VoTeR Center

UConn Center for Voting Technology Research

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Technological Audit of Memory Cards
for the November 8, 2011 Connecticut Elections

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Summary

The University of Connecticut Center for Voting Technology Research (VoTeR Center) performed pre-election and post-election audits of the memory cards for the Accu-Vote Optical Scan (AV-OS) tabulators used in the November 8, 2011 elections. The cards were programmed by LHS Associates of Salem, New Hampshire, and shipped to Connecticut districts.

For the pre-election audit, the Center received 453 memory cards from 331 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).

Among these 453 cards, 223 (49.2%) fall into category (a). 100% these cards were correct. These cards contained valid ballot data and the executable code on these cards was the expected code, with no extraneous data or code on the cards. We note that the adherence to the election procedures by the districts is improving, however the analysis indicates that the established 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.

There are 230 cards (50.8% of all cards) that were found to be unusable by the AV-OS, thus falling into category (b). In particular, 215 contained apparently random (or 'junk') data, 12 cards were unusable by AV-OS, but did not contain random data (these require further investigation), 2 cards were formatted using AV-OS utility, however, they were not programmed, and 1 card contained only zeros. All these cards are 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 this audit the percentage of unusable cards is between 7.4% and 17.4%, and this is consistent with prior audits.

For the post-election audit, the Center received 157 cards. Out of these cards 20 cards were used on Election Day. Given that the small sample of such cards does not allow for a meaningful statistical analysis, we report our finding in abbreviated form. To enable more comprehensive future post-election audits it is important to significantly increase the submission of cards that are actually used in the elections.

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

Contents

1 Preface

The University of Connecticut Center for Voting Technology Research (VoTeR Center) conducted pre-election and post-election audits of the memory cards used in the Accu-Vote Optical Scan (AV-OS) tabulators in the November 8, 2011 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 453 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. The majority of the pre-election cards arrived at the Center during November, 2011. If noteworthy irregularities that might affect integrity or security are detected, they are reported to the SOTS office without delay. Preliminary results were reported to the SOTS office during the audit.

For the post-election audit, the Center received 157 cards. Out of these cards only 20 cards were used on Election Day. Given that the small sample of such cards does not allow for a meaningful statistical analysis, we report our finding in abbreviated form. To enable more comprehensive future post-election audits it is important to significantly increase the submission of cards that are actually used in the elections.

The memory cards were subject to several integrity tests. A comprehensive overview of the procedures followed by the Center personnel in conducting such audits is presented in prior reports[1]. We do not repeat here the description of the engineering that was performed to enable the audit,

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[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. 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.

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 report[2].

In this report, we present the objectives of the audits 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 electro-magnetic) of the memory cards.

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.

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.

2 Introduction

In this section we overview the AV-OS based election system used in Connecticut, and describe the goals of the pre-election memory card audits.

2.1 Brief Description of the AV-OS

The AV-OS election system consists of two components: the Accu-Vote Optical Scan voting terminal (AV-OS terminal) and the ballot design and central tabulation system, GEMS, for Global Election Management System. See our report at URL http://voter.engr.uconn.edu/voter/Report-OS.html for details on this election 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 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.

- 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. In the State of Connecticut, GEMS is not used for central tabulation of election results.

- The memory cards are 40-pin, nominally 128KB cards. The memory card is installed into the 40-pin card slot of the AV-OS. It is worth mentioning that recent (summer 2009) instances of this card were manufactured by Smart Modular Technologies for Premier Election Systems, Inc., and that commercial-off-the-shelf readers and writers for this card have not been found.

For election deployment the system is secured within a ballot box so that no sensitive controls or connectors are exposed to the voter. Each memory card contains executable code that is used for printing the reports. The code, called *bytecode*, is written in a proprietary symbolic language. Such executable files are identified by means of the suffix .abo (AccuBasic Object). The installation of the GEMS software on the PC contains several databases that include the data and ballot layout corresponding to each district, as well as the bytecode for AV-OS.

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

2.2   Goals of the Memory Card Audits

The VoTeR Center prepares for and implements memory card audits at the request of the SOTS. Here we present the goals of the pre-election and post-election technological audits.

