



Pre-Election Audit of Memory Cards for the November 6, 2012 Connecticut Elections

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Summary

The University of Connecticut Center for Voting Technology Research (VoTeR Center) performed pre-election audit of the memory cards for the Accu-Vote Optical Scan (AV-OS) tabulators that were used in the November 6, 2012 elections. The cards were programmed by LHS Associates of Salem, New Hampshire, and shipped to Connecticut districts.

Cards were submitted for two reasons per instructions from the SOTS Office (a) one of the four cards per district was to be selected randomly and submitted directly for the purpose of the audit, and (b) any card was to be submitted if it appeared to be unusable. Given that cards in category (a) were to be randomly selected, while all cards in category (b) were supposed to be submitted, and that the cards were submitted without consistent categorization of the reason, this report considers all unusable cards to fall into category (b).

The VoTeR Center received 150 memory cards from 141 districts. Among these 150 cards, 94 (62.6%) fall into category (a). All of these 94 cards were correct. There are 56 cards (37.4% of all cards) that were found to be unusable by the AV-OS, thus falling into category (b). In particular, 53 cards contained apparently random (or ‘junk’) data, one card was unusable by AV-OS, but did not contain random data (this requires further investigation), one card was formatted using AV-OS tabulator, however, it was not programmed, and one card contained only zeros. All these cards were unreadable by the tabulators and could not have been used in an election. Given that such cards were not selected randomly, we estimate that for pre-election audit the percentage of unusable cards is between 1.7% and 9.9% and this range is consistent with the results for prior audits.

Cards that fell into category (a) contained valid ballot data and the executable code on these cards was the expected code, with no extraneous data or code on the cards. Overall the audit found no cases where the behavior of the tabulators could have affected the integrity of the elections. We note that the adherence to the election procedures by the districts has improved compared to prior years, however the analysis indicates that the prescribed procedures are not always followed; it would be helpful if reasons for these extra-procedural actions were documented and communicated to the SOTS Office in future elections.

The audit was performed at the request of the Office of the Secretary of the State.

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1 Preface

The University of Connecticut Center for Voting Technology Research (VoTeR Center) conducted pre-election audit of the memory cards used in the Accu-Vote Optical Scan (AV-OS) tabulators in the November 6, 2012 primary elections in the State of Connecticut. The audit was performed at the request of the Office of the Secretary of the State of Connecticut.

The memory cards were programmed by LHS Associates of Salem, New Hampshire, and provided by LHS to the districts in Connecticut. The pre-election audit was performed on the set of 150 memory cards that were shipped to the VoTeR Center by the towns, where the cards should have been randomly chosen for pre-election testing. The cards are tested as they arrive. All pre-election cards arrived at the Center during October and November of 2012. If noteworthy irregularities that might affect integrity or security of ballot tabulation are detected, they are reported to the SOTS Office without delay. Preliminary results were reported to the SOTS Office during the audit.

The memory cards were subject to several integrity tests. A comprehensive overview of the procedures followed by the Center personnel in conducting such technological audits is presented in prior reports^{1 2}. We do not repeat here the description of the engineering that was performed to enable the audit, including the log analysis, and the technical setup used in the tests. For the compilation of the technological audit results for the years 2007 to 2010 please consult our prior report³.

In this report, we present the objectives of the pre-election audit and the audit results. The audit process included testing, comparison, and analysis of the data collected during the audit. The procedures followed in this audit include a strict chain of custody policy with regard to handling the cards, maintaining a log of all transactions and activities, and safekeeping (both physical and electromagnetic) of the memory cards. This report is a high-level, non-technical presentation of the audit results and it omits technical details. We also note that we did not use any vendor documentation regarding the design and the internals of the AV-OS terminal.

We conclude the report with several observations based on what was learned during the audit process. We believe that technological audits are crucial in maintaining the integrity of the electoral process.

2 Introduction

We start by briefly describing the electronic election system used in Connecticut. We then review the goals of the pre-election memory card audit, and present a preview of the audit results.

2.1 Brief Description of the AV-OS

The State of Connecticut uses an election system that consists of two main components: the Accu-Vote Optical Scan voting terminal (AV-OS terminal) and the ballot design and central tabulation system called GEMS (Global Election Management System). We point out the following characteristics of these components:

- The AV-OS systems currently in use in the state of Connecticut contain the firmware version 1.96.6. This model is equipped with an optical scanner, a paper-tape dot-matrix printer, a

¹ Pre-Election Audit of Memory Cards for the November 2007 Connecticut Elections. UConn VoTeR Center, Version 1.0, January 24, 2008. Available online at <http://voter.engr.uconn.edu/voter/Reports.html>.

² Automating Voting Terminal Event Log Analysis. UConn VoTeR Center, EVT09, Montréal, Québec, Canada, August 2009, available at <http://voter.engr.uconn.edu/voter/wp-content/uploads/evt09.pdf>.

³ Technological Audits of Optical Scan Voting Systems: Summary for 2007 to 2010 Connecticut Elections, VoTeR Center, 2011, at <http://voter.engr.uconn.edu/voter/wp-content/uploads/VC-TechAudits-2007-2010c.pdf>

LCD display, a serial communication port, and telephone jacks leading to a built-in modem.

