Audit Analysis of the Venango County 2011 Municipal Primary Initial Report

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Acknowledgments

This resport would not have been possible without the actions and contributions of others.

This effort literally would not have begun without the decision by the Venango County Board of Elections (Craig Adams, Martha Breene, and Eleanora Miller) to seek assistance from outside analysts pursuant to their responsibilities to the citizens of Venango County. Early on, Attorney Michael Hadley was instrumental in providing background information and organizing a public hearing which served to introduce me to Venango County. Denise Jones, the Board's Chief Clerk, described details of how Venango County prepares for and carries out election activities and also provided us with necessary records.

Marybeth Kuznik, Executive Director of VotePA, a state-wide non-partisan voting rights and election integrity alliance, was instrumental in introducing the Board of Elections to individuals, including myself, who were available to assist the Board. In addition, she provided significant assistance as an interpreter between the Board and jargon-dense technologists.

Contract negotiation required substantial efforts by Attorney Charles A. Pascal, Jr., who represented the Board of Elections, and Attorney Jonathan B. Robison, who represented me.

My colleague Gregory Kesden of the Carnegie Mellon University Computer Science Department, who teaches Information Forensics and serves as a forensic computer scientist in criminal and civil cases, provided the foundation for my work by making a forensically sound copy of the hard disk drive of Venango County's main tabulation computer, by researching the contents of the hard drive, and by helping me interpret the results.

Professor Candice Hoke, Founding Director of the Center for Election Integrity at Cleveland State University, provided invaluable perspective on legal and technical issues surrounding voting system assessments, including efforts in other states.

Jil McAleer of the Venango County Democratic Committee graciously provided scans of the iVotronic final-print tape and other return materials from "Cornplanter 1."

Significant assistance in analyzing Unity^{TM} log files was provided by Professor Duncan Buell of the University of South Carolina Department of Computer Science and Engineering. He and his co-workers (Peggy Brown, Eleanor Hare, Frank Heindel, Chip Moore, and Barbara Zia) have produced two significant studies [3, 2] describing procedural errors in a South Carolina election using ES&S equipment (South Carolina uses iVotronic DRE's state-wide). Professor Buell allowed me to use his log-analysis tool and helped interpret results, and also interpreted the implications of phenomena observed in the public South Carolina log files with respect to iVotronic internals.

Professor Doug Jones of the University of Iowa Department of Computer Science and the ACCURATE voting research center steered me toward relevant technical information and helped confirm my reasoning about iVotronic data structures based on externally observed phenomena.

Though I am employed by the Carnegie Mellon University Computer Science Department, and though I have benefited from the advice and support of those mentioned above (and others I may have inadvertently omitted), the responsibility for these opinions is solely my own.

Contents

1 Background

1.1 About this report

On May 17, 2011, each Pennsylvania county held a municipal primary election (which, despite the name, contained a mixture of municipal, school board, county-wide, and state-wide races). In Venango County, Pennsylvania, the election was held on iVotronic® DRE (direct-recording electronic) voting machines[1] manufactured by Election Systems & Software, Inc., of Omaha, Nebraska ("ES&S") and certified by the Secretary of the Commonwealth of Pennsylvania. Results were tabulated using ES&S's Unity™ Election Reporting Manager software running on top of the Microsoft Windows XP® Professional operating system (Version 2002).[2]

After the election was held, and before the results were certified, questions arose about the operation of the iVotronic DRE's and about the results in some races. After hearing public testimony from voters and others, including this author, the Board decided to retain outside expertise to advise them on various questions they had. Among the issues raised were:

1. Some voters complained that particular candidates for particular offices were not available for them to select.
2. Concerns were raised about the number of undervotes in some contests.
3. It was suggested that a tie vote in one race was surprising.

This mission of this work was:

1. To shed light on these issues, to the extent possible.
2. To evaluate the degree to which the election system used during the municipal primary is auditable, and
3. To comment on the processes used by Elections staff in Venango County to prepare for, run, and report on elections.

1.2 About the author

Since 1997 David A. Eckhardt has served as an appointed Judge of Elections in Mt. Lebanon, Pennsylvania. This position entails managing a single polling place serving approximately 800 registered voters. Initially voters in that polling place used two mechanical voting machines manufactured by the Automatic Voting Machine Corporation of Jamestown, NY; since 2006 voters have used three or four ES&S iVotronic DRE's. The duties of a Judge of Elections include transporting voting materials from and to a County regional reporting center, overseeing the operation of voting machines, determining who is eligible to vote and who is eligible to assist voters, and educating voters when necessary.

Since 2003 Dr. Eckhardt has taught Computer Science at Carnegie Mellon University in Pittsburgh, Pennsylvania. His areas of specialty are operating systems and computer networks.

These two areas of activity, formerly independent, began to overlap in 2006 when Allegheny County voters began to vote using computers. Since then Dr. Eckhardt has contributed to various

[1] Absentee ballots were scanned by a Model 100™ optical scanner.

[2] Use of the trademarks of various companies is for purposes of identification, not endorsement.

reports as a member of VoteAllegheny, a non-partisan election integrity group [4, 5, 6] and as a member of the Allegheny County Citizens' Election System Advisory Panel [1].

2 Scope and Limitations

The conclusions of this work are limited by certain restrictions. Among the most important:

1. At the direction of the Board of Elections, the voting system equipment and records were sequestered so they would be available for analysis. However, limited time was available between the conclusion of contract negotiations and when Elections staff needed to begin preparing for the November general election. While it was possible to obtain a forensically valid copy of the hard disk drive of the primary Unity tabulation computer, it was not feasible at that time to copy the iVotronic CF cards.

2. We copied and examined the hard disk drive of the primary Unity tabulation machine, but did not image the disk of a second identical computer, which was represented to us as being used for display of results to media representatives. In the same locked cabinet as the primary Unity tabulation machine was a third machine manufactured by Dell (of a "small form factor" design). As the purpose and use of that machine was not clear, we did not investigate its contents.

3. As we understand it, during preparations for the November general election, some fraction of the iVotronics were reset. In addition, some fraction of the flash cards were rewritten.

4. Limited time was available between the copying of the Unity tabulation system hard drive and the due date for this report. As is typical for an investigation of this sort, some of that time was used to acquire hardware and to reproduce a running system environment.

5. No ES&S program code, whether part of the Windows-based Unity program suite or embedded in iVotronic or M100 voting equipment, was disassembled, nor was any ES&S program code made available in source form. Inferences about the operation of ES&S code were drawn from published documentation and program output (e.g., menus, dialog boxes, and reports).

