenario 10: Remote mobile phone voting through the Internet / Passwords	3.88
9th	Scenario 12: Remote mobile phone voting through the Internet / Third –party systems	3.53
10th	Scenario 9: Remote SFTP voting through the Internet / Passwords	3.39
11th	Scenario 8: Remote e-mail voting through the Internet	2.96
12th	Scenario 6: Remote fax voting	2.65



Scenario 7 (Remote computer voting through the Internet / Passwords) is the scenario that obtains the best score against the established principles and constraints, as it scores perfectly against the accessibility, security and usability and convenience criteria. The cost and complexity factors of this scenario score reasonably good.

The on-site scenarios (Scenarios 1, 2 3 and 4) obtain a respectable position (2nd, 3rd, 4th and 6th, respectively) as they obtain the highest score against the accessibility and security factors. However, these scenarios imply extra cost and complexity, as they require a central infrastructure and an on-site infrastructure.

The Scenario 11 is the 5th scenario, scoring in a similar way as Scenario 7 (the main difference in both scenarios is the voter authentication scheme used).

The Scenarios 5, 10 and 12 (7th, 8th and 9th) are the ones that provide a phone voting option to voters, either by landline/cell coverage or though the Internet, obtain a reasonable score (they score 3 or more points).

The Scenarios 9 and 8 (SFTP and e-mail), 10th and 11th, respectively, pose concerns relative to the level of security, which significantly affect the global score obtained. The Scenario 6, the worst ranked one, obtains the lowest score in the security factor, which affects to the global scenario score.

3.2.5 Discarded scenarios

Of the twelve scenarios that have been described and analyzed, the following scenarios are eliminated:

- Scenario 6 (Remote fax voting) scores poorly against the accessibility and security criteria.
- Scenario 8 (Remote e-mail voting through the Internet) scores poorly against the security criteria.
- Scenario 9 (Remote SFTP voting through the Internet / Passwords) scores poorly against the security criteria comparably to other computer voting scenarios.
- Scenarios 11 and 12 (Remote computer voting through the Internet / Third –party systems and Remote mobile phone voting through the Internet / Third –party systems), which use third-party

systems[4] for voters' authentication, must be eliminated because a third-party authentication system or service is not available in Virginia at present. This option should be explored in future, however, as conditions change.

The following table provides a more detailed rationale for these eliminations:

Discarded scenario	Rationale
Scenario 6: Remote fax voting	This scenario scores poorly against the security (the voter's right to a private ballot is lost and voters cannot be considered as accurately authenticated) and accessibility criteria. However, this scenario could be used as a contingency channel in case an emergency is declared.
Scenario 8: Remote e-mail voting through the Internet	This scenario scores poorly against the security criteria (voters cannot be accurately authenticated). However, this scenario could be used as a contingency channel in case an emergency is declared.
Scenario 9: Remote SFTP voting through the Internet / Passwords	This scenario is not secure enough, depending on the implementation of the FTP system. Although a lot of security enhancements could be made to the Secure FTP return system, in order to increase the security of the system, the resulting system would be more like the system described in Scenario 7. Citizens that would use this channel can most probably use any channel that employs a computer with strong security features, and therefore, they will not be disfranchised in any case.
Scenario 11: Remote computer voting through the Internet / Third –party systems	Given the current situation in Virginia, where there is not a third party entity that can provide the required voter identification mechanism to a critical mass of voters, this scenario is not feasible. However, given the benefits of this authentication, we encourage Virginia to reassess it in the future when some third party entity can assume this challenge.
Scenario 12: Remote mobile phone voting through the Internet / Third –party systems	As in Scenario 11, it requires at least one third party that can provide the voter identification mechanism, which is not currently available in Virginia. In addition to that, as with Scenario 10, it is not currently cost-effective to implement a scenario that relies only on mobile Internet voting.

[4] This third party system could be an e-Government system, online banking, government extranets, university portals and alike. This mechanism is also known as Single Sign On (SSO), as several different systems share a single authentication mechanism.

As mentioned before, it should be noted that although these scenarios have been discarded, they could be used as contingency scenarios in case an emergency is declared.

3.2.6 Viable scenarios

Therefore, the following scenarios could be applied in Virginia. No scenario is ideal, as each one faces weaknesses and risks. However, rather than selecting scenarios individually, the combination of several scenarios could reduce the risks and enhance the strong points each one provides.

The advantages and disadvantages of the remaining scenarios are as follows:

Scenario	Advantages	Disadvantages
Scenario 1: On-site computer voting / Physical ID	• Voters can vote from established polling places through a very user-friendly interface. • Voters visiting the polling places just need to show an existing ID, facilitating their voting process. No pre-registration is necessary. • Accessibility is available for all voters, whether they know how to use a computer or not.	• Requires a centralized voters' list to avoid duplicate voting. • Voters may have to travel to vote • Cost and complexity associated with polling site deployment and operations.
Scenario 2: On-site telephone voting / Physical ID	• Voters can vote from established polling places using an audio interface. • Voters visiting the polling places just need to show an existing ID, facilitating their voting process. No pre-registration is necessary. • Visually impaired voters can vote with no assistance. • The required infrastructure at polling places is easier to deploy and cheaper to procure (when compared to computers).	• No accessibility to voters with audio and motor disabilities. • Voters may have to travel to vote • Requires a centralized voters' list to avoid duplicate voting.
Scenario 3: On-site computer voting / Passwords	• Voters can vote from established polling places through a very user-friendly interface. • Accessibility is available for all voters, whether they know how to use a computer or not.	• Many voters will just forget their passwords when attending the polling place (or will not have followed the pre-registration process). • Voters may have to travel to vote • Cost and complexity associated with polling site hardware deployment.