- The GEMS software is installed on a conventional PC (or a laptop). It includes a ballot design system and a tabulation system. Connecticut does not use GEMS for central aggregation of the election results.
- Once the election data is entered into the GEMS system, the specifications of the election are downloaded into a memory card via an AV-OS system connected to GEMS by a serial line cable.
- The memory cards are 40-pin, nominally 128KB cards. The memory card is installed into the 40-pin card slot of the AV-OS. Older (pre-2012) memory cards use an on-board battery to maintain the data on the card. Once the battery charge is depleted, the cards lose their data. This affects memory card reliability, and it is a source of ongoing concern. Recently, non-volatile cards (that do not require a battery) became available. These cards are undergoing testing, and a pilot deployment of such cards started in 2012.

For election deployment the system is secured within a ballot box so that no sensitive controls or connectors are exposed to the voter and unauthorized personnel. Each memory card contains executable code that is used for printing the reports. The code, called *bytecode*, is originally written in a proprietary programming language. The installation of the GEMS software on a PC system contains several databases that include the data and ballot layout corresponding to each district, as well as the bytecode for AV-OS.

See our report at URL <http://voter.engr.uconn.edu/voter/Report-OS.html> for additional details on this election system.

2.2 Goals of the Pre-Election Memory Card Audit

The VoTeR Center prepares for and implements memory card audits at the request of the SOTS.

The pre-election audit has three primary goals: (i) determine whether or not the memory cards are properly programmed for the specific district and specific election, (ii) determine whether or not proper pre-election procedures are followed by the election officials, and (iii) determine whether or not any technical failures occurred.

The memory cards contain the data and the ballot layout for the elections. The memory cards used in the AV-OS terminals also store the tally of the ballots cast and report the results of the election. In this sense the memory cards are the electronic analogue of a physical ballot box. The data, layout, and the functionality of the memory cards are loaded onto each memory card using the AV-OS terminal from the GEMS database. The election-specific GEMS database is also provided by LHS Associates prior to the election to be used as the baseline for the audit.

Prior to the election, each polling center receives four programmed memory cards from the external contractor, LHS Associates. According to the instructions from the SOTS Office, each district is supposed to perform pre-election tests of the four cards. After the testing is complete, they are asked to select randomly one memory card per district and send it to VoTeR Center for the pre-election technological audit. The procedure for random selection of memory cards applies to district-based tabulators and does not include central absentee ballot tabulation. (Sometimes the cards are submitted for the audit before the pre-election test, and sometimes after the pre-election test. This should be made consistent in the future). When the cards are submitted for the audit after they undergo pre-election testing and preparation for the election, such memory cards should be in “election mode” with all counters set to zero.

As the cards arrive from the districts at the Center, the contents of each card is examined to determine whether the data and code on the cards are correct for the given district and election, and

whether the pre-election testing was performed and the cards are set for election. This is done by comparing the card contents to the known baseline data received from the external contractor, and by checking the status of the card and its audit log that should contain the timestamped events that correspond to the cards being programmed, tested, and set for election. The analysis of the card data is semi-automated, where the basic analysis is done automatically, and then any noteworthy issues cause additional manual analysis. Any discrepancies or deviations from the baseline are logged and analyzed. Specifically, the memory cards are audited for any deviations in the ballot data/layout, and any deviations in the bytecode (executable). Additionally the state of the counters and the content of the event logs are analyzed for consistency with the expected election procedures. The event logs contain significant events in the life of a card since the last time it was formatted, allowing for such an analysis to be performed.

This audit also includes the analysis of the cards that were submitted by the districts because the cards were unreadable/unusable per instructions from the SOTS Office.

3 Summary of the Pre-Election Audit Results

We now highlight pre-election audit results for the cards that were received and analyzed by the VoTeR Center.

We received 150 memory cards. These cards correspond to 141 distinct districts in Connecticut (for the purpose of this audit, the name ‘district’ denotes any polling or tabulation place for which specifically programmed memory cards are produced). All cards were received during October and November of 2012.

Cards were submitted for two reasons per instructions from the Secretary of the State (SOTS) Office: (a) one of the four cards per district was to be selected randomly and submitted directly for the purpose of the audit, and (b) any card was to be submitted if it appeared to be unusable. Given that cards in category (a) were to be randomly selected, while all cards in category (b) were supposed to be submitted, and that the cards were submitted without consistent categorization of the reason, this report considers all unusable cards to fall into category (b). We note that the audits did not detect any cards whose data raised concerns about the integrity of tabulation.

Additional details concerning pre-election audit are given in Section 4.

Category (a): Correctly Programmed Memory Cards. For the purpose of this audit we consider a card to be *correct* if it contains the correct election data for the corresponding district, its bytecode is the expected bytecode, and it does not contain any unexplained or extraneous data or code. We note that some correct cards were involved in card duplication; such cards are grouped together with all correct cards, but we note the number of cards that were involved in duplication.

Among the 150 cards received for the pre-election audit, 94 (62.6%) were correct. That is, these cards contained correct election data. This category includes both 81 (54.0%) cards programmed according to the correct procedure, and also the 13 (8.6%) cards whose event logs contain duplication events. All of these cards (including those that were involved in duplication) contained valid ballot data and the executable code on these cards was the expected code.

