Interpreting Babel: Classifying Electronic Voting Systems

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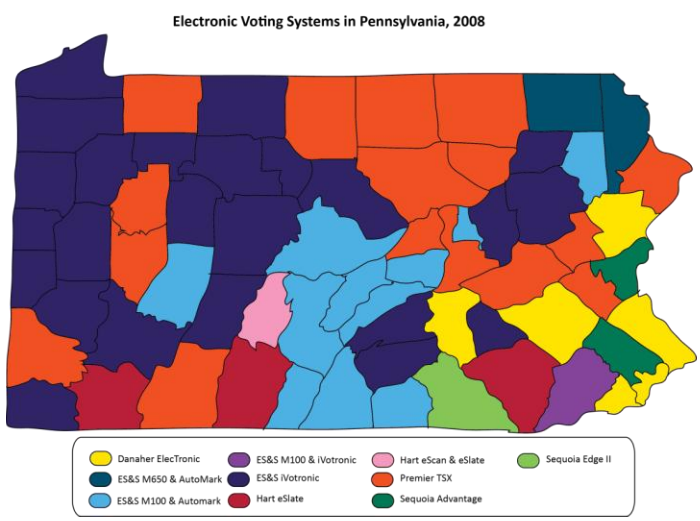
Abstract: In an effort to promote a greater understanding of the voting systems that sit in the middle of the election technology spectrum - somewhere between hand counted paper ballots and Internet voting - this work presents a classification of the electronic voting technologies currently used in the U.S. A classification structure is presented and characteristics of current and future technologies are discussed. Finally, the paper concludes with a discussion of practically using the structure and future expansion to include other voting technologies.

Introduction

Electronic voting systems have been in use since the advent of Optical Scan and Punch Card technology [Jo03]. Since that time, new classes of voting equipment emerged, coinciding with the creation and development of the personal computer. In the United States, lever machines were introduced to modernize elections in the late 1800s [Ca01]. Over the next century, voting technology used in the U.S. changed dramatically. From touchscreen machines to Internet voting, the voting landscape across the U.S. is now a tapestry of new technologies and aging equipment. As technology advances, more pressure is applied to election officials to expand their knowledge regarding voting system technology innovations and implementations.

Election administration in the U.S. is complex and necessitates the involvement and combined knowledge of federal, state and local officials. Election administration and voting system implementation in the U.S. are decentralized, meaning the role and influence of federal and/or state government varies from jurisdiction to jurisdiction. In contrast, a number of other countries use a singular voting system with one version of hardware and software in one approved configuration. In those countries, one voting system is used everywhere and is centrally administered, with higher levels of government (i.e., national government) playing a more active role in elections. The lack of a singular, uniform voting system in the U.S. and decentralized election administration contributes to the diversity of voting system technology used in each election jurisdiction. For example, ***Figure 1***[1] is a map of Pennsylvania; each color represents a different voting system and each county is colored to represent the voting system used in that jurisdiction. Since there are so many manufacturers and systems in one state, it is unlikely that federal and state election officials could implement practices that would apply to all jurisdictions. This situation is not unique to Pennsylvania.

Figure 1



[1] Image based on a map from Pennsylvania Department of State, Secretary of the Commonwealth's Office, 2010.

Just as election administration practices differ, the types of voting technology used from country to country varies widely. Many countries use voter marked paper ballots, which are hand counted, as a primary method of voting. Some of these countries are now exploring the newest voting technologies, including Internet voting. The massive leap from hand counted paper ballots to Internet voting skips over the middle ground of systems most commonly used in the United States: Direct Record Electronic and Optical Scan technologies. In an effort to promote a greater understanding of the voting systems that sit in the middle of the election technology spectrum - somewhere between hand counted paper ballots and Internet voting - this work presents a classification of the electronic voting technologies currently in use or available in the marketplace today.

In 2011, we developed a classification structure for Internet Voting systems during the course of researching and writing the U.S. Election Assistance Commission's *Survey of Internet Voting*. We discovered there is nothing clearly describing and classifying the equipment used in the U.S. This made it difficult for us to have a base of understanding and convey certain concepts when talking with other countries about their process compared to the U.S. process. This led to a decision that we should create a classification structure for the systems used in the U.S. and then, eventually, create an overall structure combining all of the voting equipment available.