2.2.1   Goals of the pre-election audit

The pre-elecion 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 cards is examined to determine whether the data and code on the cards is 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, any deviations in the bytecode, the state of the counters and the content of the audit logs. These audit logs contain significant events in the life of a card since the last time it was formatted.

 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.

2.2.2   Goals of the post-election audit

Post-election audits focuses on the memory cards that were used in the election. The audits have three primary goals: (i) determine whether or not the memory cards are still properly programmed after the election is closed for the specific district and specific election, (ii) determine whether or not proper pre-election procedures are followed by the election officials, and whether the usage of the cards is consistent with the proper conduct of the election, and (iii) determine whether or not any technical failures occurred. The post-election audit employs a procedure similar to the pre-election audit.

   The selection of cards for the post-election technological audit differs from the pre-election audit as follows. The SOTS Office randomly selects 10% of the districts that are the subject of post-election hand-counted audit (this audit is not covered in this document). These districts are also asked to submit the cards that were used in the election for the post-election technological audit. Additionally, any district, in principle, is able (and encouraged) to submit their cards for the post-election audit.

   As the cards arrive from the districts at the Center, the contents of the cards is examined to determine whether the data and code on the cards is correct for the given district and election, and whether the events recorded in the card's audit log correspond to a proper programming, preparation for the election, and conduct of the election. As before, this is done by comparing the card contents to the known baseline, and by checking the status of the card and its audit log.

3   Summary of the Pre-Election Audit Results

We now highlight audit results for the 453 cards that were received and analyzed by the VoTeR Center. These cards correspond to 331 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). Figure 1 graphs the arrival of these cards. Note that the majority of these memory cards, 322 out of 453, were received prior to the Election Day.
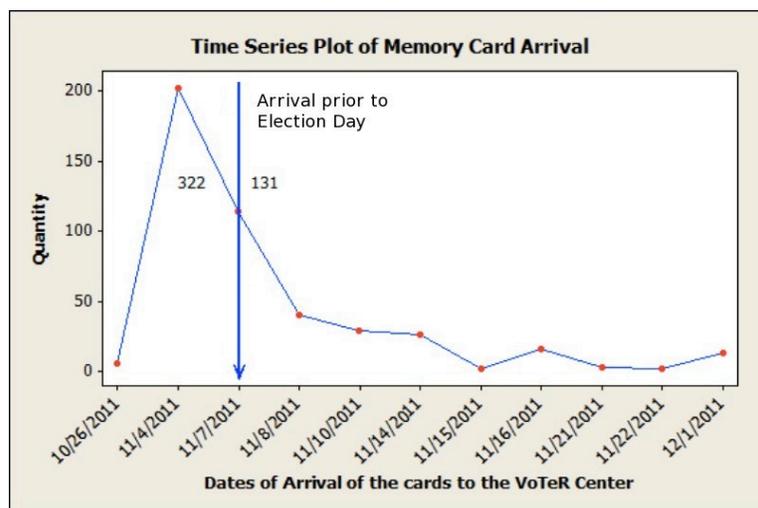

Figure 1: Arrival of memory cards for the audit

   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).

   Additional details 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 correct cards are grouped together with the correct cards, but we note the number of cards that were involved in duplication.

Among the 453 cards received, 223 (49.2%) were correct. That is, these cards contained correct election data. This category includes both 205 (45.2%) cards programmed according to the correct procedure, and also the 18 (4.0%) cards whose audit 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 two hundred and thirty (230) cards, 50.8%, that were unusable by the tabulators. Consulting the summary[3] 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 this audit the percentage of unusable cards is between 7.4% and 17.4% within the overall card population. This is consistent with prior observations and represents a high failure rate. This calculation is given in Section 4.1.

In prior investigations,[4] we determined that weak batteries are the primary cause of memory cards losing their data and becoming unreadability by the tabulators. Recently, new non-volatile (battery-less) memory cards have been developed by the vendor. This has the promise of addressing the failures associated with weak batteries. These cards are undergoing testing, and it is anticipated that the new cards will gradually replace the old cards in Connecticut.

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.