Category (b): Unusable Cards. The SOTS Office instructed the districts to submit any cards that were found to be unusable by the tabulators to the VoTeR Center. Since these cards were not selected randomly for the audit, and these cards were not identified as the cards submitted in addition to the random audit, they appear in disproportionately high numbers.

The audit identified fifty six (56) cards, 37.4%, that were unusable by the tabulators. Consulting

the summary⁴ of pre-election audits performed since 2007, we note that on the average there are about 9.0% of unusable cards encountered in elections.

We estimate that for the pre-election audit the percentage of unusable cards is between 1.7% and 9.9% within the overall card population. This range is consistent with prior observations and represents a high failure rate. The estimation calculations are given in Section 4.1.

Event log analysis. The pre-election technological audit includes the analysis of the event (or audit) logs on the memory cards. AV-OS records in these event logs certain events that occur during the use of the tabulator. Table 1 presents the action types recorded by AV-OS in the event log along with a brief description. The event log has *action-time* entries and *date* entries. Most action-time entries contain the action name and the time of occurrence (no date). Some action-time entries, i.e., INITIALIZED and SESSION START also add the date.

| Event Name | Event Description |
|-----------------|--|
| AUDIT REPORT | Appears when an Audit Report is printed. |
| BAL COUNT END | After the ender card is inserted in an election, this action appears. |
| BAL COUNT START | Appears when the first ballot is cast in an election. |
| BAL TEST START | Records the beginning of a test election. |
| CLEAR COUNTERS | Appears when the counters are set to zero. |
| COUNT RESTARTED | Appears if the machine is reset during an election, after at least one ballot is cast. |
| DOWNLOAD END | Record the end of data load during the programming of the card using GEMS. |
| DOWNLOAD START | Recorded the start of data load during the programming of the card using GEMS. |
| DUPLICATE CARD | Appears when a card duplication takes place (in both the master card and the copy). |
| ENDER CARD | Records when an ender card is inserted, signifying the end of an election. |
| INITIALIZED | The 1st action in the Event Log; this action records date. |
| MEM CARD RESET | A memory card reset returns a card in 'not set' status, if it was set for election. |
| OVERRIDE | Records an override by a poll worker. Used for overvoted ballots in CT. |
| POWER FAIL | If the machine is unplugged or a power failure occurs, this action is recorded. |
| PREP FOR ELECT | Recorded when the card is set for election. |
| SESSION START | Date action. Appears every time you reset the machine. |
| TOTALS REPORT | Appears when a Totals Report is printed. |
| UNVOTED BAL TST | Appears when an unvoted ballot test is performed. |
| UPLOAD END | When an upload is completed, this action is recorded. |
| UPLOAD ERROR | Appears when an upload error is detected. |
| UPLOAD STARTED | Marks the beginning of an upload. |
| VOTED BAL TEST | Appears when an voted ballot test is performed. |
| ZERO TOT REPORT | Appears when a Zero Totals Report is printed. |

Table 1: Audit log action types

The audit log is analyzed using a program developed for this purpose. The analysis examines the sequence of events reported in the audit log and checks that such sequences are consistent with the expectation of a properly conducted election. For example, one rule is that a zero counters report must precede the election. The report that documents our approach and the log analysis tool is available online⁵.

The rules implemented in the audit log checker do not cover all possible sequences, and the Center continues refining the rules as we are enriching the set of rules based on our experience with the election audits. For any sequence in the audit log that is not covered by the rules a notification

⁴ Technological Audits of Optical Scan Voting Systems: Summary for 2007 to 2010 Connecticut Elections, VoTeR Center, 2011, at <http://voter.engr.uconn.edu/voter/wp-content/uploads/VC-TechAudits-2007-2010c.pdf>

⁵T. Antonyan, S. Davtyan, S. Kentros, A. Kiayias, L. Michel, N. Nicolaou, A. Russell, and A. Shvartsman, "Automating Voting Terminal Event Log Analysis", <http://voter.engr.uconn.edu/voter/wp-content/uploads/evt09.pdf>, EVT09, Montréal, Canada, August 2009, www.usenix.org/events/evtwote09/.

is issued, and such audit logs are additionally examined manually. For the cases when the audit log is found to be consistent with a proper usage pattern we add rules to the audit log checker so that such audit logs are not flagged in the future.

Some results of the event log analysis are included in the presentation summary earlier in this section. Additional details of the event log analysis are presented in the next sections.

Bytecode analysis for the readable cards. The readable/usable cards include an executable program in the form of *bytecode* that is originally written in the proprietary AccuBasic language. The bytecode governs the printing of the reports. Incorrect bytecode may result in erroneous reporting of the election results.

We have analyzed the bytecode that is loaded into each programmed memory card. Based on the analysis we conclude that the bytecode provided by LHS Associates for the elections is safe to use. The bytecode performs the expected reporting functions. Note that it is not possible to overwrite the contents of the card with the AccuBasic bytecode.

When, and if, a new version of GEMS and the AV-OS firmware will be used in Connecticut, the AccuBasic bytecode analysis support will need to be updated to correspond with the new version.

4 Pre-Election Audit Results: Additional Details

We now present additional details for the pre-election audit. The high level breakdown of the received cards is as follows.

