



## Post-Election Audit of Memory Cards for the August 14, 2012 Connecticut Primary Elections

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### Summary

The University of Connecticut Center for Voting Technology Research (VoTeR Center) performed post-election audit of the memory cards for the Accu-Vote Optical Scan (AV-OS) tabulators that were used in the August 14, 2012 elections. The cards were programmed by LHS Associates of Salem, New Hampshire, and shipped to Connecticut districts.

Cards were submitted for two reasons per instructions from the SOTS Office (a) the 10% of the districts that are the subject of post-election hand-counted audit are randomly selected by the SOTS Office and asked to send their cards for the post-election technological audit, and (b) any card was to be submitted if it appeared to be unusable. Given that cards in category (a) belong to randomly selected districts and were used in the election, while all cards in category (b) were supposed to be submitted, and that the cards were submitted without consistent categorization of the reason, this report considers all unusable cards to fall into category (b).

The Center received 86 memory cards from 66 districts. Among these cards, 44 (51.2%) fall into category (a). All of these 44 cards were correct. Out of these cards, 16 cards show elections, with 15 cards that were actually used on Election Day (one card shows an election on a different date). There are 42 cards (48.8% of all cards) that were found to be unusable by the AV-OS, thus falling into category (b). All of these cards contained apparently random (or 'junk') data. These cards were unreadable by the tabulators and could not have been used in an election. Given that such cards were not selected randomly, we estimate that the percentage of unusable cards is between 1.4% and 15.9% in this audit, and this is consistent with prior audit results.

All cards in category (a) contained valid ballot data and the executable code on these cards was the expected code, with no extraneous data or code on the cards. Overall the audit found no cases where the behavior of the tabulators could have affected the integrity of the elections. We note that the adherence to the election procedures by the districts had improved compared to prior years, however the analysis suggests 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.

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

## Contents

<b>1</b>	<b>Preface</b>	<b>3</b>
<b>2</b>	<b>Introduction</b>	<b>3</b>
2.1	Brief Description of the AV-OS . . . . .	3
2.2	Goals of the Post-Election Memory Card Audit . . . . .	4
<b>3</b>	<b>Summary of the Post-Election Audit Results</b>	<b>4</b>
<b>4</b>	<b>Post-Election Audit Results: Additional Details</b>	<b>7</b>
4.1	Overall Card State Analysis . . . . .	7
4.2	Analysis of Cards Used in the Election . . . . .	7
4.2.1	Event Log Analysis: 16 Cards Used in the Election . . . . .	8
4.3	Analysis of Cards Not Used in the Election . . . . .	10
4.3.1	Overall Card State Analysis (Part a) . . . . .	11
4.3.2	Analysis of the Readable/Usable Cards Not Used in the Election . . . . .	12
4.3.3	Event Log Analysis: 28 Cards Not Used in the Election . . . . .	13
<b>5</b>	<b>Addressing Memory Card Reliability</b>	<b>15</b>
<b>6</b>	<b>Conclusions and Recommendations</b>	<b>17</b>

## 1 Preface

The University of Connecticut Center for Voting Technology Research (VoTeR Center) conducted post-election audit of the memory cards used in the Accu-Vote Optical Scan (AV-OS) tabulators in the August 14, 2012 primary elections in the State of Connecticut. The audit was performed at the request of the Office of the Secretary of the State of Connecticut.

The memory cards were programmed by LHS Associates of Salem, New Hampshire, and provided by LHS to the districts in Connecticut. The post-election audit was performed on the set of 86 memory cards that were shipped to the VoTeR Center by the towns between September 13, 2012 and September 20, 2012. The cards are tested as they arrive. If noteworthy irregularities that might affect integrity or security of ballot tabulation are detected, they are reported to the SOTS Office without delay. Preliminary results were reported to the SOTS Office during the audit.

The memory cards were subject to several integrity tests. A comprehensive overview of the procedures followed by the Center personnel in conducting such technological audits is presented in prior reports<sup>1 2</sup>. We do not repeat here the description of the engineering that was performed to enable the audit, including the log analysis, and the technical setup used in the tests. For the compilation of the technological audit results for the years 2007 to 2010 please consult our prior report<sup>3</sup>.

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 electromagnetic) of the memory cards. This report is a high-level, non-technical presentation of the audit results and it omits technical details. We also note that we did not use any vendor documentation regarding the design and the internals of the AV-OS terminal.

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

## 2 Introduction

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

### 2.1 Brief Description of the AV-OS

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

- The AV-OS systems currently in use in the state of Connecticut contain the firmware version 1.96.6. This model is equipped with an optical scanner, a paper-tape dot-matrix printer, a LCD display, a serial communication port, and telephone jacks leading to a built-in modem.

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<sup>1</sup> 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>.

<sup>2</sup> 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>.

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

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

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

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

## 2.2 Goals of the Post-Election Memory Card Audit

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

The post-election audit 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 cards 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, by checking the status of the card, and by analyzing its event log.

