

# Auditing a DRE-Based Election in South Carolina

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## Abstract

Following a highly publicized and anomalous outcome in the South Carolina statewide Democratic primary South Carolina in June 2010, the authors undertook to audit the election results based on data obtainable through the Freedom of Information Act. The state votes entirely on paperless ES&S iVotronic Direct Recording Electronic (DRE) machines. There is thus no auditable primary data (such as paper ballots), but there are several audit trail files that are produced by the software of the ES&S system. We have analyzed these files and have been able to show that votes were not counted, that procedures that should have been checked automatically were not checked, and that vote data to support the certified counts has not been collected or stored.

## 1 Introduction

The authors undertook an audit of the South Carolina election results of November 2, 2010, using software written by the authors and data obtained by FOIA from the state and its counties. Although the initial examination by the authors began in the summer of 2010 after an anomalous result in the June Democratic primary, it was motivated further by a second anomalous result in the November election—in Colleton County, South Carolina, there were 1389 more total votes certified by state and county officials than were cast in the election, and a correct count for Colleton was not obtained until several incorrect counts had first been published. Following the general election on 11/02/2010 we were able to analyze large volumes of data that we obtained through the Freedom of Information Act.

Several qualifications must be made regarding our analysis and conclusions.

First, we have now obtained and analyzed data from nineteen of the 46 counties, but our data is likely to continue to be incomplete and not entirely definitive. Several

FOIA requests are still outstanding, and we do not have data from the entire state. We also have received only partial data from some counties. And we have one instance of different data contained in the “same” log file (as specified by number) when supplied by two different counties. This makes precise comparisons across the state impossible, but we have tried to be as consistent as possible given the data that we have been able to obtain.

We emphasize that we have found no evidence either of fraud or of software failure in the individual voting machines used in the election. What we have found is evidence of failure in the election *system*. The state has relied, for producing correct results, on procedures that are to be followed in elections [13]. We have requested this document by FOIA but have been provided only the table of contents. Although we thus cannot pinpoint precisely in the procedures the steps that have not been followed, we believe we have identified several failure modes that have led to incorrect counts and problems that could lead to further and undetected incorrect counts. Our software has detected these failures by checking for self-consistency of the vote data and the audit log.

In the process of analyzing the data we obtained of the November 2010 election results in South Carolina, we identified several instances in which vote counts were incorrect and several potential problems that, if repeated in the future, could also lead to incorrect vote counts. We will in this paper first outline the South Carolina election system and explain briefly how and why the failure modes exist. We will then describe the audit data that can be collected (and is supposed to be collected) and how an audit such as ours can detect from that data that errors have occurred. In general, what we have done is verify that the data collected are self-consistent; we will also briefly describe potential problems that diminish the value of the data for audit purposes or that could provide insufficient data to determine that an error had occurred.

## 2 Related Work

There is an extensive literature on auditing elections and election data and the term “audit” is used in many different contexts. Much of the research on auditing concerns the post-election audits that would provide statistical confidence levels in the outcomes of the election [4, 5, 10]. South Carolina, however, has no paper trail except for mail-in absentee ballots; there is no software-independent vote count to sample and compare against machine counts. Some audits are performed as a measure of the quality of the election process, measuring such things as load on the precincts and voting machines and frequency of error events or poll worker intervention. Still other research has been on the design of what should go into audit logs so as to be able to make them more useful in post-election analysis to aid quality improvement for future elections [6, 8, 18, 15]. Finally, the work of Antonyan, et al. [2] describes a formal structure for the analysis of audit logs to determine whether a voting machine has acted “normally” in an election.

Other work has focused on the security issues of voting machines, and in some cases specifically on the ES&S iVotronic machines and Unity software used in South Carolina [9]. We have specifically not addressed these kinds of security issues nor dealt with ways to avert or detect fraud.

Our work instead has dealt with the system in place in South Carolina. We have looked at problems or potential problems that can in fact be detected from the audit log and vote image data that is supposed to be collected as part of the canvass [12]. In all cases, the problems on which we have focused our attention come from a failure of election workers to follow the official procedures and the lack of mechanisms to detect the failures to follow procedure. Our work has been to write programs that can detect the observed failures to follow procedure. We submit that a standard reliability analysis of what could go wrong in an election should have predicted the failures we have seen, and thus that mechanisms such as our code to detect the failures should have been in place. For example, as described below, the standard procedure is that a single “PEB” device be used to open and close all voting machines in a given precinct. We have seen errors that resulted when this procedure has not been followed. Under the pressure of an election day, and especially at the end of a long day, it should have been predicted that mistake of this sort would be made, and appropriate steps to detect and correct for these errors should also have been incorporated into standard procedures. The failures we have seen have come, in essence, from inadequate analysis and thus insufficient mitigation of errors like this at this top level of the election system when treated in the engineering sense as a “system” comprising multiple

components and human users.

This notion that these kinds of failure modes should have been anticipated was in fact the substance of some of the questioning during a subcommittee hearing of the state Senate Judiciary Committee[14], and the South Carolina State Election Commission (SCSEC), since the announcement of our results, has contracted the work of a programmer to develop code analogous to ours.

## 3 The South Carolina Voting System

For the purposes of our discussion here, we present a somewhat simplified view of the election process in South Carolina, together with a description of the “system components” that are included in our audit. The failure modes we have found are in the “system” at the top level—although a set of procedures has been established for poll workers to follow, there have been no checks to verify that the procedures were in fact followed.

Except for the mail-in absentee ballots, which are paper, South Carolina votes entirely on ES&S iVotronic voting machines (“terminals”) with no VVPAT. Each iVotronic is opened for voting on election day using a PEB (Personalized Electronic Ballot), a handheld device about the size of a paperback book. The PEB fits into a recess in the iVotronic and makes connection with the iVotronic via an infrared link with a standard protocol. At the end of an election day an iVotronic can only be closed and its votes collected by the same PEB that opened it<sup>1</sup>.