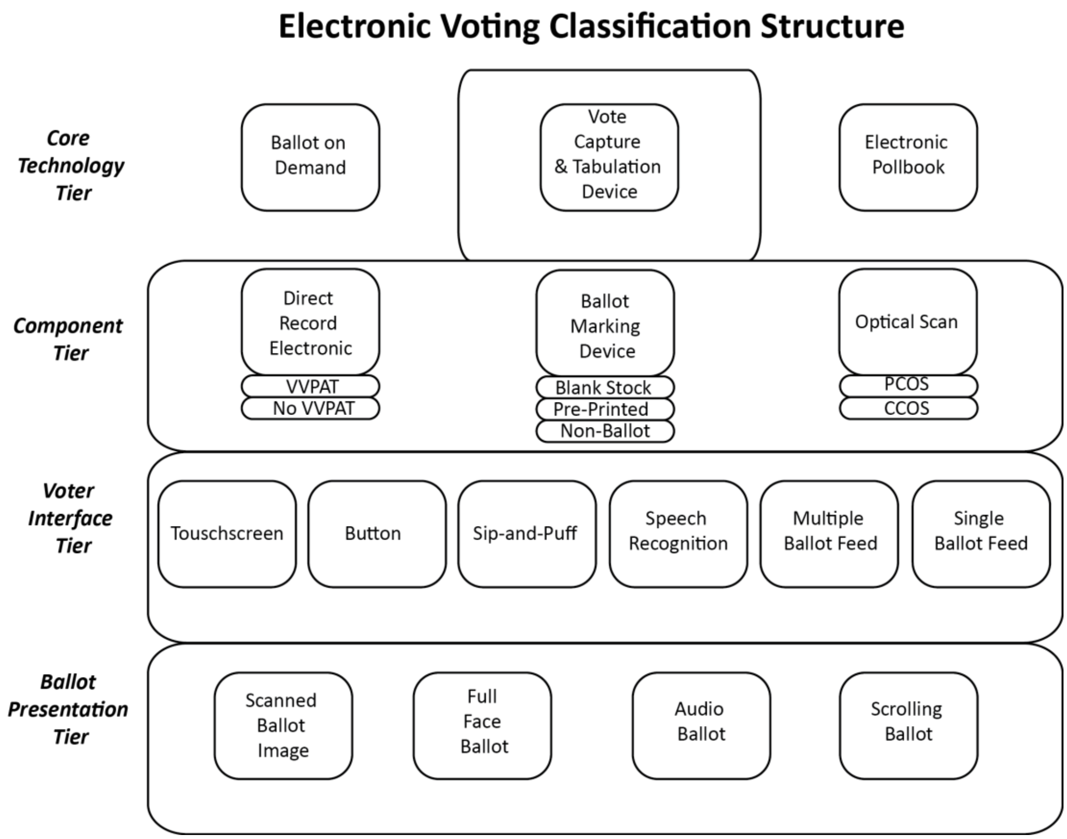
The structure contained within the *Survey of Internet Voting* and the information contained in this paper derives from our combined experience as election officials at the state and federal level, as well as experience with election administration and election support at the local level. It is a difficult task to locate individuals with the experience with these systems at both the state and federal level, which we believe provides us with valuable insight into how to develop something useful for all stakeholders (i.e., federal certification programs, state certification programs and election officials, etc.) as well as familiarity with all of the systems discussed in this paper.

First, we developed a classification structure for electronic voting systems, not including remote electronic voting. Non-electronic voting systems (i.e., lever machines or hand marked paper ballots) and punch card voting systems are not included in this structure. Electronic voting systems used directly by voters are the primary focus of this discussion. Election management systems, which are composed of voting software and utilized on dedicated PCs for a variety of election related functions (e.g. ballot creation, ballot design, election definition, etc.), and voter registration systems are not discussed within this work. Hybrid voting systems, which are systems composed of multiple electronic voting categories, are discussed. Finally, the paper concludes with a discussion about the benefits of using the classification structure and the need to expand the classification structure to include remote electronic voting and innovations in the future.