- 150 were received for the pre-election audit
- 94 were correct (this includes 13 cards that were involved in duplication)
 - 60 were set to be used in the elections
 - 33 were not set to be used in the elections
 - 1 card was in the election closed state
- 56 cards were unusable (by AV-OS)
 - 53 cards contained apparently random data ('junk' data)
 - 1 card was unusable (but the data was not random)
 - 1 card was not programmed (formatted, but contained no election data)
 - 1 card was a null card (contained all zeros)

4.1 Overall Card State Analysis (Part a, Card Format)

Table 2 shows the frequency of various states observed on the 150 audited memory cards.

(a) Card Format: Among the 150 audited cards, 94 cards were readable by AV-OS and usable for elections. These cards were correctly formatted, and contained correct data and code for the specific districts for which they were prepared.

Among these 94 cards, 81 cards (86.2%) were programmed directly using GEMS and contained data matching the baseline. These involved no duplication. 13 cards (13.8%) were involved in duplication, otherwise they contained correct data, matching the baseline.

| All Cards (150) | | |
|---------------------------|--------|---------|
| (a) Card Format | Number | % Total |
| Correct Cards | 94 | 62.6% |
| Unusable (Junk) Data | 53 | 35.3% |
| Unusable (Not Junk) | 1 | 0.7% |
| Unusable (Not Programmed) | 1 | 0.7% |
| Unusable (Null) | 1 | 0.7% |
| Totals: | 150 | 100% |

Table 2: Memory card analysis summary for all cards received: (a) Card Format.

56 cards (37.4%) were unusable and did not contain data that can be used by the tabulators in the elections. Such cards do not present an immediate security concern. 53 cards (35.3%) contained apparently random (‘junk’) data and are readily detected through pre-election testing by poll workers, thus they could not have been used in the election. One card (0.7%) was unusable by the AV-OS. Similar to ‘junk’ cards such cards are readily detected through pre-election testing by poll workers, however the contents are not random data. Such cards are retained for a follow up evaluation.

One card (0.7%) was not programmed. Such cards contain no data about the election, and this is not an intended state of the card. It is possible that such cards are the result of (inadvertent) reformatting after testing; else they may have arrived not programmed. The examination of the event log of this card showed the card was reformatted on October 22, 2012. Given that the Center received the card from the district on October 23, 2012, it appears that the card was formatted at the district. A plausible scenario is that the tabulator identified this card as unusable and displayed the prompt asking whether to format the card. Since the election official have no means for directly programming the card, it was formatted but not programmed for the election. The card in question is CORNWALL-DISTRICT_1-0004458. It is advisable that the districts should not format or attempt to program the cards, but bring any issues to the attention of the SOTS Office. A follow up with Cornwall confirmed that the card was formatted at the district due to an incorrect button being pressed during the pre-election testing process.

Lastly, 1 (0.7%) card was a *null card* (i.e., contained only zeros). None of these cards raise security concerns, since they are not usable in the elections. A null card contains zeros, except for a single byte that records the size of the card. Such a card can be obtained through the diagnostic mode of AV-OS by selecting the “Test Memory Card” option. If an attempt to test a programmed (usable) card is made, AV-OS will issue a “Card Programmed, Clear?” prompt. If however, a “junk” card is tested in this way, the prompt will read “Unknown Status, Clear?”. In either case, responding in the affirmative results in a null card. This feature of AV-OS should never be used at the districts, since it may result in the erasure of the card contents, making it impossible to diagnose any problem. If a card in question appears to be problematic, the district should bring the issues to the attention of the SOTS Office.

Estimation of Unusable Cards Percentage: Given that unusable (unreadable by AV-OS for the purpose of elections) cards were not selected randomly, we estimate that for pre-election audit the percentage of unusable cards is between 1.7% and 9.9%. This estimate is made on the basis of the following calculation. We received cards from 141 districts out of the total 820 districts that participated in this election (this includes absentees), where there are four cards per district. The number of unusable cards in the audit is 56. Thus the minimum percentage is calculated as $56/(820 \cdot 4) = 1.7\%$, given that unusable card data does not contain district information. Performing

similar calculation for the 141 participating districts, we obtain the maximum percentage as $56/(141 \cdot 4) = 9.9\%$. This range is largely consistent with the results from prior audits.

4.2 Analysis of the Readable/Usable Cards (Parts b, c, and d)

We now present the details of the audit for the 94 cards (among the 150 audited cards) that could be used in the elections.

| Usable Cards 94 | | |
|--------------------------------------|--------|---------|
| | Number | % Total |
| (b) Card Status Summary | | |
| Not Set for Election | 33 | 35.1% |
| Set for Election | 60 | 63.8% |
| Election Closed | 1 | 1.1% |
| Totals: | 94 | 100% |
| (c) Card & Counter Status | | |
| Set For Elections, Zero Counters | 60 | 63.8% |
| Election Closed, Non-Zero Counters | 1 | 1.1% |
| Not Set, Non-Zero Counters | 32 | 34.0% |
| Not Set, Zero Counters | 1 | 1.1% |
| Totals: | 94 | 100% |
| (d) Card Duplication (13) | | |
| Master Card | 11 | 84.6% |
| Copy Card | 2 | 15.4% |
| Totals: | 13 | 100% |

Table 3: Memory card analysis summary: (b) Card Status, (c) Card Record of Electoral Procedure, and (d) Card Duplication.