When the terminals are closed, the “event log” for that machine and the “vote image file” of the individual ballots cast are written to a compact flash memory card slotted into the terminal. The memory cards are then to be pulled from the terminals, placed in a plastic bag, and returned to county headquarters, where the vote image and event log files are to be uploaded into a master file as part of the canvass [12]. The PEBs as part of closing the machines will have accumulated the vote totals (but not the individual data of individual votes) into their internal memory. The PEBs are similarly returned to county headquarters, and their contents are accumulated into a master file that becomes the official and certified count, with a “system log file” recording the upload from the PEBs, among other system events.

### 3.1 Failure modes, detection, mitigation

#### 3.1.1 Relying on the PEB count

The official protocol for tabulating votes uses only the PEBs to collect the totals of the electronic ballots from

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<sup>1</sup>This isn’t quite true; there are “super” PEBs that can also be used, perhaps after the fact to correct for a failure of the precinct workers to close a terminal properly.

each terminal at the time the polls close. Each precinct is provided with one “green stripe<sup>2</sup>” and some number of “red stripe” PEBs. The green stripe PEB is supposed to be used only to open the terminals and to close the terminals; the red stripe PEBs are to be used during the day to open terminals to collect a single vote.

The totals for each terminal are to be downloaded to the green master PEB in each precinct as part of the process of closing each terminal. The totals are carried back to county headquarters in the PEBs and transferred to the Election Report Manager (ERM). The ERM accumulates the totals from the PEBs and produces a report containing the election results for the county.

The paper absentee ballots and the failsafe, emergency, and provisional ballots are included in different ways. These are somewhat harder to audit, the paper ballots because they are counted differently and the other ballots because the election commission must evaluate the legitimacy of those votes. We note that in South Carolina these other votes occur in “virtual precincts” given precinct numbers 750, 751, 752, etc., for absentee votes precinct numbers 800, 850, 851, etc., and 900 for the other votes. Some counties use the electronic (PEB) process to accumulate absentee votes from the terminals, but others create per-precinct totals for the virtual precincts and then make manual adjustments to the totals both for the iVotronic-cast and the paper-cast absentee ballots.

We have observed in Richland County and in Horry County (and will provide details below for Richland County) that votes have not been included in the certified count because more than one PEB was used to open and close terminals, but only the totals from the green stripe PEB were uploaded to the master file. It appears that a similar problem also occurred in Sumter County, but we have not been able to verify that. In Charleston County, the same error occurred both in the November 2008 and 2010 general elections, but the errors were detected and corrected prior to certifying the count. This failure mode exists because the two PEBs are functionally identical. Provided that the compact flash card data has been collected properly and uploaded to the master event log and vote image files, this failure can be detected by processing those files with a program.

### 3.1.2 Failing to collect the flash card data

The state’s Canvass Checklist [12] includes the item: “All flash card audit data has been uploaded into ERM and securely saved to a CD for required 22-month retention period.” This is an action to be taken at the county level. We have observed that in ten of the sev-

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<sup>2</sup>This refers to a green (or red in the case of “red stripe” PEBs) rubber gasket that wraps around the device and covers up the seam between the two halves of the plastic cover for the PEB.

enteen counties for which we have general election data, there were (flash) memory cards that had not been collected from terminals and thus not uploaded, and a few instances in which the data from all machines in entire precincts was missing. The absence data from the flash memory cards can be detected by comparing the certified count against the number of votes in the vote image file. It was usually the case that the discrepancy (the certified count would be larger) was of roughly the same size as the number of votes on other terminals in the precinct, suggesting that one terminal’s data was missing, and in most counties there were probably only a few, perhaps five to ten, missing cards. In Horry County, however, 53 of the 125 precincts had missing data. This can be detected when the certified count is larger. If there is no data from the precinct at all, it is of course harder to determine how many terminals were used in the precinct.

Failing to collect the event log and the vote image file may not be in and of itself a major problem. However, the existence of the vote image and event log data means that the terminal has been closed by some PEB; the contents of the vote image file provides a second count of vote totals that will corroborate the totals from the PEBs; and the contents of the event log provide a way to detect that a PEB has accumulated votes that have not been included in the certified counts. If the PEB were to be cleared and used again (the June primaries in South Carolina were only 14 days apart), one could only detect but could not correct the error because the data could be erased. Some authors [7] have argued that memory cards should be single-use items, but in South Carolina they are normally re-used, so the data collected will routinely be erased.

We note that in one case, in Spartanburg County, the election director’s transmittal letter with the FOIA-d primary data stated that the data from two of the flash cards (out of just under 500) could not be collected because the cards themselves were unreadable. This may have happened elsewhere, but we have not been informed of memory card failures except in this one instance.

### 3.1.3 Failing to close terminals

Although it is almost certainly a problem with any voting machine, not just the ES&S system and the iVotronics, the failure to close a terminal properly can result in votes not being included in the count.

In Bluff Precinct in Richland County, six of the eight terminals were not closed on election night. The fact that they were not closed was not noticed until several days later, and the terminals were not closed until 9 November 2010, after the count had been certified on 5 November. There are several indicators that are produced by the voting system that should have alerted officials to

the existence of unclosed terminals. The paper summary tape, printed off and posted at the precinct door when the polling place is closed, specifically says, in capital letters, “MACHINE NOT CLOSED” for the six terminals in question. And further indication should have come from a count on that summary tape totalling only 254 votes, although the poll book would have recorded more than a thousand signatures. Failure occurred, however, in spite of the indicators. Our programs as written, analyzing the data as available to us, would not have detected this failure prior to certification. However, the addition of a computer-readable list of terminals in use on an election day would have permitted our programs, modified to use this list, to detect this failure prior to certification.

### 3.1.4 Detection and mitigation

Our audit in effect tries to detect these failure modes by accounting for the three sets of hardware devices—iVotronic terminals, PEBs, and flash memory cards. Apart from running programs such as ours or that being written by the state’s contract programmer, the only addition to standard practice that should be made is to create an electronic list of iVotronics by serial number and PEBs by serial number prior to an election. This will permit software to process the audit data and produce an exception list of devices not accounted for in the audit. Absent that, the only way to determine which hardware devices have been used is to cross-reference serial numbers in the various files we have processed, and it is possible for devices to be missed if data is not collected.