Electronic Voting Classification Structure

The Electronic Voting Classification Structure (EVCS) is composed of four tiers: Core Technology, Component, Voter Interface, and Ballot Presentation. ***Figure 2*** presents the classification structure developed to assist in the identification and classification of electronic voting systems.

Figure 2



Each tier denotes a specific characteristic which allows for further classification of the voting system. Existing Electronic Voting systems can be distilled into functions and components based on the characteristics of these tiers, which fully describes a voting system. For instance, this structure can easily be used to classify a touchscreen electronic voting system:

Core Technology => Vote Capture and Tabulation Device
Component => Direct Record Electronic
Voter Interface => Touchscreen
Ballot Presentation => Scrolling Ballot

The process above classifies voting systems based on a set of pre-defined characteristics. The system qualifies as a Vote Capture and Tabulation Device, because it captures and tabulates voter selections and does not print paper ballots or interface with a voter registration database. The hypothetical machine described above stores voter selections in an electronic format and is classified as a Direct Recording Electronic system. In its most basic form, this structure can describe a voting system with four specific features; each major feature corresponds to a tier. Detailed descriptions of the characteristics, properties and items identified in each tier are provided in each section of this paper. Hybrid voting systems, consisting of more than one category in a tier, are becoming increasingly prevalent in the U.S., and are detailed in a later section of this paper. Many of the voting systems classified in this paper include a link in the citation to a video and/or images of how each system works.

Core Technology Tier

The Core Technology tier is the broadest classification of electronic voting technologies. Core Technology is defined by the overall function, goal, or purpose of the system, and has three categories:

- Vote Capture and Tabulation Device

- Ballot on Demand System
- Electronic Pollbook

Vote Capture and Tabulation Device is the category in the structure covering the largest proportion of voting systems currently available and is the central focus of this work. Vote Capture and Tabulation Device is the only Core Technology category directly interacting with voters; Ballot on Demand systems and Electronic Pollbooks are normally run and operated by election workers. Specifically, these devices accept voter input, record the input as voter selections and tabulate these selections to provide election results.

In the U.S., Ballot on Demand Systems are frequently implemented as an additional feature of a voting system. Usually they are combined with a Vote Capture and Tabulation Device, although they can function independently. Generally, they are not included within U.S. state or federal certification because they do not usually qualify as part of the voting system used for vote capture and tabulation. Many states print a large number of ballots in preparation for Election Day. The number of ballots printed is usually based on a percentage of total population of a county or municipality. Often, a large percentage of the pre-printed ballots are wasted, because election officials must estimate turnout prior to Election Day. Ballot on Demand Systems print blank ballots as needed, which potentially allows jurisdictions to save some of the cost of printing ballots. Voters do not interact with or make selections with pure Ballot on Demand Systems, as the systems only print blank ballots on blank paper stock on request. An example of a Ballot on Demand system is the Advanced Ballot Solutions system recently reviewed in New Mexico [Nm11].

Electronic Pollbooks are the third and final category of Core Technologies. Electronic Pollbooks are used to interface with the list of registered voters. They denote whether a voter is registered properly and can create tokens (e.g., smartcards) to allow a voter access to a Direct Record Electronic (DRE) component. Electronic Pollbooks are usually comprised of software on laptops or tablet devices and utilize commercial or custom hardware. Electronic Pollbooks connect to the voter registration database via the cellular network or other network medium. An example of an Electronic Pollbook is the Premiere Express Poll 4000 used in Georgia [Ke12].

Component Tier

There are three categories within the Component Tier with each category containing subcategories:

- Direct Record Electronic
    - With VVPAT
    - Without VVPAT
- Optical Scan
    - Precinct Count Optical Scan
    - Central Count Optical Scan
- Ballot Marking Device
    - Blank Stock
    - Pre-Printed Ballot
    - Non-Ballot

Equipment in the Component Tier is defined by where and how a voter's selections are stored. These selections can be stored on physical media (e.g., paper ballots) or electronic media (e.g., USB). In some cases, this means a full ballot printout or receipt is provided for the voter to read and retain. In other cases, voter selections are stored on paper, but are not presented in a human readable format. These formats include encrypted voter selections, barcodes, or Quick Response (QR) codes, which require additional equipment, such as a barcode scanner, that allows voters to review their selections.