6. No iVotronic voting machines were checked to ensure they were running the firmware certified by the Secretary of the Commonwealth. It is believed that, while Allegheny County examines firmware on a sample of machines [6], this is not done in any other Pennsylvania counties.

7. No ES&S proprietary data formats were decoded. Again, inferences were drawn by examining plain-text logs and by observing the operation of various parts of the system.

8. No direct examinations were made of the contents of "PEB ballot cartridges," iVotronic internal flash memory, or Compact Flash ("CF") cards written by iVotronics.

9. Questions were raised about program code written by a contractor retained by the County. As these programs have not been made available to us in source or executable form, we are unable to comment on their purpose, use, or effect.

The primary sources of knowledge and data for this report are:

1. The author's knowledge of the operation of computers, including low-level code, networks, and operating systems,

2. The author's experience as a Judge of Elections, including: hands-on experience with AVM mechanical voting machines and ES&S iVotronic DRE voting machines, and observations of many voters in a polling place over a period of years.

3. The author's observations of equipment setup and vote tabulation activities in Allegheny County, and observations, published and otherwise, of deployment and operational irregularities associated with with voting equipment,

4. Documentation for the ES&S Unity system, including published manuals available online [9] and system prompts and guidance,

5. Published reports which consider iVotronic DRE's, particularly the Ohio "EVEREST" report [8], the "SAIT/Sarasota 2007" report [11], and the work of the South Carolina team [3, 2].

6. Unity output files, primarily files matching the specification `C:\ELECDATA\VCMP2011\*.LST`.

3 Questions

A wide variety of questions were posed about the process and results of the 2011 municipal primary election. In some cases we heard partial descriptions of issues but have not to date obtained sufficiently clear descriptions to look into them.

These questions can be broken down into several categories:

Election-day issues

We were asked to look into various issues that arose during the course of the election. In some cases we will address these questions briefly as we list them, and in other cases our response will be deferred to a later part of the document.

Election Results

We were asked to investigate the outcomes reported for certain races. In two cases we speculate briefly but believe the question should probably be investigated further by a statistician. In one case we believe we can provide a definitive answer.

Election-Computer Integrity

We were asked to comment on the integrity of the tabulation machine whose disk we imaged. We will defer discussion of these questions until Section 7.

Auditability of iVotronics and Unity

We were asked to comment on the degree to which it is feasible to "recount" or "audit" the results reported by Unity based on data from iVotronic voting terminals and to which it is possible to audit the behavior of the iVotronic voting terminals themselves.

The remainder of this document is organized as follows. In the remainder of Section 3 we will present in greater detail the issues we investigated. When possible, we will respond to a question directly after asking it. Then we present two pieces of background information: in Section 4 we

will present an abbreviated framework for discussing risks to election integrity and in Section 5 we describe relevant features of the iVotronic voting terminal. In Section 6 we present observations made of system state found on the Unity tabulation computer, after which we attempt to address questions which were previously deferred in Section 7. Finally, we make recommendations in Section 8 and discuss further work that could be done in Section 9.

3.1 Election-Day Issues

"Cornplanter 2": candidates missing from ballot?

Norm Dinberg reports, in sworn testimony, that, on the Democratic ballot, Stan Grzasko was missing from the County Commissioner race and that Jessica M. Deets-Snyder was missing from the two-year Oil City School Board race. Mr. Dinberg also reports "vote jumping" (consistent with a mis-calibrated touch screen) for those races but not others. We will discuss this issue below, in Section 7.1.

"Oil City 2": candidates missing from ballot?

Lawrence Bowers reports, in sworn testimony, that he is "100% positive" that, on the Republican ballot, Ron Gustafson was missing from the Oil City Council race. Mr. Bowers also reports "vote jumping" in the County Commissioner race. We will discuss this issue below, in Section 7.1.

"Franklin 2": lost vote after screen calibration problem?

Reportedly a voter who wishes to remain anonymous "gave up" because of "vote-switching" problems; reportedly his ballot was canceled.

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Pinegrove Township": screen problem with one iVotronic?

Reportedly screen problems (pixel illumination and/or calibration) were experienced with one iVotronic.

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Sandycreek": startup problem with V5178126?

Reportedly poll workers could not obtain a zero print, reportedly because one or more iVotronic(s) already contained votes. Also, reportedly iVotronic V5178126 shows zero votes on the polling-place final print.

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Emlenton": voter-count mismatch?

Reportedly the Return Sheet shows 102 R + 54 D = 156 but the Public Tally shows 104 R + 51 D = 155.

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Victory": problems opening and closing?

Reportedly there was a staffing problem requiring one or more replacement workers at the polling place. Reportedly poll workers were unable to obtain a final print; reportedly the iVotronics were transported to the Courthouse and closed there.

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Oil City 4": PEB chain of custody issue?

Reportedly the location of the PEBs from this polling place was uncertain for some time. Do the PEB results and the flash-card results match?

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Cranberry 4": was iVotronic V5167819 used?

Reportedly neither the Return Sheet nor the Public Tally Sheet shows a vote total for this machine. Was this machine used?

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Oil City 7": was iVotronic V5185935 used?

Neither the Return Sheet nor the Public Tally Sheet shows a vote total for this machine. Was this machine used?

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

"Clintonville Borough": was one iVotronic not used?

Reportedly not all iVotronics were used.

As of the time of the filing of this report, this issue has not been investigated to our complete satisfaction; further analysis could be conducted.

3.2 Election Results

Excessive undervotes in the Republican Auditor race?

The official results from the County web site for the Republican race for County Auditor (vote for not more than two candidates) show:

Candidate/Category	Votes
Republican ballots	5,372
Mary L. Danzer	2,900
Heather S. Mohnkern	3,134
Barry A. Goughler	1,779
Write-in	13
Undervotes	2,918

Reportedly Mr. Goughler dropped out of the race, but after the deadline for removal from the ballot. Questions that have been raised about this race include:

1. Is the number of votes assigned to Mr. Goughler surprisingly high?
2. Is the number of undervotes surprisingly high? The undervote total is greater than the number of votes received by the incumbent, Mary L. Danzer.

An initial step toward answering this question would be to use the EL155 "ballot image log" to produce counts of how many voters selected two candidates, one candidate, or zero candidates; the zero-candidate case could be compared to the undervote rate in other Republican races; the one-candidate voters could be broken down by which single candidate was voted for; and the two-candidate voters could be categorized by which pair of candidates were selected. These detailed results could be examined by people conversant with the candidates and local political sensibilities. More-detailed statistical analyses are possible, e.g., breaking some of these questions down by precinct.