1. PEBs: If a PEB is used to open and close terminals, and thus to collect vote totals, then that PEB’s totals must be uploaded into the county totals. As it turns out, it is not really any more effort to account for *all* PEBs in use in an election.
2. iVotronic terminals: All iVotronic machines known to be in use on election day need to be verified as closed before the count is certified.

It is here that a list of serial numbers prepared beforehand is most important in order to prevent terminals from “going missing” and whose absence from the count cannot be determined from the existing audit logs. Terminals appear by serial number in the vote image file and in the event logs, and as they are accounted for they can be checked off the list. Without a list, a terminal not yet closed will not have had its flash card data collected, and the existence of the terminal can only be discovered by the manual check of post-election precinct tapes.

3. Memory Cards: The flash memory cards from each terminal contain the vote image file data and event

log data that corroborate the certified results. If this data is not collected, then other errors can lead to machines being completely overlooked in the counts.

## 4 Our Audit of the Election System

### 4.1 Data files

#### 4.1.1 The vote image file

In addition to using the totals collected from each terminal by the PEBs, a second mechanism by which one can produce a count is to count the individual ballots in the “vote image file”, which has an internal “EL155” file name, and it is this count that has allowed us to detect most of the errors we have seen.

A snapshot of data from this file appears as Appendix A. This file as we have received it, and as the contract programmer for the SCSEC is using it, is essentially a printout file such as one might send to a printer. At the top of each page the precinct is labeled. The delimiter to indicate that a new ballot exists is the asterisk. A single ballot extends from one asterisked line to the next asterisked line, and each vote in a contest appears as a single line of data. The first entry in each line is the iVotronic serial number. The second number is the ballot style number (B/I). The third number is what we refer to as the candidate sequence number. By combining precinct number, iVotronic serial number, ballot style number, and candidate sequence number, one can identify the individual candidate and contest.

A count of the number of asterisks in the vote image file should equal the count of terminal ballots collected in the PEBs, the number of official terminal votes in an election and the number of “vote events” in the event log file. The vote image file is, after all, or should be, a copy of the official master file of all electronic votes cast. The totals in the official counts, derived from the ballot totals collected into the PEBs, should be reconcilable with the counts from the vote image file.

The vote image file is created in the Election Report Manager by accumulating the data from the flash memory cards from each terminal.

#### 4.1.2 The event log file

Our second source of data for the audit has been the “EL152” event log file. This is the accumulation of the individual event logs from each terminal. The event log file is supposed to contain a record of each event that occurs in each terminal<sup>3</sup>. An example of a subset of event

<sup>3</sup>It is clear that not all “events” get logged, and some of the log messages provide less than unambiguous information, but this is the

log data is given in Appendix B. Wagner and others have commented on desiderata for event logs [6, 8, 18].

Among other things, the event log records the existence of individual votes cast by voters, and one can count the number of “vote cast” events in a given terminal. This number should be reconcilable with the other counts of total votes cast.

Importantly, the event log file also contains the opening and closing events for each terminal and the serial number of the PEB used for these tasks. To the extent that the “time and date” are correct inside the terminal, each event has a timestamp logging time and date. Unfortunately for audit purposes, the time and date are often incorrect, but the timestamp can nonetheless sometimes have useful information and can indicate problems that could be corrected for subsequent elections. Questions of fraud regarding timestamps have come up in other elections using iVotronics [16, 17]. In our data, most of the incorrect timestamps are for “explainable” date/time errors (12/02/2010 or 2/10/2011 instead of 11/02/2010). In only one or two cases do we have timestamps that could be considered “suspicious” (one or two days after the election, for example), but we do not have any reason to believe these were anything but simple errors.

#### 4.1.3 The system log file

The third file used is the ERM EL68A “system log” file. This records the upload of electronic ballots collected by the PEBs and audit data collected from the CF cards in each terminal to the ERM. It also records the consolidation of audit data, the creation of the vote image file and the event log file and the uploading of ballot data from the optical scanners that read paper ballots.

In all counties except one, the EL68A file includes lines such as

```
PEB votes retrieved for P0119424
```

which indicates that vote totals have been uploaded from PEB 119424. The file from Beaufort County does not contain this information. This is important in that these lines in the EL68A file are the means by which one can determine that an event log entry for a PEB’s closing of a terminal corresponds to a system log entry for that PEB’s totals being uploaded to the master file.

#### 4.1.4 The manual adjustments log file

The final file used is the EL68 “manual adjustments” log file. Precincts in which election workers carry out manual modifications of the vote count for individual candidates are recorded in the EL68A “system log” file. The

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best that we have at present, and in spite of the flaws the file does have significant forensic value.

actual changes are recorded in the manual adjustments log file.

#### 4.1.5 Certified vote counts

In addition to the data described below, we have also used the official vote totals posted on the South Carolina State Election Commission (SCSEC) website [11]. In our analysis, we compare the counts in these files against counts that would be supported by the data in the vote image file, the terminal event log file, the ERM system log file and the ERM manual adjustments file. The files posted on the SCSEC website must come from the master file created from the ERM. Were the steps we propose executed by election workers, we expect the source file for the official counts to come from the ERM.

## 4.2 Processing the data

Our goal in auditing is essentially to verify that all the data gathered is consistent with itself and with the certified count. To verify that the part of the voting process dependent on the DREs has been done correctly, we need to ensure that

- each iVotronic terminal used in the election has been closed;
- the vote image and event log data from each terminal has been written to the CF card, and that the vote totals have been collected by a PEB;
- the CF cards have been pulled from the each terminal and that the event log data and the vote image data have been uploaded into the master file at the county level;
- all PEBs used to collect votes at the precinct level have had their vote totals collected into the master file at the county level.

Ensuring that the above have taken place will ensure that all system hardware components in the election have been accounted for and that the system data components have been created. This will still fail to catch instances of terminals not closed and instances of a second PEB collecting totals from terminals whose memory cards were not pulled. These two errors will generate no data and thus no data that would be inconsistent with itself, but would be caught if one were able to check off from the data and logs the terminals and PEBs used from an electronic list prepared beforehand.

