VoTeR Center

UConn Voting Technology Research Center

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Post-Election Audit of Memory Cards for the November 2009 Elections

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Summary

The Voting Technology Research (VoTeR) Center at the University of Connecticut performed a post-election audit of the memory cards for the Accu-Vote Optical Scan tabulators that were used in the November 2009 elections. The cards were programmed by LHS Associates of Methuen, Massachusetts, and shipped to Connecticut districts for use in the elections. The VoTeR Center received in total 120 memory cards from 49 districts after the elections. The cards were received during the period from December 12, 2009 to February 12, 2010. Among the received cards, 49 were used in the elections, the rest remained unused (either being unusable or serving as back-up cards). This document reports on the findings obtained during the audit.

Among the 49 cards actually used in the elections all were properly programmed, however 2 cards were involved in duplication and one card was a non-standard (32K) card. 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. Concerning the remaining cards, 14 (12% of the total number of cards) were found to contain junk data, that is, they were unreadable, which is easily detected by the tabulators; had a card contained junk data at the time of the election, it could not have been used. A separate report will document our findings regarding the reasons causing occurrences of such cards.

The contents of 7 additional cards (that were not used in the election) did not match the reference data received by the Center from LHS before the election: 4 of these cards were programmed for Avon special election, and 3 cards were non-standard (32K) cards, otherwise they were programmed correctly. There were also 2 cards that were blank (not programmed). There are 30 cards that, although not presenting an immediate security concern, had audit log entries showing unexpected procedural event sequences. For example, there are 5 card duplication events prior to the election. We note that the adherence to the election procedures by the districts is improving, however 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 summary, (a) all cards representing those used in the election were properly programmed, (b) cards with junk data continue to be a problem; we believe we know the reason and are finalizing the findings, (c) a number of cards show that the pre-election procedures are not followed uniformly and that cards continue to be duplicated; we recommend that in addition to the prohibition of duplication of cards, that whenever there is a perceived necessity to duplicate a card, the reason be documented and furnished to the SOTS Office. The audit was performed at the request of the Office of the Secretary of the State.

Contents

1 Preface

The Voting Technology Research (VoTeR) Center at the University of Connecticut conducted a post-election audit of the memory cards used in the Accu-Vote Optical Scan (AV-OS) tabulators in the November 2009 elections in the State of Connecticut. The audit was performed at the request of the Office of the Secretary of the State (SOTS) of Connecticut.

The memory cards were programmed by LHS Associates of Methuen, Massachusetts, and provided by LHS to the districts in Connecticut. The audit was performed on all memory cards that were shipped by the districts and received by the VoTeR Center at the University of Connecticut in Storrs between December 12, 2009 and February 12, 2010. After the initial release of the audit results to the SOTS Office the report was revised to reflect the findings of several follow-up investigations (for example, some cards from Ridgefield contained the results of the recount conducted one week after the November elections).

The memory cards were subject to several integrity tests. A comprehensive overview of the procedures followed by the VoTeR 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, including the log analysis, and the technical setup used in the tests.

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

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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, Montral, Qubec, Canada, August 2009, available at http://voter.engr.uconn.edu/voter/wp-content/uploads/evt09.pdf.

We conclude the report with several observations based on what was learned during the post-election 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.

About the UConn VoTeR Center

Following our participation in the Connecticut Voting Technology Standards Board in 2005, the Voting Technology Research (VoTeR) Center was established in 2006 to advise state government in the use of voting technologies, to research, investigate and evaluate voting technology and voting equipment, and to develop and recommend safe use procedures for the computerized voting technology in elections. The personnel of the Center includes several faculty members, graduate students, and staff of the Computer Science and Engineering Department at the University of Connecticut.

The work of the Center is funded by the Secretary of the State (SOTS) for the state of Connecticut, and we function in close contact with the personnel at the office of the SOTS. We offer the state an independent, objective analysis of the voting technologies offered by several vendors, we advise the state on selecting and administering the voting equipment for its election needs, and we are not associated with any of the voting technology vendors. The evaluations of the voting technology are performed at the VoTeR Center laboratory at the University of Connecticut. These include hands-on evaluations, exploration of possible attack vectors, physical integrity checks of the terminals and memory cards, and mitigation strategies. The VoTeR Center is not involved in establishing the states policies for procuring the voting technology, but limited to providing technical expertise on, and evaluations of these technologies before deployment and during the use by the state. In this sense the VoTeR Center is a third party independent technical consulting resource for the State of Connecticut.