- 453 were received for the pre-election audit

- 223 were correct (this includes 18 cards were that were involved in duplication)

  - 134 were set to be used in the elections
  - 89 were not set to be used in the elections

- 230 cards were unusable (by AV-OS)

  - 215 cards were contained apparently random data ('junk' data)
  - 12 cards were unusable (but the data was not random)
  - 2 cards were not programmed (formatted, but blank)
  - 1 card was a null card (contained all zeros)

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

[4]"Determining the Causes of AccuVote Optical Scan Voting Terminal Memory Card Failures", 2010 Electronic Voting Technology Workshop/Workshop on Trustworthy Elections, EVT/WOTE'10, Washington, DC, August 2010, <www.usenix.org/event/evtwote10/>.

4.1   Overall Card State Analysis

Table 1 shows the frequency of various states observed on the 453 audited memory cards.

All Cards (453)		
(a) Card Format	Number	% Total
Correct Cards	223	49.2%
Unusable (Junk) Data	215	47.5%
Unusable (not Junk)	12	2.7%
Unusable (Not Programmed)	2	0.4%
Unusable (Null)	1	0.2%
Totals:	453	100%

Table 1: Memory card analysis summary for all cards received: (a) Card Format.

(a) **Card Format:**

Among the 453 audited cards, 223 cards 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 223 cards, 205 cards (45.2%) were programmed directly using GEMS and contained data matching the baseline. These involved no duplication. 18 cards (4.0%) were involved in duplication, otherwise they contained correct data data, matching the baseline.

230 cards (50.8%) 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. 215 cards (47.5%) 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. 12 cards (2.7%) were unusable by the AV-OS. Similar to 'junk' cards they are readily detected through pre-election testing by poll workers, however these cards did not contain random data and these cards have been retained for a follow up evaluation.

2 cards (0.4%) were not programmed. Such cards contain no data about the election, and this is not an intended state of the card. It is possible that these cards were (inadvertently) reformatted after testing; else they may have arrived not programmed. Lastly, 1 (0.2%) 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.

Given that unusable (unreadable by AV-OS for the purpose of elections) cards were not selected randomly, we estimate that for this audit the percentage of unusable cards is between 7.4% and 17.4%. This estimate is made on the basis of the following calculation. We received cards from 331 districts out of the total 780 districts (this includes absentees), where there are four cards per district. The number of unusable cards in the audit is 230. Thus the minimum percentage is calculated as $230/(780{\cdot}4) = 7.4\%$, given that unusable card data does not contain district information. Performing similar calculation for the 331 participating districts, we obtain the maximum percentage as $230/(331 \cdot 4) = 17.4\%$. This range is consistent with the results from prior audits.

4.2   Analysis of the Readable/Usable Cards

We now present the details of the audit for the 223 cards (among the 453 audited cards) that could be used in the elections.

Usable Cards 223		
	Number	% Total
(b) Card Status Summary		
Not Set for Election	89	39.9%
Set for Election	134	60.1%
Totals:	223	100%
(c) Card & Counter Status		
Set For Elections, Zero Counters	134	60.1%
Not Set, Non-Zero Counters	85	38.1%
Not Set, Zero Counters	4	1.8%
Totals:	223	100%
(d) Card Duplication (18)		
Master Card	12	66.7%
Copy Card	6	33.3%
Totals:	18	100%

Table 2: 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.

134 cards (60.1%) were in Set For Election state. This is the appropriate status for cards intended to be used in the elections. This percentage is an improvement over the 2010 November pre-election audit, where 41.6% of the cards were set for elections.

89 cards (39.9%) were in Not Set for Election state. This status would be appropriate for the cards that either did not undergo pre-election testing or were not prepared for elections, but not for the cards that are fully prepared for 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 & 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 134 cards (60.1%) 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.

85 cards (38.1%) 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.

4 cards (1.8%) were found to be in Not Set for Elections state with Zero Counters. This is

similar to the 85 cards above. This situation would have been similarly 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 ($60.1\% + 38.1\% = 98.2\%$) performed pre-election testing 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. Cards 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 18 cards involved in duplication. 12 of these cards (66.7%) were *m*aster cards used for duplication. 6 cards (33.3%) were *copy* cards produced by duplication.