We should now check

1. that the totals obtained from the PEBs are consistent with the totals obtained by counting votes in

the vote image file and are consistent with the totals of “vote cast” events from each terminal;

2. and that the absentee ballots have been counted and that any manual adjustments are supported by data.

Our programs concentrated on the DRE-centric point (1). The first step in our processing is to count the votes in the vote image file, a sample of which is Appendix A. Each voter’s ballot lies between one asterisked line and the next, and we can extract precinct number, iVotronic serial number, ballot style number, and candidate sequence number to identify a specific vote for a specific candidate in a specific contest. We note that there is no inherent one-to-one correspondence between terminals, precincts, or ballot styles. In the first author’s precinct in Richland County, for example, there are voters who live inside as well as outside the Columbia city limits. On 11/02/2010, there were four distinct ballot styles in that precinct. Voters are given a colored slip of paper that is handed to the poll worker, and the different colors indicate which ballot style should be downloaded from the PEB to the terminal. What we have referred to as the “candidate sequence number” is the number that identifies the candidate and contest for whom that line of vote data should be counted.

In some counties, Charleston being an example, multiple precincts vote in the same location, and a single terminal might be used in as many as five different precincts. Votes on a given terminal can thus be found for multiple ballot styles in each of multiple precincts. This requires some care in counting.

We note, however, that counting votes in the vote image file is not a difficult programming task. Indeed, the hardest part of counting votes from the vote image file is the somewhat tedious issue of stripping off the print file information and of reading an ASCII file that is intended to be a human-readable formatted file. For the most part this just requires setting up rules for parsing data lines versus header lines and then tokenizing the formatted ASCII text. Once we have tokenized, the data becomes in essence the equivalent of a two-dimensional array of spreadsheet data. We have produced totals by precinct, terminal, and ballot style. We also produce a list of the total votes cast in each precinct by terminal and a list of the total votes cast for each terminal. The first author, writing in Java, used this in his class as the exercise for his students to practice using the Java `TreeMap` data structure.

As part of counting votes in the vote image file, we compare our total votes for each terminal and precinct against the official totals and print an exception list. In Richland County, for example, we found seven precincts with more official votes than were in the vote image file. The normal interpretation of this would be that a memory

card had been left in a terminal, and indeed the county officials went back to the warehouse and found the memory cards still in the terminals. We also found two precincts whose data was entirely missing; in these precincts, the cards had been pulled from the terminals and placed in the plastic bags to be turned into county headquarters but the bags had not been retrieved by county officials. None of the vote image data for those two precincts was in the file as originally delivered to us. All the data was eventually found, but would not have been found had there been an intervening election that required clearing the memory cards.

Our two versions of the counts<sup>4</sup> have agreed completely. This is not to say that we might not both have made the same errors. However, we point out that our code does not produce results that are to be trusted, but rather shows where the results of other programs ought not to be trusted and directs human beings to check the exceptions we have found. Further errors that neither program has detected might still exist, but we have found no instance in which our programs have found something to question that has not in fact been shown to be an anomaly.

### 4.3 Problems with the data and the counts

A sample of our output, in this case for precincts in Richland County, is given as Table 1 and shows some of the problems we found.

In Ward 21, there were 694 votes in the vote image file, but only 339 votes were certified by the SCSEC. In Bluff Precinct, 1026 votes appear in the vote image file, but only 254 were certified. And in Westminster, there are only 868 votes in the vote image file, but 1124 votes were certified, for an overage of 256 votes. Six other precincts besides Westminster had more votes certified than were in the vote image file.

What we can also determine by counting votes in the vote image file and comparing that to the SCSEC official count is that two precincts in Richland County—Gadsden and Riverside—had no votes at all uploaded to the vote image file. Had we begun with a list of the iVotronic terminals in use, as would be available to the officials conducting the election, we could easily have determined that no data existed from the terminals assigned to these two precincts.

Our initial forensic analysis of the discrepancies such as are in these three precincts has now become standard. In the seven precincts with more votes certified, it certainly appears from the size of the discrepancy that perhaps two iVotronic terminals did not have their memory

<sup>4</sup>The first and fourth authors wrote independent programs in Java and Perl, respectively.

Westminster	Serial # 5125133	Serial # 5126604	Serial # 5127201	Serial # 5127722	Serial # 5127746	Serial # 5131971	Serial # 5138514	Total
Vote Image Totals	117	121	140	121	119	119	131	868
Certified Count								1124
Discrepancy								256

Ward 21	Serial # 5120652	Serial # 5134730	Serial # 5135715	Serial # 5136586	Serial # 5138357	Serial # 5139525	Total
Vote Image Totals	121	101	130	104	112	126	694
Certified Count							339
Discrepancy							(355)

Bluff	Serial # 5121076	Serial # 5131255	Serial # 5133311	Serial # 5135064	Serial # 5136068	Serial # 5137738	Serial # 5137832	Serial # 5138461	Total
Vote Image Totals	133	133	121	115	136	128	139	121	1026
Certified Count									254
Discrepancy									(772)

Table 1: Richland County Sample Results

cards pulled and the data uploaded. Among these seven precincts, a total of 2816 votes in the certified total did not correspond to data in the vote image file.

After discussing these discrepancies with county officials, the officials went back to the warehouse and indeed found all the missing data. In spite of the protocol to pull the memory cards from each terminal, ten terminals still held their memory cards. In the case of the two precincts that were entirely missing, the bags containing the memory cards were found underneath the power and networking cords. When these cards were uploaded to the master vote image file, these discrepancies disappeared.

It took slightly more analysis for us to determine what had happened in Ward 21 and Bluff Precincts. In the case of Ward 21, we observed that terminals 5134730, 5138357, and 5139525 contained a total of 339 votes, and the other three terminals contained a total of 355 votes. This breakdown led us to examine the event log. As it turned out, PEB number 153090 opened, closed, and collected the votes from the first three terminals, and PEB 152732 opened, closed, and collected the votes from the other three terminals. However, the third of the files we examined, the EL68A system log file, records that only PEB 153090 had its votes included in the master count on 11/02/2010. The event log shows that the data for the second PEB was not collected until 11/09/2010. Our conclusion was that, contrary to the official protocol, both a red stripe and a green stripe PEB had been used to open and close terminals, but then protocol was followed and only the green stripe PEB had its vote totals collected into the master count.