Scenario	Advantages	Disadvantages
Scenario 4: On-site telephone voting / Passwords	• Voters can vote from established polling places using an audio interface. • The required infrastructure at polling places is easier to deploy and cheaper to procure (when compared to computers).	• Many voters will just forget their passwords when attending the polling place (or will not have followed the pre-registration process). • Usability/privacy issues for visually impaired voters. • No accessibility to voters with audio and motor disabilities. • Voters may have to travel to vote
Scenario 5: Remote telephone voting / Passwords	• Voters can vote from anywhere and using an audio interface. • No cost of rollout to polling locations.	• No accessibility to voters with audio and motor disabilities. • Usability/privacy issues for visually impaired voters. • Requires a centralized voters' list to avoid duplicate voting. • Pre-registration process required.
Scenario 7: Remote computer voting through the Internet / Passwords	• Voters can vote from anywhere using a computer. • Voters with disabilities can vote from home using an adapted computer • No cost of rollout to polling locations.	• Requires a centralized voters' list to avoid duplicate voting. • Pre-registration process required.
Scenario 10: Remote mobile phone voting through the Internet / Passwords	• Voters can vote anywhere a 2G or newer cell network is available with a smartphone. • No cost of rollout to polling places.	• It is not currently cost-effective to implement a scenario that relies solely on mobile Internet voting. • Requires a centralized voters' list to avoid duplicate voting. • Requires extra effort to develop for multiple device platforms (including corresponding impact on testing and support). • Pre-registration process required.

Each combination of these viable scenarios should be reviewed in detail in order to determine which one is the most appropriate to be tested in a proof of concept and further implemented in Virginia.

This further analysis should consider not just the principles and constraints used in the White Paper, but several other sub-factors and principles, including security, logistics, convenience, political will, accessibility, cost, schedule, etc.

The recommendation at this stage is to pilot the remaining scenarios in elections (either mock or binding elections) with real voters to evaluate the real feasibility of the scenarios in the Virginia context. Once the scenarios have been successfully piloted, combinations of different scenarios could be provided in binding elections, combining on-site and remote voting options.

4 Next Steps

The Advanced UOCAVA Solutions Research Project was able to produce valuable evaluations of potential accessibility and secure electronic return scenarios. In the next steps, the top scoring scenarios should be further evaluated in live voting environments. Additionally, the research found that there are a number of legislation-based restrictions which are preventing some of the highest scoring scenarios from being deployed. The State of Virginia and other jurisdictions should consider legislative changes that would allow for these scenarios to be deployed, even if the deployment is on a limited trial basis.

4.1 Accessibility evaluation of additional improvements

The prototype deployed with this project covered the automatic audio ballot generated dynamically from the ballot content. Other improvements such as the binary ballot and others were not evaluated due to time and resource constraints. These advancements should be deployed into a prototype and further evaluated.

4.2 Solutions for accessibility difficulties in the transfer from electronic to paper

In electronic balloting scenarios under today's legislation, voters are required at some point in the process to take a ballot in electronic form and convert it to paper for the return. This is advantageous for its low security risk but it is difficult for voters with visual or motor disabilities and almost always requires these voters to enlist the help of others. This project found solutions which mitigate for this (see the Accessibility Research Summary) but no solutions. As a next step, legislators and election authorities should consider modifications to the law to allow for the secure electronic return of these ballots.

4.3 Deployment of audio ballot in live elections

This project helped developed the first dynamically generated audio ballot that plays through the web browser for voters. It does not require the voter to have any special devices or software outside of standard computer peripherals such as their keyboard and speakers/headphones. This technology has been evaluated by election officials but not by voters. As a next step, this technology should be used in mock and live elections and be further developed to be a widespread solution.

4.4 Development of advanced secure electronic return prototypes

Many of the technology presented in the Secure Electronic Return White Paper holds significant promise for solving some of the most difficult security problems facing secure electronic return. Some of this technology is costly to produce and evaluate but should be considered in any next steps. Secure electronic return has advantages for all voters which do not fall into the normal voting model and this population continues to grow.

4.5 Legislative authority to evaluate secure electronic return technologies

With the passage of the Virginia Senate Bill 11 *Absentee voting and procedures; secure return of voted absentee military-overseas ballots,* new legislative authority has been given to the State Board to evaluate secure electronic return. The efforts in this project should, therefore, provide a strong foundation for the State Board's requirement to provide instructions, procedures, services, a security assessment, and security measure for the secure return of military-overseas ballots. It is recommended that each of the highest-scoring scenarios and the conclusions from the White Paper on Secure Electronic Return be used as the starting point for the State's efforts.