VoTeR Center personnel continue to assist the state in developing safe use procedures for the Optical Scan terminals. The procedures in place for the election include strict physical custody policy, tamper-resistant protection of the equipment, and audits. The Center provides ongoing recommendations to improve the security of elections based upon our findings in evaluating the voting equipment and conducting pre- and post-election technological audits.

2   Introduction

We start by surveying the AV-OS based election system used in Connecticut, the goals of the post-election memory card audit, and a preview of the audit results.

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 a custom product of Smart Modular Technologies produced 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 the districts of the state of Connecticut, as well as the bytecode for AV-OS.

2.2   Goals of the Post-Election Memory Card Audit

The VoTeR Center prepares for and implements memory card audits at the request of the SOTS. The primary goals of the post-election audit was to perform integrity checks on the contents of the memory cards that were used in the elections and to obtain quantitative measures of the integrity of the contents of the memory cards.

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 GEMS database to be used as the baseline for the election data was provided by LHS Associates prior to the election.

For the post-election the VoTeR Center examined 120 cards received as of February 12, 2010. These cards came from 49 districts in Connecticut.

The contents of the cards were then extracted and compared with the intended contents using the GEMS database as the reference; this portion of the audit process is semi-automated. Any discrepancies or deviations from the baseline that were inconsistent with the use of the cards in the election were then logged and analyzed. Specifically, the memory cards were 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.

2.3   Overview of the Audit Results

We now overview the overall audit results for the 120 cards that were received and analyzed by the VoTeR Center. More detailed information is in the next section.

For the purpose of this audit we consider a card to be *correctly programmed* when 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 correctly programmed cards may have been involved in card duplication, and we group them with the rest of correctly programmed cards, but we note the number of cards that were involved in duplication.

1. **Cards Used in the Election**

   The total of 49 cards received for this audit (among the total number of 120 cards) were actually used in the elections. All of these cards were correctly programmed, however 2 cards were involved in duplication and one card was a non-standard (32K) card (this does not affect its usability, but it is not a card that belongs to Connecticut). There were 4 cards (8%) for which the results print was aborted. This is normally caused by the tabulators being incorrectly shut off after the final (of possibly multiple) printing of the results. This does not present a security concern, provided the final results are printed as required.

2. **All Cards: Correctly Programmed Cards**

   Among the 120 cards for this audit, 97 cards (81%) were found to have been correctly programmed for election. However, 3 of these cards were involved in duplication. Additionally 3 cards were non-standard (32K) cards. All of these cards contained valid ballot data, and the executable code on these cards was the expected code, with no extraneous data or code.

3. **All Cards: Cards with Duplication Events**

   The audit identified three (3) cards that were involved in duplication (the audit log of such cards contains card duplication events). Card duplication is not authorized per SOTS Office instructions. Otherwise the cards were correctly programmed for elections.

4. **All Cards: Cards Programmed for Different Elections**

   There were 4 cards submitted for this audit that were not programmed for November 2009 elections, but instead programmed for Avon special elections on November 24, 2009, and we did not expect such cards as special elections do not fall under this audit.

5. **All Cards: Not Programmed (Blank) Cards**

   There were 2 cards that were not programmed. The cards are formatted, but contain no election information. Such cards cannot be used in an election and the tabulators recognize such cards as blank cards.

6. **All Cards: Unreadable (Junk) Cards**

   The audit identified fourteen (14) cards, or 12%, that contained "junk" data. Such cards contain no usable or meaningful data and they cannot be used in an election. The tabulators readily identify such cards and prompt the user to format the card. We have determined that weak batteries are the primary cause of junk data on cards; a separate report will document this in more detail. It is recommended that batteries are replaced before each election.

   One of these cards was different from the other such cards in that it contained a regular pattern in a part of the card, instead of the seemingly random noise normally found on junk cards. This card came from Ridgefield, where a malfunction prevented one machine from being used. We are going to examine that machine.