Turning to Bluff, we noticed that there were in fact five ways that the votes from two terminals could be added

to produce the certified count of 254. Here again, the event log provided the explanation. The closing event log entries for iVotronic 5121076 appear in Appendix B. Clearly, this terminal was not closed, and did not have its votes collected, until Tuesday 11/09/2010, a week after the election and after the vote count had been certified by the SCSEC. Five other terminals have similar records, and we can verify that terminals 5131255 and 5133311 were the two that were properly closed and had their 254 total votes include in the count, and the other six were not closed until a week later.

#### 4.3.1 A summary of the results

We have obtained November data complete enough for some analysis from from seventeen counties, although from two of these counties we have received vote image files that terminate part way through the precincts by precinct number and are thus incomplete. Of these, four seem to have shown none of the problems we have discussed here. All the rest have vote image files with missing data. Except for Horry County, with 53 of 125 precincts with missing vote image data, it appears the data is missing in each county from perhaps one to a dozen memory cards (including missing data from the early-sequence-number precincts in the case of the two incomplete files). In Richland, Horry, and probably Sumter, there were votes that did not get counted. In two counties (Lexington and Horry) it seems clear that test votes were included in the vote image file.

#### 4.4 Richland County is not unique

Although Richland County exhibits more problems than do many counties, the problems we found there are not unique. In ten of the seventeen counties for which we have general election data, there are discrepancies that suggest that memory cards were not pulled from the terminals and the individual votes uploaded to the vote image file. In several counties we have seen only a few such missing cards. Given that Spartanburg County reported a few cards being unreadable, it is possible that this explains some of the missing data. In Horry County, however, home of Myrtle Beach, 53 of the 125 precincts had what appeared to be missing cards, and three precincts were totally absent. In Horry, nearly one in six votes included in the certified count is not corroborated by individual vote data in the vote image file.

We apparently also have at least one and possibly two further instances of the “Ward 21 phenomenon”. In Sumter County a terminal with 24 votes was not included in the official count, and in Racepath 1 precinct in Horry County, terminal 5111151 with 114 votes was not included in the count. In that precinct in Horry County no fewer than three different PEBs were used to open the machines and then two were used to close. Curiously, the PEB whose totals were included in the official count generated an “Invalid PEB for procedure” event log error message when the operator tried to open machine 5111151, but did not seem to generate a similar error when it was used to close other machines and collect vote totals.

As mentioned above, there was a serious potential for a “Ward 21” problem in Charleston County. There, 21 machines had been opened with the wrong PEB, and their votes would not have been collected into the count had it not been discovered on Wednesday 11/03/2010 that a mistake had been made. The significant change in the counts from the original Tuesday night announcements was a prominent news item [19].

#### 4.5 Problems with absentee votes

Absentee votes were about 10% of all votes cast in South Carolina in the 2010 general election[11]. Paper absentee ballots can be returned to the election office by mail or in person, but must arrive prior to the closing of polls on election day. Electronic absentee votes can be cast on iVotronic voting terminals at authorized locations in a county for about three weeks prior to election day. Absentee votes cannot be cast on voting terminals on election day [1]. With the large number of absentee ballots for the November election, it would have been important to ensure that they were counted properly. Unfortunately, we find what appear to be numerous problems in manu-

ally adding in absentee vote counts to the overall count. We leave open the possibility that we have not fully understood the process of counting absentee and similar votes—in Richland, for example, the totals are off by one because one provisional ballot was ruled unacceptable—but the scale of the differences detailed here suggests that these are genuine errors.

Berkeley County, for example, created virtual precincts 750 and 751 for absentee votes. The system log file for the ES&S Unity Election Report Manager reports uploading 4024 ballots in precinct 750 and 80 in precinct 751, 43 on paper and 37 electronic in precinct 751, or 4104 total ballots. But the county only certified 4061 absentee votes, 43 fewer than the number cast. It appears, from looking at the entries in the system log file, that the 37 electronic ballots uploaded at 9:37 pm on 11/02 *overwrote* 43 paper ballots uploaded from the optical scanner at 9:30 pm because the second operation was executed in “Replace” mode. ES&S procedures say that all ballots from an election day precinct should be downloaded from the voting terminals onto a single PEB. For most precincts, therefore, there is only one ballot source and uploading to the ERM in “Replace” mode is appropriate. But the absentee precincts may have two ballot sources. This would be an easy error for an operator to make at the end of a very long workday, but it appears that this error led to 43 votes not being counted.

Richland County counted 6486 electronic out of 14,813 total certified absentee ballots, in precincts 750 and 751, with a manual process. From each of the 13 terminals used for absentee voting in virtual precincts 750 and 751, the staff printed a paper tape of the counts for each candidate. They used the manual entry and adjustment functions in the ERM to enter the numbers for each candidate from the tapes into the Unity election database, and a record of their counts appears in the manual adjustment log file. We can compare the staff’s hand count of electronic absentee ballots to the count that is derived from the vote image file.

Joe McEachern, candidate for the State House of Representatives, received 672 absentee electronic votes in the vote image file—387 votes in precinct 750 and 372 in 751. However, the staff count gave him none in 750 and 459 in 751. All state representative contests were tagged in the absentee precincts with two different contest labels (HOU077 and HSW0077 in the case of McEachern running in house district 77), and the 300 votes McEachern received in precinct 750 in the HOU077 contest appear not to have been counted.

In the race for the School Board in District Five, none of the candidates seem to have been assigned the correct number of votes. No votes were entered for any candidate in precinct 750, though 591 appear in the vote image file. There were votes recorded for precinct 751, though

not quite enough to make up the difference. (Precincts 750, 751, 752, etc., could be considered interchangeable; we are told that multiple virtual precincts are used simply due to table size limitations in the software that really only become apparent if a terminal is to be used as in absentee voting for all precincts in a county.) While only 15 votes for the five candidates in the race are found in the vote image file in precinct 751, a much larger, but incorrect, total was entered for the candidates in the manual adjustment file.