Unusual vote patterns in the Republican County Commissioner race?

The official results from the County web site for the Republican race for County Commissioner (vote for not more than two candidates) show:

Candidate/Category	Votes
Republican ballots	5,372
James E. Speth	645
Vince Witherup	2,190
Fred Weaver	1,944
Rod Bedow	1,695
Timothy S. Brooks	2,190
James J. Dutko	916
Write-in	58
Undervotes	1,106

Questions that have been raised about this race include:

1. Is it plausible for two candidates to receive the same vote count (2,190)?
2. Is the number of undervotes surprisingly high?

Two things may be worthy of mention about the tie vote. First, while the number of total votes is the same, according to the published results the number of votes from different sources varies:

Candidate	Election Day	Absentee	Provisional
Vince Witherup	2,124	65	1
Timothy S. Brooks	2,110	78	2

Second, since the next-highest vote total is 1,944 (Fred Weaver), for the outcome of the race to be incorrect a substantial number of votes would have needed to be mis-assigned.

An initial step toward answering this question would be to use the ballot image log to produce counts of how many voters selected two candidates, one candidate, or zero candidates; the zero-candidate case could be compared to the undervote rate in other Republican races; the one-candidate voters could be broken down by which single candidate was voted for; and the two-candidate voters could be categorized by which pair of candidates were selected.

These detailed results could be examined by people conversant with the candidates and local political sensibilities. More-detailed statistical analyses are possible, e.g., breaking some of these questions down by precinct.

"Cornplanter 1": Missing write-in votes?

Reportedly two voters report casting write-in votes for Thomas Jarzab for Cornplanter Township Supervisor but they also report not seeing those write-in votes on the iVotronic final results printout.

The EL155 "ballot-image log" file shows two write-in votes matching this description, one Republican-ballot vote cast for "Thomas J Jarzab" and one Democratic-ballot vote cast for "Thomas Jarzab." A review of a copy of the iVotronic final-print tape, provided by Jil McAleer, shows both of those votes in the respective write-in areas.

It is possible that the individual(s) reporting the votes as missing saw a printout damaged in some way. If that record is still available, it might bear further investigation.

3.3 Election-Computer Integrity

We were asked to investigate issues relating to the integrity (in a computer security sense) of the Unity tabulation computer we examined.

Time span of machine use?

When was the machine used for election preparations?

Remote access?

Was the machine remotely accessed and/or connected to a non-Elections network? If so, in what circumstances?

Extra software?

Was extra software installed on the machine?

Removable read/write media?

Were removable media (such as USB "flash drives") used on the system?

3.4 Auditability of iVotronics and Unity

We were asked to investigate and comment on the extent to which the iVotronic voting terminals and Unity tabulation software can be audited, and on the amount of effort involved. This issue is complex and will require the presentation of some background information in Section 4 and Section 5 before being explicitly addressed in Section 7.3.

4 Voting-System Risk Framework

There are many ways in which an election process might produce incorrect results, i.e., results that do not reflect the combined will of exactly the eligible voters who voted. The following taxonomy is presented as background information bearing on the question of whether the 2011 Venango County municipal primary produced accurate results.

Imagine that we begin with a pool of people entitled to vote, with opinions about candidates. The desirable end state is that the votes of all of those people but no others, accurately reflecting their opinions, are collected and totaled. Many steps might go wrong.

Eligible voters might not vote

Some eligible voters might not appear—for example, a voter's registration might not appear, a voter with a disability might find a polling place inaccessible, a voter might be deterred by bad weather, a voter might be intimidated into staying home, or a voter might be incorrectly rejected by poll workers. These issues are outside the scope of this report.

Extra voters might vote

Poll workers might allow people who aren't legitimate voters to vote, either intentionally or because they are successfully deceived. This issue is outside the scope of this report.

Extra votes might be cast

Poll workers might allow people to cast multiple votes (either intentionally or because they are successfully deceived, e.g., by disguises and false identification), or they might cast multiple votes intentionally themselves. A voter might submit an absentee ballot and then vote at the polling place (this is legal in some circumstances), but the poll workers might not notice that the voter had appeared and might not void the absentee ballot. These issues are outside the scope of this report.

Votes might be improperly influenced

A voter might be convinced (through promise of reward, or through intimidation) to vote in a particular way; it is possible that the purchaser or intimidator would try to obtain proof of how the voter voted. This issue is outside the scope of this report.

Voter conceptual confusion

A voter might wish to vote for a candidate or issue that is outside that voter's scope (e.g., a suburban voter might ask how to cast a vote on a city tax policy) or wish to vote in an impossible fashion (e.g., a voter in a primary might ask how to cast a straight-party vote). This issue is outside the scope of this report.

Confusing ballot layout

A voter intending to vote for a candidate might accidentally select a different candidate. One famous example of this is the "butterfly ballot" used in the 2000 presidential election in Palm Beach County, Florida. Confusion induced by ballot layout is also one hypothesis for the unusually high undervote rate in the 2007 Florida Congressional District 13 (CD13) election. This issue is outside the scope of this report.

Accurate presentation of ballot

If a voter is shown an incorrect ballot, e.g., one with a candidate or even a race missing, the voter may fail to cast a vote as intended. This will be discussed in Section 7.1.

Accurate sensing of voter choices

A DRE voting terminal must process voter input in order to determine which choices the voter is indicating. (A paper-ballot system must also perform a sensing job, but in that case it occurs after the voter casts the paper ballot.) This will be discussed in Section 7.1.

Accurate manipulation of ballot

Electronic voting terminals, such as the iVotronic, typically show voters a "review" or "summary" screen, displaying, for each race, the candidate(s) chosen by the voter. The intent is that the voter can verify that mistakes were not made while interacting with previous screens before actually casting the ballot. Note, however, that academic research on voting-machine usability has shown that voters may not notice when a summary-screen display shows a ballot vastly different than what the voter intended. The Ph.D. dissertation work of Sarah P. Everett at Rice University [7] investigated what happened when a specially-constructed voting machine deliberately flipped votes, and even deleted or added races. Approximately 60% of the voters failed to notice these changes, as displayed on the summary screen, before casting their ballots. This issue will be discussed in Section 5.

Accurate recording of ballot

Once a voter commits to voting a ballot, a DRE voting terminal must record the voter's choices accurately (i.e., not record other choices). This issue will be discussed in Section 5.