7. **All Cards: Non-Standard 32K (Small Capacity) Cards**

   The audit identified in total 4 cards of non-standard capacity (32KB instead of 128KB): one card was used in the election; 2 cards were correctly programmed, but not used; one card was not programmed (blank). The tabulator uses only the first 32KB of the memory cards, so this is not a security concern, however all cards purchased for use in Connecticut are 128KB, which means that these cards either came from a different state or were erroneously provided for use in Connecticut (SOTS Office follow up with LHS determined that these were sent to Connecticut by mistake and LHS will ensure that correct cards are used in the future).

3   Audit Results

We now present the results of the post-election audit in more detail. For the November 2009 elections we received and examined 120 cards. These cards were programmed by LHS (with the exception of the cards that were involved in duplication). The cards were shipped by the districts to the VoTeR Center for the purposes of the post-election audit. The high level breakdown of the received cards is as follows:

- 120 were received for the post-election audit

- 49 were correctly programmed and used in the elections

- 51 were not used in the elections (in effect serving as back-up cards)

- 14 contained junk data

- 2 were not programmed (formatted, but blank)

- 3 were involved in duplication

- 4 were non-standard cards (32KB instead of 128KB)

- 4 were programmed for different elections

3.1   Cards Used in the Election

We infer that a card has been used in an election if the following are true: (i) the card appears in an "Election Closed" or "Results Print Aborted" status, and (ii) has non-zero counters. Otherwise the card is considered not to have been used in the elections.

3.1.1   Card State Analysis: 49 Cards Used in the Election

Table 1 shows the frequency of various states observed on the audited memory cards for the 49 cards used in the election. This part of the analysis does not include the analysis of the audit log stored in the memory card; the analysis of the audit log is given in the following section. Here we present the data in two parts:

(a) **Card Format**

　　47 cards (96%) were properly formatted and contained data matching the baseline.

　　2 cards (4%) were duplicated. For these cards the data on the card indicates that the cards were involved in duplication.

　　1 card (2%) was a non-standard, 32KB card, instead of the 128KB cards purchased by the state. These non-standard cards can be used without ill effects.

(b) **Card & Counter Status**

　　45 cards (92%) were in Election Closed state and had Non-Zero counters. This is the intended state for memory cards that had been used in the election.

　　4 cards (8%) were in Results Print Aborted state with Non-Zero counters. The cards are expected to have non-zero counters after the election, however this is an undesired state, indicating that poll workers either (1) shut the machine during the printing of the results,

	Cards Used in the Election		All Cards	
	Number	% Total	Number	% Total
(a) Card Format				
Good Data, Clean Card	47	96%	94	78%
Different Elections	0	0%	4	3%
Different District Number	0	0%	0	0%
Duplicated Card	2	4%	3	2.5%
(Unusable) Not Programmed	0	0%	2	2%
(Unusable) "Junk data"	0	0%	14	12%
Totals:	49	100%	120	100%
(b) Card Status				
Not Programmed (Blank)	0	0%	2	2%
Not Set for Election	0	0%	6	5.8%
Set for Election	0	0%	45	44%
Election Closed	45	92%	45	38%
Results Print Aborted	4	8%	4	3%
Results Sent/Uploaded	0	0%	0	0%
Audit Report Printed	0	0%	0	0%
(c) Card &Counter Status				
Election Closed, Non-Zero Counters	45	92%	45	38%
Election Closed, Zero Counters	0	0%	0	0%
Results Print Aborted, Non-Zero Counters	4	8%	4	3%
Results Print Aborted, Zero Counters	0	0%	0	0%
Set For Elections, Non-Zero Counters	0	0%	0	0%
Set For Elections, Zero Counters	0	0%	45	38%
Not Set, Non-Zero Counters	0	0%	6	5%
Not Set, Zero Counters	0	0%	0	0%

Table 1: Memory card analysis summary: (a) Card Format, (b) Card Status, and (c) Card Record of Electoral Procedure.

or (2) did not conclude properly the printing procedure by pressing "No" when prompted to print another copy. Neither is the intended procedure. According to election procedures, the results must eventually be printed and signed by the poll officials, but election officials either did not wait for the (final) printing to complete, and turned off the machine prematurely or did not followed the procedures to turn off the machine properly. It should be recommended that the poll workers must observe the prompt "Safe to Shut-Off the Machine", before turning off the AV-OS machines.

No cards with uploaded results were found. This is the expected observation as Connecticut does not use uploading of results for central tabulation.

No cards with audit report printed were found. This is the expected observation.