DREs are commonly referred to as touchscreens, although not all DREs are touchscreens. DRE voting systems are not defined by their method of interface, but are defined by their method of storing voter selections. Due to this fact, it is possible to have a DRE voting system comprised solely of a commercial off the shelf (COTS) personal computer with a keyboard and mouse. Some DREs use a Voter Verified Paper Audit Trail (VVPAT), which stores voter selections on paper via an internal or external printer. With a VVPAT, voter selections are stored concurrently on physical and electronic media. Some U.S. States and election jurisdictions define the physical storage (i.e., paper ballot) as the "ballot of record" and not the information stored electronically by the DRE. "Ballot of record" refers to the ballot which will be used for official canvass, vote tabulation, recount and record retention.

As stated previously, Optical Scan machines accept, read, record, store and tabulate paper ballots. Optical Scan machines fall into two subcategories: Precinct Count Optical Scan (PCOS) and Central Count Optical Scan (CCOS). The Hart eScan [Ha12] and ES&S M650 [El12] are examples of PCOS and CCOS systems respectively. Although this classification system does not make the distinction, Optical Scan equipment can be classified by the types of technology employed to digitally scan ballots (e.g., infrared, fax-bar, image scanning) [Jo03]. The voter interacts with PCOS components directly by individually scanning their ballot after making ballot selections. CCOS systems are used by an election jurisdiction to quickly tabulate large batches of ballots, so a voter never is afforded an opportunity to interact with the system. Most commonly, CCOS systems are used for absentee, military, overseas voters, and jurisdictions using a vote by mail system (e.g, Oregon). It is interesting to note that, at times, election staff may use PCOS as CCOS machines.

The Ballot Marking Device component marks paper ballots with voter selections. This is accomplished via a Touchscreen or Button Interface, which is discussed in the next section. Voter selections are stored on paper, but are entered and marked with an interface typically associated with a DRE. This feature is what distinguishes BMDs from Optical Scan and DREs. The Automark is employed by many election jurisdictions throughout the U.S. and is the most popular example of a BMD [Ci12]. The Automark is but one type of BMD and we identify three subcategories categories:

- Printing voter selections and a ballot in one operation onto blank paper stock;
- Printing voter selections onto a pre-printed ballot; and
- Printing voter selections onto a non-ballot format.

There are many ways voter selections can be printed into a non-ballot format. One possibility is printing voter selections onto a piece of paper smaller than the average ballot size and listing only the candidates the voter selected.

Interface Tier

The Interface is the method in which a voter makes selections and interacts with a voting system. Frequently, voting systems have multiple interfaces to meet accessibility requirements and needs of voter's with disabilities. An extreme example of a component with multiple interfaces is a DRE with a Touchscreen, Button, Sip-and-Puff, and Speech Recognition capabilities. There are six categories in the Interface Tier:

- Multiple Ballot Feed
- Touchscreen
- Button
- Single Ballot Feed
- Sip-and-Puff
- Speech Recognition

The Single Ballot Feed interface is only associated with Optical Scan and Ballot Marking Device components and applies to scenarios where the voter feeds a single ballot into a voting system.

The Multiple Ballot Feed interface category is associated with Optical Scan components. It does not typically include Ballot Marking Devices, except when the voting system is a hybrid, which is discussed later in this paper. Multiple Ballot Feed refers to situations in which many ballots from different voters are stacked in batches and fed into a Central Count Optical Scan (CCOS) component. Multiple Ballot Feed systems are most commonly used for military and overseas voters, but may be used to double check or recount vote totals provided from multiple Precinct Count Optical Scan (PCOS) systems.