Durable storage of ballot

A DRE voting terminal must reliably store votes without modification or deletion after they are cast. One notable failure to store votes occurred in November 2004 when a Unilect Patriot voting machine "filled up" after storing 3,005 ballots—but kept accepting votes from voters [10]. Durable storage arguably should include some degree of tamper-protection and/or tamper-detection. This issue will be discussed in Section 5.

Accurate assignment of votes to candidates

When a tabulation system receives vote data, it must correctly assign each vote from a ballot to the correct candidate. While this may sound easy, in general it is not. In some situations, where voting involves "ballot rotation," or when certain voting methods are used, such as instant runoff, ranked choice, or weighted voting, assignment is complicated enough for mistakes to be possible. This issue will be discussed in Section 5.

Accurate combining of ballots into totals

This too can be complicated. For example, if a candidate is running as a representative of multiple parties, the tabulation job is complicated because votes must be attributed not to the candidate as a person but to the candidate's ranking in each race or sub-race. This issue will be discussed in Section 5.

Ideally each step is "auditable" in this sense: after the fact, people can examine the inputs to the step and the outputs from the step and agree that those inputs should have resulted in those outputs. For example, given a list of absentee ballots delivered to the polling place and a list of voters who filed an absentee ballot but then voted at the polling place, everybody should agree on which absentee ballots should have been canceled instead of being counted. Or, given a list of the voters who appeared at a polling place and their party affiliations, everybody should agree on how many ballots of each party's ballot style should have been cast at the polling place. A step is "more auditable" if auditing it requires fewer tools, less technical knowledge, less effort, etc.

Some steps are challenging to audit for privacy reasons. For example, it would be possible to completely audit the actions of an iVotronic by videotaping the actions of all voters using it throughout the day. However, that is illegal. Auditability in other cases may depend on carefully

documented chains of custody (if material is audited after being tampered with, the audit will not be meaningful).

5 iVotronic Data Flow

In order to discuss below (Section 7.3) the auditability of the iVotronic voting terminals with respect to a defined set of specific risks (Section 4), we briefly summarize issues relevant to how the iVotronic operates.

Ballot presentation and preparation

When a voter chooses candidates on various screens, the iVotronic composes an internal representation of the voter's choices. For example, when a voter presses on a defined area of the screen, the iVotronic draws a check mark and stores a representation of the candidate's "position" (i.e., race and candidate number[3]) on the particular style of ballot being operated on. Ideally there is a perfect correspondence between the voter's presses and what the machine decides has been selected. The code to do this is somewhat complex. The primary mechanism for "auditing" the results of this process is up to the voter: when some part of the screen is pressed, is the right part of the screen marked? Note, however, that only the voter can perform this "audit," and only while in front of the machine.

Ballot summary

When the voter reaches the summary screen(s), the iVotronic transforms its internal representation of the voter's choices into an on-screen display. Note that the code for this step is necessarily different from the code for the previous step, as the summary-screen layout is structurally different from that of the voting screens. It is hoped that the "reverse code" that displays a ballot on the summary screen is compatible with the "forward code" that turned voter presses into the ballot representation. Again, the primary mechanism for "auditing" the results of this process is up to the voter: does the summary screen contain exactly the selections the voter made on earlier screens? Recall that, according to the academic study mentioned above, a significant fraction of voters may skip this step or perform it incorrectly. This is an issue because, again, only the voter can perform this step, and only while in front of the machine. When the next step happens, all evidence of this step is permanently lost. (Voting terminals *could* be designed to retain relevant information, see Section 6.4.1 of the SAIT study [11].)

Ballot recording

When the voter presses the "Vote" button, the hope is that the iVotronic stores the same ballot information that it displayed to the voter using the "summary-screen reverse code." This step cannot be audited by the voter, because the voter cannot observe the flash-memory storage inside the iVotronic. Nor can it be audited by anybody else later, because by that time the contents of the summary screen are permanently lost. It is unlikely that this step goes wrong *frequently*—if it did, surprising election outcomes would be common and might stand out statistically (e.g., compared to outcomes of absentee ballots). The authors of the SAIT study, who had access to the iVotronic source code, commented favorably on the quality of the

[3]The situation is more complex for write-in votes.

code that stores ballots (Section 8.4.21). However, if a very unusual outcome were observed, it might be desirable to audit the operation of this code as opposed to trusting its operation.

Printing of the polling-place results tape

At the end of the election, one iVotronic in each polling place is used to print a final-results tape. This iVotronic, which has access to all votes cast in the polling place "collected" onto one PEB, turns various stored ballot information into a paper printout. This, too, is "reverse code" in the sense that it transforms a representation of the voter's intent into a readily viewable form. Note that this "reverse code" is inherently different than the summary-screen code, because it prints a summary of many ballots instead of displaying one ballot. Auditing the operation of this code is difficult because the content and operation of PEBs is proprietary. The functioning of this code can be compared to that of other bodies of code (see the next two paragraphs), but that provides only indirect and partial assurance.

Unity collection from PEBs

Typically initial results on the night of an election are obtained by uploading, from each polling place, the contents of the PEB holding all of the vote data. Unity then generates vote totals for all races. This "reverse code" that reads the PEB and enters information into a race/candidate database is inherently different than the previous bodies of code. Auditing the operation of this code is difficult because the PEBs and Unity's internal database are both proprietary. To some extent the previous body of code, this body of code, and the next body of code act to mutually check each other.

Unity collection from flash cards

Typically "after the dust settles," e.g., the day after an election, all flash cards from all iVotronics are loaded into Unity. Unity then generates vote totals for all races; these vote totals should match the PEB totals and should also match any manual computations done from paper final-results tapes. The "reverse code" that reads a flash card and enters information into a race/candidate database is inherently different than the previous bodies of code. Auditing the operation of this code is difficult because the formats of the flash cards and of Unity's internal database are both proprietary. To some extent the previous two bodies of code and this body of code act to mutually check each other. However, since no one of them can be audited without access to proprietary data, the behaviors of the three bodies of code, as a group, cannot readily be audited.

Note that the operation of these bodies of code can be tested, to some extent, by holding mock elections in which people cast predetermined (or recorded) votes and then the vote totals produced by various means are checked. However, computers are very complicated (see the SAIT report for examples of things that might potentially go wrong inside a voting machine). It is precisely when the operation of a computer goes wrong in an obscure and unexpected way that it is useful to be able to audit its behavior.

Auditing is one tool to provide credibility; others exist. For example, these bodies of code could be subjected to rigorous analysis which would prove their operation correct to a very high degree of likelihood. Alternatively, they could be produced using "high-assurance development methods." It is not believed that currently-deployed electronic voting machine software was either proven correct or developed using high-assurance methods.