(b) Card Status Summary: Here status refers to the current state of the memory card, for example, loaded with an election, set for election, running an election, closed election, and others.

60 cards (63.8%) were in Set For Election state. This is the appropriate status for cards intended to be used in the elections.

One card (1.1%) was in Election Closed state. This status would be appropriate at the end of an election, but not prior to an election. It is possible that instead of running a test election, poll workers ran an election to test the tabulator. The election was run on October 24, 2012 (this is 12 days prior to the election day). There were 25 ballots cast. Zero totals report was printed at 18:14, and the totals report was printed at 18:19.

33 cards (35.1%) were in Not Set for Election state. This status would be appropriate prior to preparation for an election, but not prior to an election. This suggests that the corresponding districts sent these cards for the audit without first finalizing the preparation for the election. This is not a security concern, but an indication that not all districts submit cards at the right time (that is, after the completion of pre-election testing and preparation of the cards for the elections).

(c) Card and Counter Status: Here additional details are provided on the status of the counters on the usable cards. The expected state of the cards following the pre-election testing is Set for

Elections with Zero Counters.

All of the 60 cards (63.8%) that were found in Set For Election state had Zero Counters. This is the appropriate status for cards intended to be used in the elections.

There was 1 card in Election Closed status and had Non-Zero counters. This indicates that instead of running a test election and preparing cards for election, poll workers tested the tabulators by running an election (using test ballots) and left the card in that state. This situation would have been detected if such cards were to be used on the election day.

32 cards (34.0%) were in Not Set for Election state and had Non-Zero Counters. This is not an expected state prior to an election. This suggests that the cards were subjected to pre-election testing, but were not set for elections prior to their selection for the audit. This situation would have been detected and remedied if such cards were to be used on Election Day as the election cannot be conducted without putting the cards into election mode.

1 card (1.1%) was found to be in Not Set for Elections state with Zero Counters. This is similar to the 32 cards above. Manual examination of the audit log of this card revealed that it underwent pre-election testing. This card was most likely tested at LHS, since the date of the testing is the same as the initialization date. Here the counters were re-set to 0 after testing. This situation would have been detected and remedied if such cards were to be used on the election day.

Taking the above percentages together, it appears that almost all districts (63.8% + 34.0% = 97.8%) performed pre-election testing as required before submitting the cards for the audit.

(d) Card Duplication: The only authorized source of the card programming in Connecticut is the external contractor, LHS Associates. The cards are programmed using the GEMS system. Card duplications are performed using the AV-OS voting tabulator; one can make a copy (duplicate) of a card on any other card by using the tabulator's duplication function. SOTS polices do not allow the districts to produce their own cards by means of card duplication.

Card duplication is a concern, as there is no guarantee that duplication faithfully reproduces cards, and it masks the problem with card reliability. Additionally, it is impossible to determine with certainty who and why resorted to card duplication.

There were 13 cards involved in duplication. 11 of these cards (84.6%) were *master* cards used for duplication. 2 cards (15.4%) were *copy* cards produced by duplication.

We manually examined the event logs of all duplicated cards and compared the initialization date of the card to the date of the duplication. We observed that the majority of these cards (84.6%) (as well as the majority of usable cards (84.0%)) submitted for pre-election audit have an invalid initialization date: this date is 00/00/127. For those cards we could not establish whether the cards were involved in duplication at LHS or at the districts. It is extremely important that both LHS and the districts set the AV-OS date/time correctly. The remaining two cards (15.4%) were most likely involved in duplication at LHS. This is because both cards were involved in duplication 5 days after the initialization, while pre-election testing was performed 20 days after the initialization.

Regarding the clock settings at LHS, the SOTS Office followed up with LHS requesting that correct time/date is set for the AV-OS machines used to program the cards.

Given the SOTS polices, the districts must not be producing their cards locally. If a district finds it necessary to duplicate cards, they need to make records of this activity and bring this to the attention of the SOTS Office.

4.3 Event Log Analysis Results

Here we present the result of the event log analysis for all the usable cards. Out of the 94 correct⁶ cards, 86 (91.0%) cards were flagged because their event logs did not match our sequence rules.

The event log analysis produced 133 notifications. Note that a single card may yield multiple notifications. Also recall that not all notifications necessarily mean that something went wrong – a notification simply means that the sequence of events in the audit log did not match our (not-all-inclusive) rules. We next present the details of the analysis.

4.3.1 Out-Of-Bounds Dates

This notification indicates that an event sequence in the log contains events that occurred outside of the expected chronological boundaries. For our analysis we dated the following chronological stages of an election: (a) Election Initialization, (b) Test Election, and (c) Preparation for Election.