In all, out of 6486 Richland County electronic absentee ballots, 563 seem to have been miscounted, an error rate of 8.7%.

Lastly, in Colleton County, erroneous use of the manual adjustment features resulted in more than 1000 ghost votes in more than a dozen contests in a county where only 11,656 ballots were cast. For instance, in the Governor's race, the four candidates together received 13,045 votes. The incorrect counts were certified by the SCSEC.

To manually adjust the vote for a candidate, a user enters the number by which the candidate's count will be incremented or decremented. If candidate A has 300 votes, and that number needs to be increased by 3, the user enters 3 in the adjustment field for the candidate. In Colleton County, election officials entered the new count for the candidate. So, for candidate A, they would have entered 303 in the adjustment field, making the new total for the candidate 603.

The Colleton director of elections has acknowledged his errors, releasing on December 31st, 2010 a revised set of election results. The new numbers fixed many errors, but in the absentee precinct, where 1588 votes were cast, the candidates for governor still received 1711 votes.

The results in Richland, Horry, and Colleton Counties, where large numbers of ballots were hand-counted, present examples of why post-election verification tools such as the authors propose are necessary to insure accurate election returns. We are continuing to work with election officials to determine why errors in using the ES&S system appear to be so easy to make.

## 5 Other Problems

We have observed several other problems that do not necessarily contribute to incorrect counts but that could make auditing more difficult.

### 5.1 Test votes in vote image files

It was observed in an iVotronic election in Texas [16, 17] that test votes might well have been included in the vote image file and then included in the final count. We have observed test votes, or what appear to be test votes in the vote image files. In Lexington County, we observed that

the data from one machine in the vote image file consisted of a total of 25 votes, spread across 18 precincts, with 16 of those precincts getting a single vote each. Many of these votes were straight party votes, including straight party votes for minor parties. When asked about this by the first author, the election director for Lexington County said that probably the vote image file had not been reset to zero before after testing and before vote data was uploaded.

It appears that a similar failure-to-reset might have occurred in Horry County. There, one machine shows three votes, in three different precincts. In two of these precincts, it is impossible to go further with an analysis because there are votes missing from the vote image file (probably from missing memory cards). In Atlantic Beach precinct, however, the vote image file shows one more vote than does the certified count. We would suspect this is also an instance of testing the system by voting three times and then failing to reset the vote image file to empty, and that if we had the data from all the memory cards in the other two precincts, they would also show one vote too many in the vote image file.

In Sumter County, we apparently either have the same phenomenon or else we have uncounted votes. There, machine 5136056 shows 24 votes in the vote image file, but this machine does not appear in the event log. Unlike Lexington and Horry Counties, though, all these votes are in a single precinct, Sumter High 1. These votes also break down roughly as would regular votes (13 and 11 for the gubernatorial candidates, for example) and not spread as straight party votes for both major and minor parties. This is not the broad-spectrum testing of precincts and parties as in Lexington County. What also makes this look more like a failure to count is that one of the other three machines with vote data in this precinct had only 33 votes, so a small number of votes on this machine would not be anomalous. On the other hand, what makes this resemble a test-vote phenomenon is that the iVotronic terminal serial number (5136056) does not appear in the EL152 or EL68A log files, consistent with the files from Lexington and Horry.

### 5.2 "Timestamps" are not authoritative

The analysis of the Webb County, Texas, election [16, 17] also commented on the fact that the "timestamps" in the iVotronic terminals cannot be considered to be authoritative. On the one hand, there is a strong argument that can be made that terminals should not be designed not to be able to accept votes, since having terminals not being usable in the field would be a bad thing. On the other hand, as was observed in the Texas case, having the timestamps when votes are cast not be the election day but be some day shortly thereafter can look very sus-

picious.

It appears that the Daylight Savings Time algorithm, at least in Richland County, is the old algorithm prior to the 2007 change. This would have daylight time ending on the last weekend in October (in 2010, Sunday morning the 31st), not on the first weekend in November as under current law. All the terminals in Richland County started counting votes an hour early, and a roving technician went to all precincts during the election to reset the time ahead one hour. Had this not been done, it would have taken a PEB with greater access power to close the terminals; the one controlling time issue in the terminals seems to be that they cannot be closed earlier than the specified time. (Terminals collecting votes after the specified closing time log an extra message to that effect, but voting after the closing time has to be permitted because voters in line at closing time are permitted to vote.)

The problem with the timestamp in the machines, however, is that it diminishes the audit value of the log data. In Blythewood 1 precinct, a machine started the day with the date and time set to all zeros and collected 14 votes before this was changed. We have seen this happen in other counties as well. Indeed, almost no county seems immune to the problem of having “Vote cast by voter” events logged with incorrect dates. In Richland, one machine ran all day with the date set to 11/02/2006. In Anderson County, one machine was initially set to 04/12/2053, rolling over to 4/13/2053 because it had begun the day at 6pm and not 6am. In many counties, the date was 12/02/2010; in some counties it was 1/02/2011 or 2/01/2011, and in several instances we see machines set to begin at 7PM and not 7AM. One would like the log data to be more authoritative.

### 5.3 Data tables are duplicated

Although we have not thoroughly analyzed this point, it has become clear that some data tables in the ES&S system are duplicated. Duplication of data is a very well known problem in software, because errors can occur when these tables are not synchronized and different data is used by different components in the software system.

One of the more noticeable instances of duplication of data is that there is apparently no master file of precinct names in a given county. The precinct names in the SC-SEC website for results of the election [11] are different from the names that appear in the vote image file. In some cases the differences are minor—dropping apostrophes or a trailing “s” in a name or changing two words into one—but in at least one instance there is a genuine misspelling of “chruhc” for “church”.

More serious issues of tables arise, apparently, in the definition of the contests and ballots. In Lancaster County, none of the results could be collected or accumu-

lated electronically. The email from the Public Information Officer for the SCSEC, Chris Whitmire, regarding the Lancaster County problem reads as follows.