When analyzing a system of this complexity it may be useful to compare it to other systems that perform similar jobs. Systems in which voters mark paper ballots have auditability characteristics which are very different. It may be less convenient to preserve and securely duplicate paper ballots, but many of the steps discussed above either are unnecessary or can be readily audited. For example, there is no need to audit the step of generating a summary from a paper ballot, because the voter does that (to whatever degree of accuracy) by visually scanning the paper—there is no code, proprietary or otherwise, involved. Likewise, while there are non-trivial sensing issues involving paper ballots, the encoding of those ballots (marks on paper) is not proprietary, and they can be scanned by machine or by human eyes, or both, repeatedly.

6 Observations

Based on examining the state of the forensic clone of the hard disk drive of the Venango County tabulation computer, and by booting a copy of that disk on another computer, examining files found there, and running the Unity program, we present a variety of observations. These can be summarized as follows:

- It seems likely that the computer experienced a transient hardware failure in April.
- The computer appears to have been connected via a network which was also connected to a machine which has at other times been connected to a different network.
- It appears that remote-access software was installed on the computer after it was purchased. This software appears to have been used at least once for a non-trivial amount of time.
- Various remote-access settings are configured in a way that is probably unwise.
- We observed an anomaly related to a "log file" obtained from Unity.

In addition, we ran a voting-data analysis program provided by Professor Buell, yielding the following results.

- In a general, non-exhaustive sense, the vote totals reported on the Venango County web site are supported by information collected from iVotronics.
- In the case of two precincts, anomalies were observed that, at present, suggest reduced attestation of certain votes. Further investigation is warranted in these cases.

6.1 Examination of Tabulation Computer

Here we present more detail on some of the issues mentioned above related to the contents of the machine whose disk we imaged.

Probable memory error

According to the Windows operating system event log, it is likely that on April 19, 2011, the tabulation computer experienced a memory error which crashed the "Election Data Manager" application. The operator of the application probably saw a pop-up window explaining that an error had occurred and that the application had been forcibly shut down.

At present it is difficult for us to say much about what caused this event or how important it might be. Here are some possibilities to consider.

First, it is literally possible that the memory error was caused by a cosmic ray or other rare, unpredictable event, and that the machine immediately detected the memory error before it affected the output of the program (in this case, given the date of the event, the machine was probably being used for ballot layout).

However, it is also possible that the error was due to "wear and tear" on the memory chip, and that there have been other errors that were not detected, in which case it is possible that some answers previously produced by the machine were wrong, or that things done by the machine presently or in the future will be wrong.

For a "regular" PC, being used to send and receive e-mail and work on documents and spreadsheets, a single memory error would probably be no cause for alarm, and it would make sense to take a "wait and see" approach, escalating the response if more errors occurred.

Due to the sensitivity of this machine, however, it might make sense to act more aggressively. Here are some options:

- Depending on the features of the PC in question and the kind of memory which was purchased for it, the BIOS may contain a hardware event log which might list more memory-error events. If so, it might be possible to determine whether there is an indicative pattern of errors.
- It would also be possible to run a specialized memory testing program on the machine (this needs at least two hours to produce meaningful results, and really should be run overnight), or to remove the memory from the machine and test it using a dedicated memory tester (which would provide a useful indication in under an hour).
- It would also be possible to preemptively replace the memory in the machine with other memory tested or otherwise believed to be good.

Network connectivity

The computer appears to have been connected via a network which was also connected to a machine which has at other times been connected to a different network. In particular, the Windows operating system's printing component has stored a list of printing servers that it has previously contacted; the name of one of those print servers suggests it is not one of the machines in the Elections equipment room. Furthermore, one of the printers that the print server in question manages appears to be named after an organization that is not obviously part of the Venango County government.

Remote access software

Based on information from my colleague Gregory Kesden, a remote-access application was probably installed on November 2, 2009. Based on information from the Windows operating system's event log, this program was used on multiple occasions. The most recent significant usage is probably 80 minutes on November 1, 2010. Based on observing the behavior of the system while it is running, that application is configured to launch when the system boots. Given the information readily available to us, it is not possible to determine which other system accessed this system. For example, the other machine could well have been in the same room.

Settings which cause concern

The access-control settings of various remote-access applications appear to be excessively lenient.

Unity "log file" anomaly

When requested, Unity will produce a file named EL68A.LST. The documentation [9] describes this file as follows:

> System Log: Generate a System Log report to list every action performed in your election system in chronological order.

However, some records appear *not* to be in chronological order. Here is an excerpt from the EL68A file found on the computer when we imaged it:

```
05-13  01:34 pm  DATABASE RESET
05-13  01:34 pm  THERE ARE NO VOTING TERMINAL AUDIT DATA TO BE CLEARED
05-13  01:34 pm  CLEARED CONSOLIDATED AUDIT DATA
05-13  01:34 pm  EXITED ELECTION REPORTING MANAGER SYSTEM
05-13  01:35 pm  EXITED ELECTION REPORTING MANAGER SYSTEM
07-09  12:05 am  ENTERED ELECTION IN ELECTION REPORTING MANAGER
07-09  12:07 am  ELECTION SUMMARY-GROUP DETAIL WAS PRINTED TO EL45A.LST
07-09  12:07 am  EXITED ELECTION REPORTING MANAGER SYSTEM
07-09  12:11 am  ENTERED ELECTION REPORTING MANAGER SYSTEM - REL 7.1.2.0^M
07-09  12:11 am  PRECINCT REPORT-GROUP DETAIL WAS PRINTED TO EL30A.LST
07-09  12:12 am  EXITED ELECTION REPORTING MANAGER SYSTEM
05-16  03:39 pm  ENTERED ELECTION REPORTING MANAGER SYSTEM - REL 7.1.2.0^M
05-16  03:40 pm  ELECTION SUMMARY-GROUP DETAIL WAS PRINTED TO EL45A.HTM
05-16  03:57 pm  ELECTION SUMMARY-GROUP DETAIL WAS PRINTED TO EL45A.HTM
05-16  04:19 pm  ENTERED ELECTION IN ELECTION REPORTING MANAGER
05-16  04:21 pm  EXITED ELECTION REPORTING MANAGER SYSTEM
05-16  04:25 pm  EXITED ELECTION REPORTING MANAGER SYSTEM
```

In addition, we ran a voting-data analysis program provided by Professor Buell, which flagged the following results as anomalous (among others):

Oil City 5

The vote totals reported by the County do not appear to be fully supported by the data obtained from the "ballot image log" file (EL155.LST) generated by Unity. In particular, roughly 40 votes were certified for which a "ballot image" is not clearly available. This discrepancy does *not* by itself suggest any particular cause or motivation; it is possible that this situation results from a single iVotronic's flash card having been lost or unreadable. The vote data which were not observed may well be present in an iVotronic's internal memory, and it is very likely that the vote totals represented by the data were printed on the polling-place result tape.