The notification statistics for each stage appear in Table 4.

| Out-of-Bounds Dates | Cards Usable for the Election | | | |
|---------------------------------|-------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| Sequence: Initialization | 79 | 84.0 % | 79 | 84.0% |
| Sequence: Test Elections | 20 | 15.0% | 20 | 21.3% |
| Sequence: Prepare For Elections | 9 | 6.8% | 9 | 9.6% |

Table 4: Pre-Election Event Log Analysis Results – Out-of-Bounds Dates

(a) **Initialization: 79 cards contained unexpected initialization times.**

Card initialization is performed by LHS. We expect this process to start and complete no more than two months and no less than two weeks respectively before the election day. Thus, for these elections we expected initialization to be performed between 09/06/2012 and 10/23/2012. Our assumptions for the sequencing of events are based on the SOTS documentation⁷.

We discovered that the initialization date of the majority of correct cards (84.0%) fell outside of the assumed period. This is apparently due to the fact that the AV-OS machine used for initializing these cards at LHS does not have its date/time set correctly. Instead, the date of initialization appears as 00/00/127 in the even log of all correct cards. We reiterate that it is important that all AV-OS tabulators have the date/time set correctly. The SOTS Office requested that LHS set the time/date correctly on their AV-OS machines.

(b) **Test Elections: 20 cards were tested at unexpected times.**

Test elections are performed after the cards are delivered to the districts. Here the districts test the usability of the memory cards they receive. Thus, we expect Test Elections to be performed two weeks after the beginning of card Initialization and ten days before the election day⁸.

For this election we expect this process to be completed between the dates 09/13/2012 and 10/28/2012. Table 5 lists districts that show unexpected test dates.

⁶Correct cards are those that contain correct programming for the current election. Usable cards exclude those containing data unreadable by the tabulators, unprogrammed cards, and cards programmed for different elections.

⁷For example, “Marksense Voting Tabulator”, Section 9-242a-5, states that memory cards should be tested “as soon as ballots and ballot cards are available and not later than the tenth day before the election or primary”. Hence, the testing of the cards must be completed no later than the tenth day before the election, and the initialization at least two weeks in advance. The document can be found at <http://www.ct.gov/sots/lib/sots/legislativeservices/>

| Card Name | Test Election | |
|---------------------------------|---------------|-------|
| | Date | Time |
| HARTFORD-DISTRICT_10-0003193 | 10/31/12 | 14:23 |
| HARTFORD-DISTRICT_11-0003195 | 10/31/12 | 14:49 |
| HARTFORD-DISTRICT_13-0003204 | 11/01/12 | 10:50 |
| HARTFORD-DISTRICT_17-0003221 | 10/31/12 | 11:25 |
| HARTFORD-DISTRICT_18-0003226 | 10/31/12 | 11:54 |
| HARTFORD-DISTRICT_19-0004444 | 11/01/12 | 15:19 |
| HARTFORD-DISTRICT_20-0003232 | 11/01/12 | 12:54 |
| HARTFORD-DISTRICT_2-0003156 | 10/31/12 | 12:04 |
| HARTFORD-DISTRICT_23-0004977 | 10/31/12 | 15:14 |
| HARTFORD-DISTRICT_4-0003165 | 10/31/12 | 12:54 |
| HARTFORD-DISTRICT_8-0005711 | 11/01/12 | 15:14 |
| WATERBURY-DISTRICT_73-1-0004112 | 10/30/12 | 09:35 |
| WATERBURY-DISTRICT_73-2-0004095 | 10/30/12 | 09:53 |
| WATERBURY-DISTRICT_73-3-0004099 | 10/30/12 | 10:08 |
| WATERBURY-DISTRICT_74-2-0004121 | 10/30/12 | 12:08 |
| WATERBURY-DISTRICT_74-3-0004126 | 10/30/12 | 13:21 |
| WATERBURY-DISTRICT_74-5-0004110 | 10/30/12 | 14:31 |
| WATERBURY-DISTRICT_75-1-0005394 | 10/31/12 | 09:17 |
| WATERBURY-DISTRICT_75-2-0004392 | 10/31/12 | 09:47 |
| WATERBURY-DISTRICT_75-3-0004397 | 10/31/12 | 09:54 |

Table 5: Test Election dates outside of the assumed time window.

- (c) **Preparation for Election: 9 cards were prepared for elections at unexpected times.** Cards should be prepared for elections after the testing is completed but before the election date. This is the expected state for the cards submitted for the pre-election audit. Since election preparation needs to be done immediately after the cards are tested, the date boundaries are the same as for the Test Election sequence. Table 6 lists the district that shows preparation for elections on unexpected date.

| Card Name | Prepare for Election | |
|---------------------------------|----------------------|-------|
| | Date | Time |
| WATERBURY-DISTRICT_73-1-0004112 | 10/30/12 | 09:40 |
| WATERBURY-DISTRICT_73-2-0004095 | 10/30/12 | 09:59 |
| WATERBURY-DISTRICT_73-3-0004099 | 10/30/12 | 10:12 |
| WATERBURY-DISTRICT_74-2-0004121 | 10/30/12 | 12:12 |
| WATERBURY-DISTRICT_74-3-0004126 | 10/30/12 | 13:26 |
| WATERBURY-DISTRICT_74-5-0004110 | 10/30/12 | 14:38 |
| WATERBURY-DISTRICT_75-1-0005394 | 10/31/12 | 09:27 |
| WATERBURY-DISTRICT_75-2-0004392 | 10/31/12 | 09:52 |
| WATERBURY-DISTRICT_75-3-0004397 | 10/31/12 | 09:59 |

Table 6: Prepare for Election dates outside of the assumed time window.