3.1.2   Log Analysis: 49 Cards Used in the Election

Here we present the results of the log analysis on the cards that were used in the election.

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 zero counters reports must precede the election. The rules of audit log checker do not cover all sensible sequences, and it continues to be refined as we are enriching the set of rules based on our experience with the election audits. For any sequence that is not covered by the rules a warning is issued, and such logs are additionally examined manually. The report that documents our approach is available online[2].

Out of the 49 cards, 24 (49%) appeared to have some inconsistencies in their audit logs, compared to our sequence rules.

Our analysis produced 64 warnings; they appear in Table 2. Note that a single card may yield multiple warnings. Below is a short description of our findings:

Out-Of-Bounds Dates

(a) **Initialization: 1 card presented abnormal initialization times.**

Card Name	Initialization Date
RIDGEFIELD-DISTRICT_2-0005785	**11/05/2009 12:21**

The card "RIDGEFIELD-DISTRICT_2-0005785" appears to have been programmed after the elections. Follow up discussions with the district established that Ridgefield conducted a recount a week after the election, and this card was reprogrammed for the recount.

(b) **Test Elections: 2 cards were tested at abnormal times.**

Card Name	Test Election Date
RIDGEFIELD-DISTRICT_2-0005785	**11/05/2009 12:25**
WALLINGFORD-DISTRICT_4-0001871	**11/03/2009 06:57**

The Ridgefield card is the same as the one that was reprogrammed for the recount. It is fine that the card "WALLINGFORD-DISTRICT_4-0001871" had zero counters event on election day, because elections followed as expected.

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[2] "Automating Voting Terminal Event Log Analysis", http://voter.engr.uconn.edu/voter/wp-content/uploads/evt09.pdf, EVT09 , Montreal, Canada, August 2009, www.usenix.org/events/evtwote09/ .

	Cards Used in the Election			
	# Warn	% Warn	# Cards	% Used
(a) Out of Date Bounds				
Sequence: Initialization	1	2%	1	2%
Sequence: Test Election	2	3%	2	4%
Sequence: Prepare For Election	2	3%	2	4%
Sequence: Election	17	27%	17	35%
(b) Many Instances				
SESSION START (allowed 10)	3	5%	3	6%
DUPLICATE (none allowed)	2	3%	2	4%
MEMORY CARD RESET (none allowed)	2	3%	2	4%
COUNT RESTARTED (none allowed)	3	5%	3	6%
(c) Sequence Inconsistencies				
Action Missing	19	30%	4	8%
Action Exceeded Rules' Scope	0	0%	0	0%
Action Beyond Rules' End	16	25%	2	4%

Table 2: Log Analysis Results - Cards Used in the Election

(c) **Prepare for Election: 2 cards were prepared for elections at abnormal times.**

Card Name	Prepare Election Date
RIDGEFIELD-DISTRICT_2-0005785	**11/09/2009 15:13**
WALLINGFORD-DISTRICT_4-0001871	**11/03/2009 07:05**

Both cards appear earlier in the analysis. For Ridgefield this was the preparation for their recount. Wallingford prepared the card for election on election day.

(d) **Elections: 17 cards were prepared for elections at abnormal times.**

The examination of the log revealed that 13 of those cards had just printed zero reports before election day. Here we present the remaining 4 cards that appear to run elections after election day:

Card Name	Run Election Date
MANCHESTER-DISTRICT_7-0003884	**10/24/2009 13:09**
RIDGEFIELD-ABSENTEES-0001940	**11/10/2009 10:42**
RIDGEFIELD-DISTRICT_1-0001930	**11/10/2009 12:56**
RIDGEFIELD-DISTRICT_2-0005785	**11/10/2009 15:33**
RIDGEFIELD-DISTRICT_3-0003123	**11/09/2009 15:21**

It appears that Manchester, instead of running a test election, ran an election on October 24th to test the tabulator. An election also appears on the proper day.

Follow up with Ridgefield established that these are the cards from the recount that was conducted a week after the election.

Unexpected Number of Event Instances

The automated audit log analysis sets certain bounds on the number of events that can occur. Some of these bounds are ad hoc, for example, the analysis flags any audit log that contain more than 10 Session Start events (this indicates that a tabulator was reset, but such action does not interfere with ballot counting). Other bounds are determined by the policies and procedural rules, such as that 0 card duplication events are allowed, thus 1 or more duplication events result in a warning.