We manually examined the audit logs of all duplicated cards and compared the initialization date of the card against the date of the duplication. We established that most of the cards (16 out of 18) were most likely involved in duplication at LHS. 12 out of 16 were involved in duplication either on the day of initialization, or the day after. The remaining 4 cards were involved in duplication within 4 days of initialization, however they were tested and prepared for election at a later date (4 to 7 days after the duplication occurred).

Only two cards out of 18 were most likely involved in duplication at the district, as they were prepared for election within a few minutes after the duplication event was recorded. This is an improvement from prior audits.

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 SOTS Office.

4.3   Audit Log Analysis Results

Here we present the result of the audit log analysis for all the usable cards.

AV-OS records on the memory card certain events that occur during the use of the tabulator. Table 3 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.

The audit log 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 to adutomated audit log analysis is available online [5].

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 is issued, and such audit logs are additionally examined manually. For the cases when the audit log

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[5]T. 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/ .

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 programing of the card using GEMS.
DOWNLOAD START	Recorded the start of data load during the programing of the card using GEMS.
DUPLICATE CARD	Appears when a card duplication takes place (in both the master and copy cards).
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 to insert 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 3: Audit log action types

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.

Out of the 223 correct [6] cards, 54 (24.2%) cards were flagged because their audit logs did not match our sequence rules.

The audit log analysis produced 106 notifications. Note that a single card may yield multiple notification. Also recall that not all notifications necessarily mean that something went wrong — a notificatin 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 Elections, and (c) Preparation for Elections.

The notification statistics for each stage appear in Table 4.

(a) **Initialization: 18 cards contained unexpected initialization times.**
   Card initialization is performed by LHS. We expect this process to start and complete no more

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[6]Correct 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.

	Cards Usable for the Election			
Out-of-Bounds Dates	# Notif.	% Notif.	# Cards	% Usable
Sequence: Initialization	18	17.0%	18	8.1%
Sequence: Test Election	26	24.5%	26	11.7%
Sequence: Prepare For Election	16	15.1%	16	7.2%

Table 4: Audit Log Analysis Results - Out-of-Bounds Dates

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 09/08/2011 and 10/25/2011. Our assumptions for the sequencing of events are based on the SOTS documentation[7]. Several cards fell outside of our assumed initialization period, but all were initialized prior to Election Day, so this is not a security issue.

The cards that appeared to have initialization dates that differed from our assumption (sorted by district name) are given in Table 5 for completeness.

	Initialization	
Card Name	**Date**	**Time**
ANSONIA-ABSENTEES-0001644	10/26/11	13:57
ANSONIA-WARD_5-0001633	10/26/11	13:58
ANSONIA-WARD_6-0001636	10/26/11	13:56
ANSONIA-WARD_7-0005581	10/31/11	9:53
BURLINGTON-DISTRICT_1-0001592	11/2/11	10:33
DERBY-ABSENTEES-0005518	10/27/11	12:46
DERBY-WARD_3-0005517	10/27/11	12:50
EAST_LYME-DISTRICT_2-0002993	10/31/11	11:23
EAST_LYME-DISTRICT_3-0002994	10/31/11	11:25
KILLINGLY-DISTRICT_1-0002108	10/27/11	10:39
MARLBOROUGH-DISTRICT_1-0002607	10/26/11	10:47
MONROE-DISTRICT_1-0005523	10/26/11	11:26
MONTVILLE-DISTRICT_3-0005550	10/26/11	10:49
SEYMOUR-DISTRICT_1-0005508	10/26/11	11:28
SEYMOUR-DISTRICT_3-0005509	10/26/11	11:28
SOUTH_WINDSOR-DISTRICT_2-0003838	10/28/11	11:39
SOUTH_WINDSOR-DISTRICT_4-0003846	10/28/11	11:40
SPRAGUE-DISTRICT_001-0001538	10/27/11	10:29

Table 5: Initialization dates outside of our assumed time window.

All listed cards show initialization prior to the election day; this is expected. Most of these cards were initialized more than a week prior to the elections. It is possible that some cards needed to be reinitialized and that some districts requested additional cards close to the election day.

(b) **Test Elections: 26 cards were tested at unexpected times.**
Test elections are performed after the cards are delivered to the districts. During this stage the

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[7] For 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/regulations/12_opscanusereg.pdf`.