The Touschscreen, Button, Speech Recognition, Sip-and-Puff, and Mouse interfaces are all possible interfaces on BMD and DRE components. Touchscreen interfaces are most commonly associated with DRE and BMD components. Button interface are provided on certain DREs, including the Danaher ELECTronic 1242 used in Delaware [De12] and the Virgin Islands [Vi12]. A Button interface describes any voting system with buttons provided for the voter to interact with a component. These buttons may be built into the component's chassis or a tangible COTS keyboard. An example of a system with a keyboard interface is the Scytl/Hart Electronic Pollbook used in Washington, D.C. [Ha10]

Speech Recognition and Sip-and-Puff interfaces are usually designed as options for persons with cognitive and/or physical disabilities. To our knowledge, Speech Recognition has not yet been commercially produced in an electronic voting system, although one prototype voting system exists, Prime III, and uses a Speech Recognition interface. Sip-and-Puff is a binary input device, commonly used by voters with upper body paralysis [Cl12]. The Sip-and-Puff device is owned by the voter and is a "wand" or straw which allows the voter to inhale (sip) or exhale (puff) to move around the ballot, make ballot selections and cast the ballot.

Presentation Tier

The Presentation Tier describes how ballots and, therefore, candidates, contests, and referendum/questions, are presented to voters. This is usually done in one of four ways:

- Full Face Ballot
- Scrolling Ballot
- Scanned Ballot Image
- Audio Ballot

If a voter's ballot is presented in its entirety, the system presents what is known as a Full Face Ballot. If the entire ballot is not presented upfront and the voter must scroll or navigate through the ballot to view it, it is called a Scrolling Ballot. Each state and jurisdiction has requirements regarding ballot presentation. For example, New York requires the ballot to be presented as a Full Face Ballot, resulting in a 21" ballot for their election in 2010.

The Scanned Ballot Image category describes a system which scans a ballot and presents this scanned image to the voter. The Dominion Imagecast presents the voter with a scanned ballot image after the voter confirms their selections [Ne12]. Scanned ballot images are often championed for their value to voters with disabilities, because all ballots are interpreted and tabulated the same way, no matter the interface used to input the data. More specifically, one method is used to gather voter selections from disabled voters and non-disabled voters. The system then uses the same data to tabulate results and requires no additional interaction from the voter allowing voters with dexterity problems to cast ballots in the same manner. Audio Ballots are often used to meet accessibility requirements on U.S. voting systems and allow the voter to listen to an audio file that reads the ballot to them.

Hybrid Voting Systems

Hybrid Voting Systems are voting systems that combine the functions and capabilities from several categories of the Core Technology and Component Tiers. Hybrid Voting Systems are the most recent additions to electronic voting technology and are in the process of being deployed in the U.S. As an example, a voting system might have the characteristics of both a Ballot Marking Device and DRE by combining both units into a single chassis and interface. A current example of this hybrid voting system is the Unisyn OVI [Un12].

Core Technology => Vote Capture and Tabulation Device
Component => DRE / Ballot Marking Device
Voter Interface => Touchscreen / Button / Sip–and–Puff
Ballot Presentation => Full Face Ballot / Scrolling Ballot

Another example is the Dominion ImageCast used in New York [Ne12].

Core Technology => Vote Capture and Tabulation Device / Ballot on Demand
Component => Optical Scan / Direct Record Electronic / Ballot Marking Device
Voter Interface => Single Ballot Feed / Touchscreen / Button / Sip–and–Puff
Ballot Presentation => Full Face Ballot / Scrolling Ballot

In other cases, voting systems are combined in interesting ways. For example, stacking the ESS Automark on top of a precinct scanner, like ESS's M100 or DS200, is a fairly common set up in polling places across the U.S.

Applying the Classification Structure

The classification structure presented is useful in a number of ways. We believe a structure of this nature is necessary to develop and define a working language of electronic voting technologies. This is especially useful in the world of consumer electronics, which many of these voting technologies leverage, where systems are designed, developed, and depreciated within a few years. Too often voters, election administrators, election technologists, and other concerned parties are not speaking the same language when discussing voting technology. Through the publication of this information and development of a classification structure, election officials can understand what characteristics different types of voting technology possess. Also, it can help those unfamiliar with certain types of systems to gain a foundation of understanding. Given enough time, iterative refinement, and acceptance, the structure can ensure that voting technology is described in a more succinct and meaningful manner. Common language and terminology may allow for better communication between election officials of different counties, states, or countries. Additionally, if those working with voting technology can understand each other and share information more easily it is easier to share best practices and innovations, which promotes better elections.