Richland Township

Professor Buell's tool reported it was unable to locate any "ballot image" data reported by

iVotronics used in Richland Township. According to Professor Buell, this situation has been observed in South Carolina to be related to a configuration or database discrepancy between Unity and iVotronics which can cause Unity to reject ballot-image data from iVotronics. Again, this issue does *not* by itself imply any particular cause or motivation; we are informed that a check of the polling-place result tape suggests that the official election results are in line with the number of voters who appeared in the Richland Township polling place on the day of the election.

7 Answers

Here we present answers to some questions raised above which require extended treatment and/or background information.

7.1 Candidates Missing from iVotronic Ballot Display?

With respect to the report from "Cornplanter 2" that Stan Grzasko and Jessica M. Deets-Snyder were missing from the ballot, we make the following observations.

1. In Cornplanter 2, the official results show 113 ballots cast (107 "election day" and 6 absentee) by all voters.

2. The "ballot image log" shows 107 votes recorded on iVotronics V5164351, V5182617, and V5185960.

3. Twenty-two votes for Stan Grzasko were recorded on the three iVotronic terminals (7 on V5164351, 9 on V5182617, and 6 on V5185960). This matches the number of "election day" votes in the official results.

4. The situation is more complicated for Jessica M. Deets-Snyder, who was seeking both the Republican and Democratic nominations for two school-board seats (two-year and four-year). Here the "ballot image log" shows votes recorded, on each of the three iVotronics, from voters of each party, in both races; a hand tally of the vote totals matches the numbers reported on the web site.

This suggests that, regardless of which machine machine was used by Mr. Dinberg, some voters were able to cast votes for Stan Grzasko and Jessica M. Deets-Snyder on that machine.

In terms of anomalies reported by the iVotronics, these log records appear to be relevant to Cornplanter 2. For clarity, they have been reformatted to explicitly show iVotronic number and PEB number on every line (the original log file replaces iVotronic numbers and PEB numbers with blanks when they are identical on successive lines).

```
5164351  217396  SUP   05/17/2011 12:29:24   0001718 PEB pulled during PEB block read
5164351  217396  SUP   05/17/2011 14:09:17   0001649 Term - entered service menus
5164351  217396  SUP   05/17/2011 14:09:21   0000169 Select: Calibrate Screen
5164351  217396  SUP   05/17/2011 14:10:00   0001652 Terminal touch-screen test
5164351  217396  SUP   05/17/2011 14:10:08   0001655 Terminal touch-screen recalibrated
5164351  217396  SUP   05/17/2011 14:10:11   0001650 Term - exited service menus

5182617  197777  SUP   05/17/2011 13:56:38   0001649 Term - entered service menus
```

```
5182617  197777  SUP   05/17/2011 13:56:46   0000169 Select: Calibrate Screen
5182617  197777  SUP   05/17/2011 13:57:17   0001652 Terminal touch-screen test
5182617  197777  SUP   05/17/2011 13:57:52   0001652 Terminal touch-screen test
5182617  197777  SUP   05/17/2011 13:57:57   0001655 Terminal touch-screen recalibrated
5182617  197777  SUP   05/17/2011 13:58:12   0001650 Term - exited service menus
5182617  217396  SUP   05/17/2011 14:05:11   0001649 Term - entered service menus
5182617  217396  SUP   05/17/2011 14:05:14   0000169 Select: Calibrate Screen
5182617  217396  SUP   05/17/2011 14:05:53   0001652 Terminal touch-screen test
5182617  217396  SUP   05/17/2011 14:06:01   0001655 Terminal touch-screen recalibrated
5182617  217396  SUP   05/17/2011 14:06:05   0001650 Term - exited service menus

5185960  217396  SUP   05/17/2011 12:23:03   0001633 Terminal shutdown
5185960  217396  SUP   05/17/2011 12:23:45   0001633 Terminal shutdown
5185960  217396  SUP   05/17/2011 12:24:26   0001649 Term - entered service menus
5185960  217396  SUP   05/17/2011 12:24:42   0000169 Select: Calibrate Screen
5185960  217396  SUP   05/17/2011 12:25:14   0001652 Terminal touch-screen test
5185960  217396  SUP   05/17/2011 12:26:29   0001652 Terminal touch-screen test
5185960  217396  SUP   05/17/2011 12:27:28   0001652 Terminal touch-screen test
5185960  217396  SUP   05/17/2011 12:28:16   0001652 Terminal touch-screen test
5185960  217396  SUP   05/17/2011 12:29:20   0001652 Terminal touch-screen test
5185960  217396  SUP   05/17/2011 12:30:14   0001655 Terminal touch-screen recalibrated
5185960  217396  SUP   05/17/2011 12:30:14   0001650 Term - exited service menus
5185960  217396  SUP   05/17/2011 14:06:18   0001649 Term - entered service menus
5185960  217396  SUP   05/17/2011 14:06:21   0000169 Select: Calibrate Screen
5185960  217396  SUP   05/17/2011 14:07:05   0001652 Terminal touch-screen test
5185960  217396  SUP   05/17/2011 14:07:46   0001655 Terminal touch-screen recalibrated
5185960  217396  SUP   05/17/2011 14:07:53   0001650 Term - exited service menus
5185960  0       UNK   05/17/2011 20:01:27   0001721 PEB pulled while getting PEB type
5185960  0       UNK   05/17/2011 20:01:27   0002405 Failed to get PEB type
5185960  0       UNK   05/17/2011 20:01:27   0002400 PEB access failed
5185960  0       UNK   05/17/2011 20:01:27   0002400 PEB access failed
5185960  0       UNK   05/17/2011 20:01:29   0002400 PEB access failed
5185960  0       UNK   05/17/2011 20:01:29   0000706 Failed to retrieve EQC from PEB
5185960  0       UNK   05/17/2011 20:01:29   0001635 Terminal shutdown - IPS exit
```

The "PEB pulled during PEB block read" condition reported by V5164351 is consistent with a poll worker inserting a PEB and accidentally removing it before the iVotronic has finished activating. This is also a plausible explanation for the "UNK" activity reported by V5185960.

It is clear from these log records that the screens of these three iVotronics were recalibrated during the election (one iVotronic was apparently calibrated twice).