Card Name	Test Election	
	Date	Time
ANSONIA-WARD_7-0005581	10/31/11	10:00
BRANFORD-DISTRICT_3-0002288	10/29/11	13:20
BRANFORD-DISTRICT_7-0002299	10/29/11	17:29
BURLINGTON-DISTRICT_1-0001592	11/2/11	11:53
CHESHIRE-DISTRICT_6-1-0003016	11/1/11	12:36
COLUMBIA-DISTRICT_1-0001409	11/1/11	17:00
DERBY-ABSENTEES-0005518	11/1/11	9:29
DERBY-WARD_3-0005517	11/1/11	11:07
EAST_LYME-DISTRICT_2-0002993	10/31/11	11:35
EAST_LYME-DISTRICT_3-0002994	10/31/11	11:39
FRANKLIN-DISTRICT_1-0003749	11/1/11	16:55
KILLINGLY-DISTRICT_1-0002108	11/1/11	18:51
KILLINGWORTH-DISTRICT_1-0001651	11/1/11	16:09
MARLBOROUGH-DISTRICT_1-0002607	11/2/11	12:19
OXFORD-DISTRICT_1-0001330	11/1/11	18:00
SEYMOUR-DISTRICT_1-0005508	10/29/11	9:59
SEYMOUR-DISTRICT_3-0005509	00/21/00	05:31
SHELTON-WARD_1-0003127	11/2/11	16:27
SHELTON-WARD_4-0003136	11/2/11	16:23
SPRAGUE-DISTRICT_001-0001538	11/1/11	10:03
SUFFIELD-DISTRICT_1-0002559	11/1/11	14:53
VOLUNTOWN-DISTRICT_1-0005046	11/1/11	17:08
VOLUNTOWN-DISTRICT_1-0005830	11/1/11	17:20
VOLUNTOWN-DISTRICT_1-0005831	11/1/11	17:15
WATERFORD-ABSENTEES-0001168	11/1/11	10:24
WINDSOR-ABSENTEES-0002259	11/7/11	12:07

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

districts test the usability of the memory cards they receive. Thus, we allow Test Elections to be performed two weeks after the beginning of card Initialization and ten days before the election day[8]. For this election we expect this process to be completed between the dates 09/15/2011 and 10/28/2011. Table 6 lists districts that show unexpected test dates.

The table shows invalid Test Election date for the card SEYMOUR-DISTRICT_3-0005509. This is apparently due to the incorrect settings of date and time. These should always be correctly set. Invalid dates cause inappropriate timestamps for other events in the log.

(c) **Preparation for Election: 16 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. The following shows preparation for elections on unexpected dates.

The audit log for all but one of these cards shows preparation for elections at least seven days before the election. One card, WINDSOR-ABSENTEES-0002259, was prepared for election a day before the election day. As the preparation dates are still prior to the election, this should not

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[8]Ibid.

Card Name	Prepare for Election	
	Date	Time
ANSONIA-WARD_7-0005581	11/1/11	11:49
BRANFORD-DISTRICT_3-0002288	10/29/11	13:30
BRANFORD-DISTRICT_7-0002299	10/29/11	17:35
CHESHIRE-DISTRICT_6-1-0003016	11/1/11	12:44
DERBY-ABSENTEES-0005518	11/1/11	9:35
DERBY-WARD_3-0005517	11/1/11	11:10
EAST_LYME-DISTRICT_2-0002993	11/3/11	11:09
EAST_LYME-DISTRICT_3-0002994	11/3/11	10:37
FRANKLIN-DISTRICT_1-0003749	11/1/11	17:02
KILLINGLY-DISTRICT_1-0002108	11/1/11	18:55
OXFORD-DISTRICT_1-0001330	11/1/11	18:27
SHELTON-WARD_1-0003127	11/2/11	17:58
SHELTON-WARD_4-0003136	11/2/11	17:34
SPRAGUE-DISTRICT_001-0001538	11/1/11	10:11
SUFFIELD-DISTRICT_1-0002559	11/1/11	15:15
WATERFORD-ABSENTEES-0001168	11/1/11	10:43

Table 7: Prepare for Election dates outside of the assumed time window.

be a cause for concern. However, according to the SOTS regulations[9] 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 audit 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 warning notification.