This classification is useful for certification efforts in the United States as well as promoting a general understanding of the types of voting systems available. In the U.S., standards exist to test and certify voting equipment [Us12]. The classification system employed by this standard is based on a set of older standards that only envisioned DRE, Optical Scan, and Punchcard technology. These standards do not consider BMD technology or a number of interfaces described in this paper, such as keyboard input or speech recognition. By classifying systems with this structure, requirements can be tailored to test very specific functionality.

With a more detailed classification structure, election administrators can better understand what characteristics are needed to meet their jurisdiction's specific needs. Once these requirements are identified, it is easier to clearly specify and communicate those needs in a Request for Proposal (RFP) for procurement of a voting system. In the U.S., contracting for new voting technology is a high risk process with long term consequences. When purchasing new equipment, jurisdictions generally expect (and are usually told) new technology will last at least 10 years and will require maintenance contracts for upkeep and upgrades. The process of purchasing systems with the latest innovations must be balanced with the need to sustain aging technology for as long as possible. Legacy systems are technology that, at one time, was innovative and new, but is now reaching the end of its life cycle. Many of the systems currently fielded across the U.S. qualify as legacy systems and will need to be replaced in the near future.

Figure 3 classifies the majority of electronic voting systems either in use or federally certified for use in the United States, including legacy systems and hybrid technologies. Only Vote Capture and Tabulation Devices are presented in this table.

Figure 3

Unit	***Core Technology***	***Component***	***Interface***	***Ballot Presentation***
AVS	VCTD	DRE	Touchscreen / Button / Sip-and-Puff	Scrolling Ballot / Audio
Automark	VCTD	BMD	Touchscreen / Button / Sip-and-Puff	Scrolling Ballot / Audio
Danaher ELECTronic	VCTD	DRE	Button / Sip-and-Puff	Full Face Ballot / Audio
Diebold OS	VCTD	OS	Single Ballot Feed	Full Face Ballot
Diebold TS	VCTD	DRE	Touchscreen / Button / Sip-and-Puff	Scrolling Ballot / Audio
Dominion ImageCast (As used in New York)	VCTD/BOD	OS / DRE / BMD	Single Ballot Feed / Touchscreen / Button / Sip-and-Puff	Full Face Ballot / Scrolling Ballot / Audio
Dominion ICC	VCTD	OS	Multiple Ballot Feed	Full Face Ballot
Dominion ICE	VCTD	OS / DRE / BMD	Single Ballot Feed / Touchscreen / Button / Sip-and-Puff	Full Face Ballot / Scrolling Ballot / Audio
Dominion ICP	VCTD	OS / DRE	Single Ballot Feed / Touchscreen / Button / Sip-and-Puff	Full Face Ballot / Audio
ES&S DS200	VCTD	OS	Single Ballot Feed	Full Face Ballot
ES&S DS850	VCTD	OS	Multiple Ballot Feed	Full Face Ballot
ES&S M100	VCTD	OS	Single Ballot Feed	Full Face Ballot
ES&S M650	VCTD	OS	Multiple Ballot Feed	Full Face Ballot
Hart eScan	VCTD	OS	Single Ballot Feed	Scrolling Ballot/Audio
Hart eSlate	VCTD	DRE	Button / Sip-and-Puff	Scrolling Ballot / Audio
Prime III	VCTD	DRE	Touchscreen / Speech Recognition	Scrolling Ballot / Audio
Sequoia Advantage	VCTD	DRE	Button / Sip-and-Puff	Full Face Ballot / Audio
Sequoia Edge	VCTD	DRE	Touchscreen / Button / Sip-and-Puff	Scrolling Ballot / Audio
Sequoia Edge II	VCTD	DRE	Touchscreen / Button / Sip-and-Puff	Scrolling Ballot / Audio
Unisyn OVCS	VCTD	OS	Multiple Ballot Feed	Full Face Ballot
Unisyn OVI	VCTD	DRE / BMD	Touchscreen / Sip-and-Puff / Button	Full Face Ballot / Scrolling Ballot / Audio
Unisyn OVO	VCTD	OS	Touchscreen / Single Ballot Feed	Full Face Ballot