The event log for this card shows preparation for elections six days before the election. As the preparation date is still prior to the election, this should not be a cause for concern. However,

according to the SOTS regulations⁹ the cards should have been prepared for election no later than the tenth day before the election.

4.3.2 Many Instances of Events

The log analysis sets certain bounds on the number of events. Some of these bounds are ad hoc, for example, the analysis flags any card whose event log contains more than 30 Session Start events. (These indicate that a tabulator was reset; such action does not interfere with ballot counting.) Other bounds are determined by the policies and procedural rules, such as that no card duplication events are allowed, thus one or more duplication events result in a notification.

| Event Name | Expected No. | Suggested Max. | Description |
|-------------------|--------------|----------------|---|
| SESSION START | ≥ 3 | 30 | Tabulator is turned on (e.g., 3 times: for initialization, testing, and election) |
| POWER FAIL | 0 | 10 | Tabulator switches to backup battery as the result of a main power failure |
| AUDIT REPORT | 0 | 5 | Audit report is printed |
| COUNT RESTARTED | 0 | 0 | Tabulator is restarted while in election mode and counting is resumed |
| MEMORY CARD RESET | 0 | 0 | The card is reset to a pre-election state following/during an election |
| DUPLICATE | 0 | 0 | The contents of the memory card are copied to another card |

Table 7: Events in an election timeline that may indicate a problem.

Table 7 lists such events along with the expected number of appearances and suggested maximums. The statistics for all such notifications appear in Table 8.

| Flagged Number of Instances | Cards Usable for the Election | | | |
|----------------------------------|-------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| MEMORY CARD RESET (none allowed) | 1 | 7.5% | 1 | 1.1% |
| DUPLICATE (none allowed) | 13 | 9.8% | 13 | 13.8% |

Table 8: Event Log Analysis Results - Many Instances of Events

(a) **one card contained event “MEMORY CARD RESET”:**

This event indicates that the cards were prepared for election and then were reset to a pre-election state. This notification was reported for the following card:

| Card Name | Observed |
|-----------------------------|----------|
| SUFFIELD-DISTRICT_1-0001602 | 1 |

Examination of the event log of this card revealed that the reset was recorded one day prior to the election date. The card was not prepared for election afterwards. Memory cards should never be reset and there should never be a need to do so. Furthermore, the procedures established by the

⁹Ibid.

SOTS Office do not permit memory card reset. The follow up by the SOTS Office confirmed that the card was reset due to an incorrect button being accidentally pressed during the pre-election testing.

- (b) **13 cards contained event “DUPLICATE”:** This event indicates that the cards were produced not by the expected process (i.e., programmed from GEMS), but rather by duplication of another card. These cards appear in Table 9. We already discussed card duplication in Section 4.2.

| Card Name | Observed |
|--------------------------------------|----------|
| ANSONIA-DISTRICT_7-0001641 | 1 |
| BRANFORD-DISTRICT_2-0002283 | 1 |
| DURHAM-DISTRICT_2-0002393 | 1 |
| ENFIELD-DISTRICT_359_AND_459-0001804 | 2 |
| HARTFORD-DISTRICT_16-0003218 | 1 |
| HARTFORD-DISTRICT_21-0003234 | 1 |
| HARTFORD-DISTRICT_6-0003173 | 1 |
| MONROE-DISTRICT_3-0005772 | 1 |
| NEW_MILFORD-ABSENTEES-0001443 | 1 |
| NEW_MILFORD-DISTRICT_6-0001436 | 1 |
| WALLINGFORD-DISTRICT_1-0001860 | 1 |
| WATERBURY-DISTRICT_73-3-0004099 | 1 |
| WATERBURY-DISTRICT_74-3-0004126 | 1 |

Table 9: Cards involved in duplication.

4.3.3 Miscellaneous Warnings

Table 10 reports the notification that were issued for cards caused either by unexpected events appearing in some event log sequences, or when an event occurred beyond the scope of rules covered by the current audit log analysis. In the latter case additional events appear in the log, after all the rules are satisfied.

| Sequence Inconsistencies | Cards Usable for the Election | | | |
|------------------------------|-------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| Action Exceeded Rules' Scope | 2 | 1.5% | 2 | 2.1% |
| Action Beyond Rules' End | 9 | 6.8% | 5 | 5.3% |

Table 10: Pre-Election Event Log Analysis Results - Sequence Inconsistencies

The following cards resulted in such warnings:

| Card Name | No. of Warnings |
|--------------------------------|-----------------|
| BRANFORD-DISTRICT_7-0002300 | 1 |
| DURHAM-DISTRICT_2-0002393 | 1 |
| DURHAM-DISTRICT_4-000541 | 1 |
| GLASTONBURY-DISTRICT_9-0004974 | 5 |
| GREENWICH-DISTRICT_2-0005440 | 1 |
| KENT-DISTRICT_1-0001118 | 1 |
| WALLINGFORD-DISTRICT_1-0001860 | 1 |

The (manual) examination of the event log did not reveal security issues. However we note the following deviation from the election procedures.