“Under normal circumstances, one database would be used to prepare Personal Electronic Ballots (PEBs — devices used to load ballots on voting machines) and the central vote tabulating computer. If both are not prepared from the same database, the automated vote tabulation process will not work, and paper results tapes from each precinct must be used to manually enter votes into the system.

“When the Lancaster database was originally created, it contained the names of all certified political parties. However, all parties did not nominate candidates in Lancaster County, and those that did not needed to be removed. This error would have had no effect on the functionality of the voting machines or their ability to accurately display ballots and record votes, but would cause the automated tabulation process to not work on election night. The manual process would have had to be used. In an attempt to solve this issue, a second, corrected database was sent to Lancaster. County election staff used this second database to prepare the central vote tabulating computer, but did not “re-burn” the PEBs. The result was that PEBs were prepared with the original database, and the central vote tabulating computer was prepared with the second database.

“Because two databases were used, county election officials had to manually enter vote totals using the paper results tapes from each precinct. As a result of manually entering vote totals, the audit logs from each voting machine were not created.”

We note that what this means is that there is no record of individual votes in Lancaster County, only the record of the totals collected by the PEBs.

A somewhat similar problem happened in Charleston County in the 2008 election. The *Charleston Post and Courier* reported on 11/08/2008 that the voting system technician had deleted minor parties from the straight-voting column in the database, and that this caused the actual results to appear in incorrect columns when the votes were counted [3].

Finally, the same sort of problem occurred in Florence County. In a conversation with county election director David Alford, the third author was told that Florence County had three different “databases” in use at some

points in time during the November election. The voting machines for absentee voting were using an earlier database than the one that was in the Unity system on 11/02/2010. The Unity system can only handle or accept votes that are coming from machines set up with the current one installed on Unity and would not read the early voting machines on election night. The poll workers had to get the poll tapes from each machine and manually enter the poll tapes into the database.

## 6 Solutions to Some of the Problems

We cannot hope for a silver bullet to solve all election problems. We believe we have identified some simple, fast, tests that will detect at least the errors we have seen, and that this is *system* reliability issue that needs further study. Regardless of the written procedures that are given to poll workers, there will be errors during and at the end of a long, stressful day. A reliability analysis would predict failures like the multiple-PEB, memory card, and failure-to-close problems, and that some effort to mitigate these problems be planned as standard procedure. Given a machine-readable list beforehand of iVotronic and PEB serial numbers, running a program such as ours against the log and vote image data would inform county officials, perhaps on the Wednesday afternoon following a Tuesday election, of the errors that have occurred and that could be corrected before certifying a count. Our programs run in only about a minute even on the largest counties, so the only substantial new effort required would be to ensure that all (collected) memory cards had been read into the master vote image and event log files. It was even suggested in the state Senate subcommittee hearing that the statutory deadline for certifying could be pushed back a few days in order to accommodate running these checks.

These tests could—and we believe should—be run before a count is certified as a check that the data has been collected and accounted for as would be expected if the procedures and protocols were followed precisely. Our programs accomplish these tests. If programs were written so as to use official internal data instead of parsing printout files, then those programs would be simpler and would be even more effective. In essence, what we propose to use are programs that would produce an exception list of iVotronics, PEBs, and memory cards that were missing from the results files.

It is a simple matter to determine that all the iVotronic terminals have been closed and have had their event log and vote image data collected into memory cards. There should be an electronic list of iVotronics and PEBs by serial number that is prepared by county officials. If votes appear from a given terminal in the vote image file, then the memory card for that terminal has been uploaded to

the file. This will also mean that the terminal has been closed and that the data from the PEB that closed the terminal has been uploaded. There may be a small number of terminals that do not appear in the vote image file. For example, there were in Richland County two of the approximately 820 machines that behaved badly on election day and were shut down with no votes in them. This kind of terminal will show up as an exception, but we would expect that this would be an infrequent problem.

By checking for the existence of vote image data against a list of terminals known to be in use, the Bluff precinct problem would have been avoided. The six terminals not closed would have shown up on the exception list and the county would have known to close them and collect votes before certifying the count. This is a more efficient way to verify that terminals are closed than by having election officials scanning paper tapes from precincts.

It is similarly simple to verify that all PEBs that have been used to open and close terminals and to collect data have had their data uploaded. The use of a PEB to open and close and to collect data shows up in the EL152 event log. For any such PEB, there should be a corresponding entry in the EL68A system log. For example, the Ward 21 PEB that did have its votes collected has an event log entry showing the machine being opened:

```
153090 SUP 11/02/2010 06:23:28 0002808 \  
Terminal - opening state
```

and then entries showing the machine being closed:

```
153090 SUP 11/02/2010 20:03:05 0001222 \  
Terminal vote collection successful  
153090 SUP 11/02/2010 20:03:05 0002803 \  
Terminal - closed state  
153090 SUP 11/02/2010 20:03:05 0001673 \  
Terminal Closed
```

This corresponds to lines in the system log file showing the upload of the PEB data into the PEB count:

```
11-02 09:09 pm PEB votes retrieved \  
for P0153090  
11-02 09:14 pm PRC 0121 PACK RECEIVED \  
VTR (BALS=339 TOT=339)
```

To sum up:

- If the iVotronic terminals have been closed properly, and their flash memory cards have been collected properly, then vote image data should exist from each terminal. If a terminal is known to have been in use on election day, but no vote image data exists for it, then either the flash memory card was not pulled, or the machine collected no votes. The latter should be infrequent, so the absence of a known

terminal from the vote image file is probably a machine not closed or a memory card not pulled.

- If the iVotronic terminals have been closed properly and their flash memory cards have been collected properly, then event log data should exist showing the opening and closing of that terminal and the collection of its data. From that event log data one can determine which PEB did the open/close/collect for that terminal.
- If a PEB is used to collect data, and the memory cards have been pulled from the machines whose data was collected, then the event logs should show the collection of data, and the system log should show the upload of data. If there is data collection but no upload, then the PEB was probably used improperly, and the votes collected have probably not been included in the count.
- If a PEB is used to upload data to the count, then that PEB should appear in the event log as having been used to collect data. If no such log records exist, then it is probable that flash memory cards have not been properly collected.