The following events appeared more often than they were expected.

(a) **3 cards contained more than 10 "SESSION START" events:**
These cards contained fewer than 14 session starts. While it is worthwhile to find out why there were 14 session start events, such events do not interfere with a proper conduct of an election and are not a source of concern.

(b) **2 cards contained event "DUPLICATE":**
This event indicates that the cards were duplicated at least once. The cards that contained this event are:

Card Name	Number of Instances
BRISTOL-DISTRICT_78-2-0003382	**Observed: 1 Expected: 0**
STAFFORD-DISTRICT_1-0002440	**Observed: 2 Expected: 0**

The examination showed that those were the originally-programmed cards from which the duplicates were produced.

(c) **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.

Card Name	Number of Instances
MANCHESTER-DISTRICT_7-0003884	**Observed: 1 Expected: 0**
RIDGEFIELD-DISTRICT_3-0003123	**Observed: 1 Expected: 0**

It appears that the cards were simply prepared for election twice.

(d) **3 cards contained event "COUNT RESTARTED":**
This event occurs when an ongoing election was interrupted and restarted by turning the machine off and then on.

Card Name	Number of Instances
BRISTOL-DISTRICT_77-4-0003373	**Observed: 1 Expected: 0**
RIDGEFIELD-DISTRICT_3-0001937	**Observed: 1 Expected: 0**
WILTON-ABSENTEES-0001729	**Observed: 1 Expected: 0**

All three cards show an interruption of the election on November 03, 2009 (election day). The counting restarts almost immediately. In particular "BRISTOL-DISTRICT_77-4-0003373" was restarted at 11:14, "RIDGEFIELD-DISTRICT_3-0001937" at 17:11, and "WILTON-ABSENTEES-0001729" at 18:54. This does not raise concerns, however it would be helpful to know why counting needed restarting.

Unexpected Audit Log Analysis Warnings: 6 cards

There were 6 cards for which warning were issued. Manual analysis determined that these were reasonable sequences of events, consistent with a properly conducted election. We will include new rules that cover such sequences in the next version of the audit log checker.

3.2   Analysis of All Cards Received

The Center received 120 cards for the audit. This number includes 49 cards used in the election, with the analysis results presented in the previous section. Here we present the cumulative audit results for all cards received.

3.2.1   Card State Analysis: All 120 cards

Table 1 shows the frequency of various states observed on the audited memory cards for the 120 cards received and examined. The data is presented in three parts:

(a) **Card Format**

   94 cards (78%) were properly formatted and contained data matching the baseline.

   3 cards (2.5%) were duplicated. For these cards the data on the card indicates that the cards were involved in duplication.

   4 cards (3%) was a non-standard, 32KB card, instead of the 128KB cards purchased by the state. These non-standard cards can be used without ill effects. One of these cards was not programmed.

   4 cards (3%) contained data referring to different elections than the ones we audit. We believe that the AV-OS machines, with one of these memory cards installed, would not have accepted any ballots associated with the audited elections, had anyone attempted to cast such a ballot.

   2 cards (2%) were formatted, but not programmed (i.e., they were blank). Such cards are not accepted by the AV-OS and are readily detected when inserted.

   14 cards (12%) contained "junk" data, that is the card format is unrecognizable and appears to contain arbitrary noise. Such cards are not readable by AV-OS and they are readily detected through pre-election testing by poll workers, thus, unless they became junk after they were used in the election, they could not have been used in the election.

   One of these cards was different from the other such cards in that it contained a regular pattern in a part of the card, instead of the seemingly random noise normally found on junk cards. This card came from Ridgefield, where a malfunction prevented one machine from being used. We are going to examine that machine.

(b) **Card Status**

   This refers to the current state of the memory card, such as loaded with an election, set for election, running an election, closed election, and others.

   45 cards (44%) were in the Election Closed state, which is the desired memory card state for cards that were used in the elections.

   4 cards (3%) were found to be in the Results Print Aborted state (this was discussed in the previous section).

   45 cards (44%) were in Set For Election state. This is the intended state for the cards that were not used in the election. These are the (in-effect) back-up cards.