Table 8 lists such events along with the expected number of appearances and suggested maximums. The statistics for all such notifications appear in Table 9

(a) **18 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 10.

We already discussed card duplication in Section 4.2. Here we elaborate on the cards that were apparently involved in duplication at the districts. The cards are WEST_HAVEN-DISTRICT_10-0001770 and WEST_HAVEN-DISTRICT_3-0001750. We conclude that these cards were likely involved in duplication at the district, as they were prepared for election within a few minutes after the duplication event was recorded.

(b) **2 cards 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 cards:

Card Name	Observed
WEST_HAVEN-DISTRICT_7-0001761	1
WEST_HAVEN-DISTRICT_8-0001741	1

[9]Ibid.

Action 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
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 8: Events in an election timeline that may indicate a problem.

	Cards Usable for the Election			
Flagged Number of Instances	# Notif.	% Notif.	# Cards	% Usable
DUPLICATE (none allowed)	18	17.0%	18	8.1%
MEMORY CARD RESET (none allowed)	2	1.9%	2	0.9%

Table 9: Audit Log Analysis Results - Many Instances of Events

Card Name	Observed
BROOKFIELD-DISTRICT_1-0001571	1
GLASTONBURY-DISTRICT_5-0002743	2
GROTON-DISTRICT_5-0002158	1
GROTON-DISTRICT_6-0002164	1
GROTON-DISTRICT_7-0002167	1
HARTFORD-DISTRICT_9-0005343	1
MONTVILLE-DISTRICT_2-0002965	1
MONTVILLE-DISTRICT_5-0002977	2
NEW_MILFORD-DISTRICT_2-0001419	1
SHELTON-WARD_1-0003127	1
SHELTON-WARD_4-0003136	1
SOUTH_WINDSOR-DISTRICT_1-0003833	1
WATERBURY-DISTRICT_73-4-0004107	1
WATERBURY-DISTRICT_74-2-0004124	1
WEST_HAVEN-DISTRICT_10-0001770	1
WEST_HAVEN-DISTRICT_3-0001750	1
WESTPORT-DISTRICT_2-0001689	3
WINDSOR-DISTRICT_7-0002255	2

Table 10: Cards involved in duplication.

Closer examination of the audit log of these cards revealed that the operators ran additional test elections after preparing the card for election. Since both memory reset instances were recorded two weeks prior to the election date, none of these raise concerns.

4.3.3   Miscellaneous Notifications

Table 11 reports on the notifications issued for 6 cards that were caused either by unexpected events appearing in some audit log sequences, or when an event occurred beyond the scope of analysis rules covered by the current audit log analysis.

	Cards Usable for the Election			
Sequence Inconsistencies	# Notif.	% Notif.	# Cards	% Usable
Action Beyond Rules' End	26	24.5%	6	2.7%

Table 11: Audit Log Analysis Results - Sequence Inconsistencies

In the latter case, additional events appear in the log, after all analysis rules are satisfied. Analysis of the following cards resulted in such notifications.

Card Name	No. of Warnings
BROOKFIELD-ABSENTEES-0001579	1
BROOKFIELD-DISTRICT_2-0001572	1
GROTON-DISTRICT_6-0002164	1
LISBON-DISTRICT_1-0004786	1
WEST_HAVEN-DISTRICT_7-0001761	10
WEST_HAVEN-DISTRICT_8-0001741	12

The (manual) examination of these audit logs did not reveal any security issues. However we note the following deviations from the election procedures.

- For the cards with one notification the ZERO TOTAL REPORT was reported/printed before the election day: BROOKFIELD-ABSENTEES-0001579, BROOKFIELD-DISTRICT_2-0001572, GROTON-DISTRICT_6-0002164, LISBON-DISTRICT_1-0004786. This is not an issue, provided such reports are also printed on the election day.

- WEST_HAVEN-DISTRICT_7-000176 and WEST_HAVEN-DISTRICT_8-0001741 were prepared for election and then reset. After the reset a test election was reported on both cards. This is not an issue, as additional testing of cards is not problematic.

4.4   Bytecode Analysis Result for the Readable Cards

We have analyzed the AccuBasic 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.