- For BRANFORD-DISTRICT_7-0002300, DURHAM-DISTRICT_4-000541, GREENWICH-DISTRICT_2-0005440 and KENT-DISTRICT_1-0001118 the ZERO TOTAL REPORT was reported/printed either before or after the election day. This is not an issue, provided such reports are also printed on the election day.
- For GLASTONBURY-DISTRICT_9-0004974 there was an election run prior to the election day. We only expect test election events for all cards prior to the election day.

Finally, the event log of one card indicates either an attempt to use an external system to program the card, or at least an incorrect usage of the tabulator:

- For DURHAM-DISTRICT_2-0002393 and WALLINGFORD-DISTRICT_1-0001860 the COM ERROR event was reported. This event indicates a communication error with an external system. This will be recorded in the audit log if one tries to program a memory card through direct mode from GEMS, and either a communication error occurs or the AV-OS tabulator is not connected to an external system. Also, the duplication event appears right after COM ERROR event for both cards, suggesting that after direct mode failed, duplication was performed. The SOTS Office followed up with these towns and it was confirmed that the attempt to communicate with an external system was due to an incorrect button being pressed.

5 Addressing Memory Card Reliability

We estimated the overall percentage of the cards that are not usable in the election to be between 1.7% and 9.9% for the pre-election audit. None of these cards are readable by the tabulators, and as such they do not pose a security concern: such cards are detected as unformatted cards by the tabulators and they cannot be used in the election. However, this high failure rate, consistent with prior observations¹⁰, is a reliability issue.

Our earlier investigation determined that the primary reason for memory card failures is depleted batteries. Once the battery's store of energy is depleted, the cards lose their data. The electrical properties of the batteries are such that the battery voltage output can decrease precipitously as the battery reaches the end of its service life. Therefore one cannot expect to rely on the low battery warning system built into the AV-OS. Battery depletion may happen within days after a card was programmed and tested. Thus even if a card is successfully programmed, it can fail before it is tested prior to an election, or at any time after it is successfully tested.

New non-volatile (battery-less) memory card was recently developed by the vendor. Our preliminary analysis of this card confirmed that it is compatible with AV-OS systems deployed in Connecticut. A pilot deployment of the new cards in April, 2012 was done in the Town of Vernon using 12 of the new cards. The cards performed well, no failures were detected, and no such cards lost their data. However this is a very small sample of cards. We are currently performing in-depth testing of the non-volatile cards and as of this writing the results are encouraging.

A broader pilot is being planned by the SOTS Office to occur in the near future. The use of the new card should eliminate the major cause of memory card failures.

¹⁰ See the summary of pre-election audits performed from 2007 to 2010 at: <http://voter.engr.uconn.edu/voter/wp-content/uploads/VC-TechAudits-2007-2010c.pdf>.

6 Conclusions and Recommendations

We note that adherence to the established pre-election testing procedures at the districts has improved compared to prior years. Overall the audits did not detect any cards whose data raised concerns about the integrity of tabulation. We make the following concluding remarks and recommendations.

- The SOTS Office should continue publicizing proper procedures and continue offering training. In particular, to reinforce the need to prepare all cards for election prior to the election day and prior to the pre-election audit.
- Fewer cards are being duplicated at the districts, and it is important to continue reiterating that cards must never be duplicated. Any cases of duplication should be recorded in the moderators' logs and be brought to the attention of the SOTS Office with a documented explanation of why this is necessary.
- It is important for the districts to report any problems during pre-election testing (and any card problems) to the SOTS Office as soon as possible upon completion of the tests. In particular, if a tabulator offers to format a card (this happens when the card is unusable), the district should not format the card, but contact the SOTS Office.
- It is important for the districts to report to the SOTS Office any unexpected behavior of the tabulators that seem to necessitate a restart or a memory card reset. It would be helpful if moderators' logs contained records of machine restarts, perceived causes, and reasoning for the restart or reset. There was at least one documented case of a tabulator malfunction during this primary election. In such cases it is strongly recommended that the problematic tabulator is tested by the Center personnel (either at the district or in our laboratory).
- The current number of cards with unreadable data (junk data) continues to be high. We have determined that weak batteries are the primary cause of this. The vendor developed a new non-volatile, battery-less memory card, and our ongoing evaluation continues to confirm their compatibility with the AV-OS machines used in Connecticut. A limited pilot using the new cards was successfully performed in Vernon. It is expected that a broader pilot deployment of the new cards by the SOTS Office will occur in the near future. The use of the new card should eliminate the major cause of memory card failures.
- It is important that cards sent for the pre-election audit are selected at random. One card randomly selected from four cards in each district is to be randomly selected for the audit. While the districts are encouraged to submit all malfunctioning cards to the VoTeR Center, all such cards need to be identified separately from the cards randomly selected for the audit.

When a sufficiently large collection of cards is selected randomly for audit, the results of the audit meaningfully represent the overall State landscape and help identify technological and procedural problems that need to be solved. Should the selection not be at random, for example, by avoiding sending duplicated cards in for audit, the results are less representative, and may lead to masking technological problems. Therefore training should continue stressing the need to submit appropriate cards for the pre-election audit.

- Lastly, it is important that the date and time of the AV-OS tabulators are set up correctly at LHS and at the districts. If this is not done correctly, the appearance may be created that the cards were not used consistently with the proper conduct of an election.

[End]