With respect to the report from "Oil City 2," that Ron Gustafson was missing from the Oil City Council part of the ballot, we make the following observations.

1. In Oil City 2, the official results show 116 ballots cast (111 "election day" and 5 absentee) by all voters.

2. The "ballot image log" shows 111 votes recorded on iVotronics V5168609, V5177633, V5178563, and V5179516.

3. Seventy votes for Ron Gustafson were recorded on the four iVotronic terminals (16 on V5168609, 17 on V5177633, 13 on V5178563, and 24 on V517951).

This suggests that, regardless of which machine machine was used by Mr. Bowers, some voters were able to cast votes for Ron Gustafson on that machine.

In terms of anomalies reported by the iVotronics, these log records from two machines appear to be relevant to Oil City 2 (the other two machines mentioned above appear to report only normal events). These log records have been reformatted as described above.

```
5168609  197207  SUP   05/17/2011 06:21:03   0002808 Terminal - opening state
5168609  197207  SUP   05/17/2011 06:21:52   0001303 Transfer PEB vote data to terminal
5168609  197207  SUP   05/17/2011 06:21:52   0002400 PEB access failed
5168609  197207  SUP   05/17/2011 06:21:52   0001702 Invalid PEB for procedure
5168609  197207  SUP   05/17/2011 06:21:52   0001634 Terminal shutdown - DIE exit
5168609  0       UNK   05/17/2011 06:22:01   0002804 Terminal - blank state
5168609  197207  SUP   05/17/2011 06:22:11   0002808 Terminal - opening state
5168609  197207  SUP   05/17/2011 06:22:45   0001303 Transfer PEB vote data to terminal
5168609  197207  SUP   05/17/2011 06:22:50   0002804 Terminal - blank state
5168609  197207  SUP   05/17/2011 06:22:51   0002802 Terminal - open state
5168609  197207  SUP   05/17/2011 06:22:51   0002808 Terminal - opening state
5168609  197207  SUP   05/17/2011 06:22:51   0001319 Update PEB's terminal record
5168609  197207  SUP   05/17/2011 06:22:51   0001303 Transfer PEB vote data to terminal
5168609  197207  SUP   05/17/2011 06:22:56   0001210 Transfer terminal vote data to PEB
5168609  197207  SUP   05/17/2011 06:23:21   0001211 Terminal votes to PEB successful
5168609  197207  SUP   05/17/2011 06:23:43   0002802 Terminal - open state
5168609  197207  SUP   05/17/2011 06:23:56   0001672 Terminal Opened

5178563  197207  SUP   05/17/2011 06:17:59   0001649 Term - entered service menus
5178563  197207  SUP   05/17/2011 06:18:10   0000169 Select: Calibrate Screen
5178563  197207  SUP   05/17/2011 06:18:46   0001652 Terminal touch-screen test
5178563  197207  SUP   05/17/2011 06:19:07   0001655 Terminal touch-screen recalibrated
5178563  197207  SUP   05/17/2011 06:19:24   0001650 Term - exited service menus
```

It is unclear how to describe the anomalous log records attributed to V5168609. For some reason, it appears that the machine declared PEB 197207 to be "invalid" but then, approximately a minute later, was opened successfully using that same PEB.

iVotronic V5178563 appears to have had its screen recalibrated just after it was opened in the morning.

The evidence reviewed above does not immediately suggest an explanation for the experiences reported by Mr. Dinberg and Mr. Bowers. Multiple hypotheses might be considered, including:

Inconsistent screen rendering

If an iVotronic voting terminal were somehow drawing ballots (of the "same style," e.g., Democratic vs. Republican in a primary) differently for different voters, that would be a serious failure. According to the information available to us, iVotronics in Venango County display pre-rendered ballots. If this is true, it would be unlikely that multiple displays of the same pre-rendered ballot would appear differently on the screen. Computers are complicated, and the code for this function was not reviewed as part of this study, so this possibility cannot be ruled out based on the information available.

Multiple, inconsistent ballot styles

Based on information available to us, it would be possible for an iVotronic terminal to be "programmed" with multiple ballot styles for the same party, e.g., two different ballots showing

Democratic candidates and/or two different ballots showing Republican candidates. Based on our understanding, this situation would most likely be very visible to the poll worker activating the iVotronic for each voter, as the poll worker would need to choose among more than the expected two ballot styles (Democratic and Republican). Since ballot-style selection usually takes place while the voter is watching, it seems reasonably likely that some voters would notice and ask about this oddity.

It is possible to imagine that the iVotronic programming is such that the system would allow multiple ballot styles with the same name and different contents to be "programmed," and that the iVotronic would display one or the other at different times. It was not possible to investigate whether or not this is possible within the constraints of this study.

Side effects of screen-calibration problems

A third possibility is suggested because both voters reported not only missing candidates but also screen-calibration problems, with those problems being corroborated by the iVotronic audit data. Perhaps struggling with the screen-calibration issues distracted the voters in some way, perhaps by causing them to focus their attention on the area of the screen that was misbehaving and thus reducing the amount of attention for other parts of the display.

Unfortunately, the best possible data source is unavailable to us, namely a picture of an incorrect display. Of course, such a picture would demonstrate that indeed a particular candidate is missing. But the *remainder* of the display, i.e., what was displayed where the missing candidate should have been, and how was the empty screen real estate filled in, would shed much light on the cause of such a failure. In the other direction, it would be possible for experts in Human-Computer Interaction to run a study on possible negative side-effects of touchscreen mis-calibration. It also might be possible to track down the particular iVotronics in those polling places and subject them to analysis (to look for extra ballot styles) and/or testing (though, because the screens have been recalibrated, such testing might be inconclusive).

At this time, given the information examined so far, we are not able to come to a definitive explanation of the experiences reported by Mr. Dinberg and Mr. Bowers. They should be commended for speaking up about their concerns; if an irregularity had been uncovered, it would have been as a result of their willingness to come forward. In general, speaking as a poll worker, voters who encounter trouble while voting should ask poll workers for help or, failing that, should consider following the procedure for obtaining help from a fellow citizen of their choice. Also, it would probably be wise for counties to authorize poll workers and/or roving support staff to make photographic or video evidence in the case of anomalous machine failures.

7.2 Election-Computer Integrity

We were asked to investigate issues relating to the integrity (in a computer security sense) of the Unity tabulation computer we examined. Here is a wrap-up of our findings, some of which are discussed earlier.

Time span of machine use?

When was the machine used for election preparations?