   6 cards (5.8%) were in Not Set for Election state. This is not the intended state. All cards going into the election should be in the Set for Election state following pre-election testing. This does not present a security issue, but indicates that the pre-election procedures were not followed uniformly by the districts. However we note that this is an improvement relative to the November 2008 elections: in 2008, among the cards not used in the election, about 1 out

	All Usable Cards			
	# Warn	% Warn	# Cards	% Usable
(a) Out of Bound Dates				
Sequence: Initialization	1	1%	1	1%
Sequence: Test Election	2	2%	2	2%
Sequence: Prepare For Election	2	2%	2	2%
Sequence: Election	19	22%	19	19%
(b) Unexpected Number of Events				
SESSION START (allowed 10)	5	6%	5	5%
DUPLICATE (none allowed)	3	3%	3	3%
MEMORY CARD RESET (none allowed)	4	4%	4	4%
COUNT RESTARTED (none allowed)	3	3%	3	3%
(c) Unexpected Warnings (benign)				
Action Missing	17	19%	5	5%
Action Exceeded Rules' Scope	16	18%	2	2%
Action Beyond Rules' End	16	18%	2	2%

Table 3: Log Analysis Results - All Usable Cards

of 3 cards was not set for election. For November 2009 only about 1 out of 7 cards was not set for election.

2 cards (2%) were Not Programmed. Such cards contain no data about the election, and this is not an intended state of the card. As the cards are tested after programming at LHS, the presence of blank cards suggests that perhaps these cards were (inadvertently) reformatted after testing (it is also possible that these cards arrived not programmed from LHS).

(c) **Card & Counter Status:**

45 cards (38%) were in Set For Election state and had Zero counters. This is the intended state for memory cards that were not used in the elections.

45 cards (38%) were in Election Closed state and had Non-Zero counters. This is the intended state for memory cards that had been used in the election.

4 cards (3%) were in Results Print aborted state with Non-Zero counters. As discussed above this is not an intended state for the cards that were used in elections.

6 cards (5%) were in Not Set For Election state with non-Zero counters. This is not an expected state; it is not problematic as such cards would be set for election with zeroed counters if they were to be used in the election. As we discussed earlier, this is a reduction in the frequency of Not Set For Election cards relative to November 2008.

3.2.2   Log Analysis: All 100 Usable Cards

Here we present the results of the audit log analysis for all the usable cards. Usable cards are those that contain correct programming for the November 2009 election. Usable cards exclude cards containing junk data, unprogrammed cards, and cards programmed for different elections. There were 100 usable cards. Among these 30 cards (30%) appeared to have some inconsistencies in their audit logs with respect to our sequence rules.

The analysis showed 88 warnings; they appear in Table 3. Note that a single card may yield multiple warnings. Below we provide a short description of our findings:

Out-Of-Bounds Dates

For Initialization, Test Elections and Prepare Elections we detect the same cards as the ones presented in Section 3.1.2. So we avoid repeating those results in this section.

(a) **Initialization: 1 cards present abnormal initialization times.**
Discussed in Section 3.1.2.

(b) **Test Elections: 2 cards were tested at abnormal times.**
Discussed in Section 3.1.2.

(c) **Prepare for Election: 2 cards were prepared for elections at abnormal times.**
Discussed in Section 3.1.2.

(d) **Elections: 19 cards were prepared for elections at abnormal times.**
Seventeen of those cards match the cards presented in Section 3.1.2. The other two cards each had a print zero reports event before election day. Thus, they should not raise any concern.

Unexpected Number of Event Instances

We discussed the meaning of such warnings in Section 3.1.2.

(a) **5 cards contained more than 10 "SESSION START":**

All of these cards contained fewer than 14 session starts. Thus, they did not diverge a lot from our threshold; they do not raise any concerns.

(b) **3 cards contained event "DUPLICATE":**

Two of those cards were presented in Section 3.1.2. The single remaining card is the following:

Card Name	Number of Instances
BRISTOL-DISTRICT_78-1-0004979	**Observed: 2 Expected: 0**

Closer examination showed that this is an original card from which duplicates were made.

(c) **4 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. Two of those cards were presented in Section 3.1.2. The remaining two cards are the following:

Card Name	Number of Instances
WEST_HAVEN-DISTRICT_10-0001740	**Observed: 1 Expected: 0**
WEST_HAVEN-DISTRICT_4-0001754	**Observed: 1 Expected: 0**

These cards do not raise any concern since it appears that they were prepared for election twice.