4.5   Additional Observations and Details

Here we give additional information obtained from the audit analysis.

- Preparation for elections: Among the cards submitted for pre-election audit there are still many cards (about 39.9%) that are not set for election. However, we note that this is a reduction compared to the pre-election audit for November 2010 elections. We also observe that over

98% of the cards underwent pre-election testing based on the state of the counters. This is a good indicator.

It is possible that test elections were performed, however, the cards were not set for election by the districts prior to submitting the cards for the audit. This should be done more consistently in the future.

It is extremely important that all cards are in "Set for Election" state with zero counters going into election.

- Card duplication: The SOTS Office instructed the municipalities not to duplicate cards. We note that only two cards (less than 1%) were involved in duplication at the districts. This is a good indicator. (There were 16 other cards involved in duplication, but apparently this was done at LHS.) Duplicating cards creates cards that have not been directly produced from the election database (GEMS at LHS), and should not be allowed to be used in the elections until proper procedures are developed. It is recommended that the SOTS Office continue offering training through ROVAC to reinforce that stated no-duplication policy.

- Sending cards for pre-election analysis: Three correct cards were received from Voluntown District 1 for pre-election audit. Given the fact that there are only four cards available for each district, the town should never be left with a single card, unless the rest of the cards are unusable. Recall that if all four cards are correct, only one randomly selected card should be sent to the VoTeR Center for audit purposes.

5   Summary of the Post-Election Audit Results

For the post-election audit, the Center received 157 cards. Out of these cards only 20 cards were used on Election Day. Given that the small sample of such cards does not allow for a meaningful statistical analysis, we report our finding in abbreviated form. To enable more comprehensive future post-election audits it is important to significantly increase the submission of cards that are actually used in the elections.

Cards were submitted to the Center for two reasons per instructions from the SOTS Office (a) the districts that were involved in the post-election 10% hand-count audit were asked to submit the cards for the post-election technological audit, and (b) the districts were encouraged to submit any cards that appeared to be unusable in the election. Given that cards in category (a) were to be sent from the 10% of randomly selected districts, while all cards in category (b) were supposed to be submitted, and that the cards were submitted without consistent categorization of the reason, the number of unusable cards are disproportionately represented.

The summary of the post-election memory card analysis is as follows:

- Total cards received: 157 (100%)

- Unusable (junk) cards: 83 (52.9%)

- Usable, correct cards: 69 (43.9%), this includes the 20 cards that were actually used on Election Day.

- Unusable (not junk) cards: 2 (1.3%)

- Not programmed (blank) cards: 3 (1.9%)

The usable cards were correctly programmed for the specific districts, and the executable bytecode was correct, expected code. Among these cards, 8 cards were involved in duplication (as discussed earlier, this is not permitted per SOTS Office rules, and any perceived cause for duplication at the districts should be reported).

We note that the actual percentage of unusable cards is estimated to be between 7.4% and 17.4% (see Section 4.1), and not the disproportionately high 52.9% due to many districts sending all their unusable cards for the audit.

Among these 69 usable cards 20 cards were used on Election Day. The usage was consistent with proper conduct of the election. One of these cards showed that the results print was aborted; this is not a problem, as we have previously determined that this is due to incorrect logging by the AV-OS.

6   Addressing Memory Card Failures

We estimated the overall percentage of the cards that are not usable in the election to be between 7.4% and 17.4% 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 observations[10], 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 completely compatible with AV-OS systems deployed in Connecticut. It is expected that a 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.

7   Conclusions and Recommendations

We note that adherence to the established pre-election testing procedures is improving at the districts. 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 recorded in the moderators' logs and be brought to the attention of the SOTS Office with a documented explanation of why this is necessary.

- Is is important for the districts report any problems during pre-election testing (and any card problems) to the SOTS Office as soon as possible upon completion of tests.

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[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`.

- It is important for the districts 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.

- 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 preliminary evaluation confirmed its compatibility with the AV-OS machines used Connecticut. It is expected that a 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 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.

- For the post-election we received fewer than expected number of cards, 157, out of which only 20 were used in the election. This is really a low number. It would be extremely important in the future to obtain substantially larger numbers of cards from the actual use in the elections.

[End]