According to the Windows event log, the machine was turned off between January 18, 2011 and March 18, 2011. It was used on March 18 and on these dates in April: 15, 18, 19, 20,

25, 26, 27, 29. It was used in these dates in May: 1, 3, 5, 6, 9, 13, 16, 17, 18, 19, 20, 24, 26. It was used on June 1 and then not used again before the disk was cloned. The machine was not observed to be left running from one day to another.

Remote access?

Was the machine remotely accessed and/or connected to a non-Elections network? If so, in what circumstances?

As far as we can presently determine, insufficient data is available to conclusively list all machines or networks that the machine we studied has been connected to or to conclusively list all times that remote access to the machine occurred. However, there is substantive evidence that the machine we studied is configured, and has been connected to networks, in such a way as to threaten, or at least cast doubt on, its integrity.

Extra software?

Was extra software installed on the machine?

That appears to be the case (see Section 6.1).

Removable read/write media?

Were removable media (such as USB "flash drives") used on the system?

Information provided to me by my colleague Greg Kesden indicates that USB "flash drives" were mounted by the system on multiple occasions.

7.3 Auditability

Based on our understanding (see Section 5), many steps of the operation of iVotronic voting terminals are infeasible to audit by a third party after the fact. Some can be investigated by individuals with access to the proprietary program source code (this was the basis of the SAIT study [11] and the EVEREST study [8]). In the past, such investigations have required a large staff and multiple months, suggesting they are frequently not practical to carry out between an election with surprising results and when that election must be certified.

Based on our understanding, many steps of the operation of the Unity tabulation system involve proprietary code operating on data stored in proprietary formats. Auditing the operation of Unity, too, could likely be done by individuals with access to the proprietary program source code. It is not clear to us how time-consuming such an investigation would be.

8 Recommendations

Setting policy for Venango County elections is the province of the Board of Elections. However, the author of this report wishes to beg the indulgence of the Board by suggesting some specific courses of action which might improve operations and voter confidence.

- Developing an explicit written security protocol governing the practices of Elections staff seems advisable.
- Given the importance of the results of computations performed on Elections computer hardware, it might be wise to institute a policy for routine checks of hardware health, e.g., DRAM

testing, monitoring BIOS event logs, and performing SMART checks on, and regular secure backups of, hard disk drives.

- As long as iVotronics are used, or at least as long as a firmware version including the "factory-test PEB" vulnerability is deployed, institute a firmware verification program along the lines of the one practiced in Allegheny County [6].
- It might be desirable to inquire of the Secretary of the Commonwealth about an upgrade to the iVotronic firmware to remote said vulnerability.
- The Board may wish to release voting-system data which would enable analysis by interested citizens; the data released in South Carolina would represent a good starting point.
- This report benefited from the availability online of the Unity manual [9]. Perhaps the Secretary of the Commonwealth could make such documentation available in Pennsylvania as well.
- In general, speaking as a poll worker, voters who encounter trouble while voting should be encouraged to ask poll workers for help or, if that doesn't suffice, should consider following the "assisted voter" procedure in order to obtain help from a fellow citizen of their choice. Also, it would probably be wise for counties to authorize poll workers and/or roving support staff to make photographic or video evidence in the case of anomalous machine failures.
- Ideally, future voting systems would be designed with a clean separation between code and data, i.e., all program code would be static and stored on read-only media, while read-write media would contain only ballot configuration data, election management data, and voting results data. Additionally, a clear separation between election configuration data and election results data would enable a "configuration freeze" which could reduce the likelihood of databases losing synchronization with voting terminals. Also, transparency could be improved by a clear separation (e.g., different parts of a file system or different file systems) between data in proprietary formats, if any, and data which can be released at the Board's discretion.
- The routine use of the best available auditing tools for a given election system should be encouraged.
- When purchasing election systems, an explicit focus on auditability might be desirable.

9 Future Work

Various further work could be carried out to evaluate the Venango County 2011 Municipal Primary. Some items are particularly worthy of note, however.

- Professor Buell could be requested to report in greater detail on the anomalies detected by the analysis tool his team has produced. It seems likely that a noticeable increase in clarity might result from approximately a week's work.
- A voting statistician, given access to data similar to that used by the South Carolina team's tool, might be able to comment on the various undervote issues that were raised. Again, it is plausible that a noticeable increase in clarity might result from approximately a week's work.

- Further investigation, perhaps by a party with access to proprietary knowledge, could suggest whether multiple ballot styles, or problems with ballot display, could explain the phenomena reported by voters in "Cornplanter 2" and "Oil City 2."

10 Conclusions

We carried out an examination of the contents of the Venango County Unity tabulation computer. This examination included an investigation of selected computer security issues, consultation of documentation on the Unity tabulation software, observations of limited operation of Unity, the generation and examination of various and report files generated by Unity.

Broadly speaking, our findings are as follows:

- We were unable to find evidence to either support or conclusively refute voter reports that certain candidates were unavailable on the iVotronic display for some voters to select.
- In some cases where specific concerns were raised about election outcomes, we were able to find evidence consistent with a correct outcome. Public release of detailed voting data would enable others, including statisticians, to further investigate these and other issues.
- We found evidence that some Elections staff processes and practices are inadvisable with respect to computer security considerations. We recommend that Venango County develop and adopt a written security protocol, including processes for measuring and monitoring compliance. Such a protocol would cover *at least* physical access (logging, requirements for multiple witnesses), passwords, network connectivity, and removable media.
- We found evidence of misconfiguration and operational problems with Unity, in particular evidence that some iVotronic data could not be collected and tabulated by Unity.
- Because of the anomalies uncovered by the South Carolina team's tool, and to generally improve citizen oversight and confidence in the election process, we recommend that the Board institute a policy implementing the routine release of detailed vote data, in as close as possible to its original, pre-processed form, to the public. While the exact details of what is released in which circumstances should be a matter of public discussion and agreement, the availability of specific iVotronic and Unity data in South Carolina should be considered as a starting point (e.g., it may be possible to improve on that process by releasing data pre-certification to enable detection and remediation of anomalies before results are finalized).
- We found multiple reasons to be concerned about the practicality and completeness with which the operation of the iVotronic voting terminals and the Unity tabulation software can be audited.
- If iVotronic DRE's will continue to be used by Venango County, we recommend
  - that the Board request the Secretary of the Commonwealth to aggressively pursue firmware upgrades, at least to remedy the "factory-test PEB" vulnerability publicly identified in the 2007 SAIT report and confirmed by the 2007 EVEREST report.
  - that the Board consider instituting a firmware verification process similar to that used in Allegheny County.

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