Finally, this structure provides for possible combinations of voting technologies that may not exist or are in the design stages. An example of this could be:

Core Technology => Vote Capture and Tabulation Device / Electronic Pollbook
Component => Direct Record Electronic
Voter Interface => Touchscreen / Button / Sip-and-Puff
Ballot Presentation => Scrolling Ballot

This hypothetical system is a single machine that can access voter registration information, as well as storing voter selections. If a voter is identified on the voter roll and presented with the correct ballot all in one machine, this could save time at voter check-in and potentially cut election administration costs by requiring fewer pollworkers or less duplicative equipment. Additionally, looking at the classification structure could help spur development and design of future voting technologies. The structure lays out the possible combinations in a simple and manageable format, which could help developers come up with new ways to combine different features in an effort to fully serve their customer's needs.

Conclusion

This paper creates standardized terms, as well as a classification structure, providing election officials with a clearer picture of their own system and allowing them to compare it with what is available. This structure is useful during the RFP process, because election officials can clearly articulate their needs at the beginning of the process rather than sifting through all options and trying to decipher which system meets their needs. If election officials request to have voting system information presented to them using the Electronic Voting Classification Structure provided here, manufacturers can use this to describe systems in documentation and sales information, creating a level of standardization in terms and descriptions.

Additionally, in terms of information sharing, a common language and shared terminology is essential for promoting understanding. This common language is presented clearly and makes it easier for those trying to understand election administration practices (e.g., journalists and the media) to speak and write accurately about elections, which is of the utmost importance to election officials. This method breaks the system down into manageable pieces, making it easier to train pollworkers and educate voters.

The only other methodology for classifying electronic voting systems the authors are aware of was created by the United States National Institute of Standards and Technology (NIST). This structure is part of the Draft Voluntary Voting System Guidelines 2.0, and provides a voting system and device class structure [Te07]. The NIST structure is commendable in that it is detailed, unambiguous, and provides strict terminology for all parties involved in the U.S. voting system testing and certification process (e.g., voting system manufacturers, laboratories, and governmental organizations). The NIST structure creates a hierarchy, which defines devices and assigns them a level within the hierarchy, and an inheritance structure is formally provided. Additionally, a process for creating new voting system devices is provided for via the innovation class. We are concerned that the NIST structure may be too complicated and detailed for those outside of U.S. voting system certification, where a more practical and simplified structure is warranted. One of the primary reasons we provide the structure presented within this paper is to assist stakeholders involved in day-to-day election administration with the knowledge and tools to accurately and effectively conduct, monitor, maintain and review elections. These stakeholders include contracting officers, election officials, members of the media, politicians, and the I.T. staff involved in maintaining election technology.

Future additions to this classification structure are vast and a multitude of possibilities exist. Practical first steps include classifying additional characteristics of the systems described in this paper (the four tiers) and creating distinct Component tiers for Ballot on Demand systems and Electronic Pollbooks. New items could be added to the Core Functionality tier, such as: cardreaders, ballot printers, barcode scanners, election management systems, token creators, and large ballot sorters. Additionally, the classification system could be extended to voting systems without hardware components, such as Internet voting systems. An Internet voting systems classification already exists and could be merged with this classification structure to provide the full picture of voting systems [Us11]. U.S. election officials are already discussing voting systems that only use COTS hardware components, such as iPads or desktop computers [Te11]. Other jurisdictions are even trying to crowdsource ideas to create next-generation voting systems [Lo10]. With all of these imaginative prospects on the horizon, surely the next-generation of electronic voting systems is closer than many believe. This is exciting for all parties within the election ecosystem; especially voters.

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