(d) **3 cards contained event "COUNT RESTARTED":**

Discussed in Section 3.1.2.

Unexpected Audit Log Analysis Warnings: 9 cards

As discussed earlier, these warnings did not raise any concern as they were normal sequences of events that have not yet been incorporated into our audit log checker.

3.3   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.

3.4   The Occurrence of Junk Cards

The audit identified fourteen (14) cards, or 12%, that contained "junk" data. These cards do not contain any meaningfully readable data. Junk cards present a reliability problem, but 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. Below is the historical data on the occurrence of cards with junk data.

Audit	Election	% of Junk Data Cards
Post-election	November 2009 election	12%
Pre-election	November 2009 election	9%
Pre-election	November 2008 election	9%
Post-election	August 2008 primary	5%
Pre-election	August 2008 primary	5%
Post-election	February 2008 primary	15%
Post-election	November 2007 election	8%
Pre-election	November 2007 election	4%

Table 4: Historical occurrence of cards with junk data

This is a high percentage of faulty/unusable cards.

The Center performed an investigation to determine the cause of occurrence of junk cards and reached the conclusion that the primary reason for this is the depleted/weak batteries. Once the battery is depleted, the cards lose their data. The electrical properties of the batteries is such that they may deplete rapidly as they reach the end of their 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.

If a card fails, e.g., its data becomes junk, due to the battery depletion, such a card can be restored to usefulness by changing the battery. Given the frequent occurrence of the junk data problem, it is recommended that all batteries be replaced with suitable long-life batteries before each election. We predicts that the percentage of "junk cards" will be greatly reduced once the new battery replacement policy takes effect.

We will document our detailed findings in a separate report.

4 Conclusions and Recommendations

Having performed and completed the audit, we believe that memory card audits are crucial in providing valuable information necessary to ensure the integrity of our electoral system. There are several noteworthy technological and procedural observations that emerge from the audit analysis. We now present these observations and our recommendations.

1. The current level of unusable (junk) cards, approximately 12%, is high. We have determined that the primary cause of a large percentage of such cards is the depletion of their batteries. This depletion can occur in a matter of days and AV-OS low battery warning is ineffective in timely detection of such batteries. A forthcoming report will provide additional technical detail. Our recommendation is that fresh batteries be routinely installed in the cards before each election as a step in preparing for each election. Furthermore, the batteries should be installed no earlier than six months in advance of the election. With these measure we anticipate substantial reduction in the occurrence of cards with junk data.

2. The results of the audit indicate that not all districts prepare their memory cards for election as required by the pre-election procedures. We observe that about 6% of the memory cards are not set for election as required. While this is an improvement compared to November 2008 elections, where about 12% of the cards were not set for election, we recommend that SOTS Office continue reiterating proper procedures to the relevant election officials.

3. We also observe that cards continue to be duplicated at districts prior to election despite explicit instructions from the SOTS Office disallowing card duplication. (Card duplication is possibly used to reprogram cards that were found to be junk during pre-election testing.) We note that there is an improvement in this are as well: about 3% of cards were duplicated in the November 2009 election as compared to over 9% of cards that were duplicated in the November 2008 election.

   The recommendation here is that SOTS Office continues to offer training through ROVAC, reinforcing the stated no-duplication policy. It is recommended that the election officials send reports to SOTS Office or call if they feel they cannot follow pre-election testing procedures, and to indicate why they consider memory card duplication as their only course of action.

4. There is still about 2.5% of cards whose audit logs contain Results Print Aborted event. Again, this is an improvement over the November 2008 audit where we reported 4.7% of cards with Results Print Aborted event.

   We recommend that SOTS Office continues to educate the election officials about the proper steps in concluding an election and printing the results. The election officials should make sure the tabulator display indicates that it is "safe to turn off" before shutting down the machine.

5. A number of memory cards show events in the audit logs that occur at unexpected times (e.g., election apparently not run on the right day). It is likely that this is due to incorrect setting of the clocks of the tabulators.

6. Lastly we note that the number the number of districts that submitted cards for the post-election audit is 49. This is substantially less than required by the audit. Full participation in the audit is necessary to ensure a meaningful audit. The participation in the wake of November 2008 election was substantially more significant, yielding stronger observations. We recommend that SOTS Office encourage full participation in the audits.

[End]