Performing these checks would verify that these hardware components have been accounted for. We cannot ensure that the actual votes are as they were cast, but we can at least ensure that the number of ballots cast is correct. The event log has a line for each “Vote cast” (by voter, by poll worker, etc.) event. The system log records the number of ballots uploaded. The vote image file has an asterisk at the beginning of every ballot. The counts of the number of ballots for each machine and from each PEB should be consistent, and this is easy to check.

## 7 Conclusions

We do not claim to have solved all the problems we have observed in the election system in South Carolina. However, we believe that the processing we have done, which amounts to a check for self-consistency of the data that can be collected from an election, should become standard. We especially recommend the collection and analysis of the memory card data, since the vote image file and the event log provide checks against votes going uncounted due to procedural errors on election day.

We also have concerns about manual adjustments and the counting of absentee votes. For the absentee votes cast on an iVotronic, the county officials should eschew use of the manual adjustment process in favor of electronic accumulation, on the basis that the electronic accumulation will be more reliable and certainly more easily auditable.

Some of the checks we propose are redundant, but all are simple, so there is no reason not to do the redundant checking, especially after we have observed detectable system failures. Our audit would produce an exception list usable, prior to certifying a count, for detecting the human errors that we expect to happen no matter how well-trained the poll workers. Working from the exception list, county officials could ensure that all the election data gets collected from the PEBs and the CF cards, that the vote image and iVotronic event log files created from the data on the CF cards contain data from all the terminals deployed in the election, that the number of vote events on the iVotronics equal the number of ballots in the vote image file and that, after accounting for paper ballots and manual adjustments, the proposed certified count and the totals in the vote image file agree.

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### Appendix A: Vote Image Data

RUN DATE:11/30/10 10:33 AM PRECINCT 105 - Ward #5 ELECTION ID: 40110210

VOTR.	B/I	CANDIDATES RECEIVING A VOTE	
5122984	3 *	10 Nikki R Haley	GOVERNOR
5122984	3	15 Ken Ard	LIEUTENANT GOVERNOR
5122984	3	19 Mark Hammond	SECRETARY OF STATE
5122984	3	23 Curtis Loftis	STATE TREASURER
5122984	3	27 Alan Wilson	ATTORNEY GENERAL
5122984	3	31 Richard A Eckstrom	COMPTROLLER GENERAL
5122984	3	36 Mick Zais	STATE SUPERINTENDENT OF EDUCATION
5122984	3	42 Bob Livingston	ADJUTANT GENERAL
5122984	3	45 Hugh Weathers	COMMISSIONER OF AGRICULTURE
5122984	3	50 Jim DeMint	U.S. SENATOR
5122984	3	55 Jim Pratt	CON0006 U.S. House of Rep Dist 6
5122984	3	60 W/I MICKEY MOUSE	HOU072 State House of Rep Dist 72
5122984	3	63 W/I BUGS BUNNY	5TH CIRCUIT SOLICITOR
5122984	3	66 W/I ANYBODY	PROBATE JUDGE
5122984	3	74 Mark W Huguley	Soil and Water
5122984	3	83 Susie Dibble	SAL0001 RICHLAND COUNTY SCHOOL DISTRICT
5122984	3	90 No	Amendment 1
5122984	3	92 Yes	Amendment 2
5122984	3	96 No	Amendment 3
5122984	3	99 No	Amendment 4
5122984	3	102 No	Sales and Use Tax 1
5122984	3	105 No	Sales and Use Tax 2

## Appendix B: Event Log Data

Votronic	PEB#	Type	Date	Time	Event
5121076	153424	SUP	11/02/2010	17:47:05	0001510 Vote cast by voter
	152523	SUP	11/02/2010	18:41:19	0001519 Vote cancelled - other reason
		SUP	11/02/2010	18:43:13	0001649 Term - entered service menus
		SUP	11/02/2010	18:43:17	0000114 Select: Setup & Configuration Menu
		SUP	11/02/2010	18:43:17	0000301 Start override password procedure
		SUP	11/02/2010	18:43:37	0000116 Select: Configure Terminal
		SUP	11/02/2010	18:43:41	0000117 Select: Set Time and Date
		SUP	11/02/2010	19:43:42	0001656 Set terminal date and/or time
		SUP	11/02/2010	19:43:58	0001650 Term - exited service menus
		SUP	11/02/2010	19:44:21	0001633 Terminal shutdown
		SUP	11/09/2010	14:30:03	0002810 Terminal - time to close voting
		SUP	11/09/2010	14:30:15	0001626 Close terminal
		SUP	11/09/2010	14:30:15	0002809 Terminal - closing state
		SUP	11/09/2010	14:30:15	0001221 Collect terminal vote data to PEB
		SUP	11/09/2010	14:30:44	0001303 Transfer PEB vote data to terminal
		SUP	11/09/2010	14:30:51	0001208 Merge terminal & PEB vote data
		SUP	11/09/2010	14:30:54	0002802 Terminal - open state
		SUP	11/09/2010	14:30:54	0002803 Terminal - closed state
		SUP	11/09/2010	14:30:54	0002809 Terminal - closing state
		SUP	11/09/2010	14:30:58	0001210 Transfer terminal vote data to PEB
		SUP	11/09/2010	14:31:24	0001211 Terminal votes to PEB successful
		SUP	11/09/2010	14:31:24	0001214 Transfer terminal writein data to PEB
		SUP	11/09/2010	14:31:36	0001215 Terminal write-in data to PEB successful
		SUP	11/09/2010	14:31:36	0001222 Terminal vote collection successful
		SUP	11/09/2010	14:31:36	0002803 Terminal - closed state
		SUP	11/09/2010	14:31:36	0001673 Terminal Closed
		SUP	11/09/2010	14:31:42	0001401 Copy terminal flash audit data to CF
		SUP	11/09/2010	14:31:42	0001400 Verify terminal flash audit data
		SUP	11/09/2010	14:31:50	0001416 Copy audit data from TF 1 to CF