## 3 Summary of the Post-Election Audit Results

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

We received 86 memory cards. These cards correspond to 66 distinct districts in Connecticut.

Cards were submitted for two reasons per instructions from the Secretary of the State (SOTS) Office: (a) the 10% of the districts that are the subject of post-election hand-counted audit are randomly selected by the SOTS Office and asked to send the cards that were used in the election for the post-election technological audit, and (b) any card was to be submitted if it appeared to be unusable. Given that cards in category (a) belong to randomly selected districts and were used in the election, while all cards in category (b) were supposed to be submitted, and that the cards were submitted without consistent categorization of the reason, this report considers all unusable cards to fall into category (b).

We note that the audits did not detect any cards whose data raised concerns about the integrity of tabulation.

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

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

Among the 86 cards received for the post-election audit, 44 (51.2%) were correct. That is, these cards contained correct election data. This category includes both 42 (48.8%) cards programmed according to the correct procedure, and also the 2 (2.3%) 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 forty two (42) cards, 48.8%, that were unusable by the tabulators. Consulting the summary<sup>4</sup> of pre-election audits performed since 2007, we note that on the average there are about 9.0% of unusable cards encountered in elections.

We estimate that for the post-election audit the percentage of unusable cards is between 1.4% and 15.9%, within the overall card population. This range is consistent with prior observations and represents a high failure rate. This calculation is given in Section 4.3.1.

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

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

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

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

Table 1: Audit log action types

must precede the election. The report that documents our approach and the log analysis tool is available online <sup>5</sup>.

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 is found to be consistent with a proper usage pattern we add rules to the audit log checker so that such audit logs are not flagged in the future.

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

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

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

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

<sup>5</sup>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/](http://www.usenix.org/events/evtwote09/).

## 4 Post-Election Audit Results: Additional Details

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

- 86 cards were received for the post-election audit
- 44 cards were correct (this includes 2 cards that were involved in duplication)
  - 16 cards were used in the elections
  - 26 cards were set to be used in the elections
  - 2 cards were not set to be used in the elections
- 42 cards were unusable (by AV-OS)
  - 42 cards contained apparently random data ('junk' data)

### 4.1 Overall Card State Analysis

Table 2 shows the frequency of various states observed on the 86 audited memory cards.

<b>All Cards (86)</b>		
<b>(a) Card Format</b>	Number	% Total
Correct Cards	44	51.2%
Unusable (Junk) Data	42	48.8%
Totals:	86	100%

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

### 4.2 Analysis of 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 election.

16 cards were used in the election.

14 cards (87.5%) 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.

2 cards (12.5%) were in Results Print Aborted state with Non-Zero counters. The cards are expected to have non-zero counters after the election, however Results Print Aborted is an undesired state, indicating that poll workers either (1) shut the machine during the printing of the results, or (2) did not conclude properly the printing procedure (by pressing “No” when prompted to print another copy). Although this does not present an immediate integrity concern, provided that the the results report is printed, neither of the above 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 follow the procedures for turning 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.

#### 4.2.1 Event Log Analysis: 16 Cards Used in the Election

Here we present the result of the event log analysis for the cards that were used in the election. All 16 cards (100%) used in the election, were flagged because their event logs did not match our sequence rules.

The event log analysis for the cards used in the election produced 39 notifications. Note that a single card may yield multiple notifications. Also recall that not all notifications mean that something went wrong — a notification simply means that the sequence of events in the event log did not match our (not-all-inclusive) rules. Such notifications are subsequently examined to determine their significance. We next present the details of the analysis.

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

The notification statistics for each stage appear in Table 3.

Out-of-Bounds Dates	Cards Usable for the Election			
	# Warn.	% Warn.	# Cards	% Usable
Sequence: Initialization	16	41.0%	16	100%
Sequence: Test Election	7	17.9%	7	43.7%
Sequence: Prepare For Election	7	17.9%	7	43.7%
Sequence: Election	9	23.1%	9	56.2%

Table 3: Post-Election Event Log Analysis Results - Out-of-Bounds Dates

##### (a) Initialization: 16 cards were initialized at unexpected times.

Card initialization is performed by LHS. We expect this process to start and complete no more than two months and no less than two weeks respectively before the election day. Thus, for these elections we expected initialization to be performed between 06/14/2012 and 07/31/2012. Our assumptions for the sequencing of events are based on the SOTS documentation <sup>6</sup>.

The initialization of all correct cards fell outside of our assumed period. This is apparently due to the fact that the AV-OS machine used for initializing these cards at LHS does not have its date/time set correctly. Instead, the date of initialization appears as 00/00/127 in the event log of all correct cards. We reiterate that it is important that all AV-OS tabulators have the date/time set correctly.

<sup>6</sup> 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](http://www.ct.gov/sots/lib/sots/legislativeservices/regulations/12_opscanusereg.pdf).

For completeness we list all cards with incorrect initialization dates in Table 4.

Card Name	Initialization	
	Date	Time
CHESHIRE-ABSENTEES-0005045	00/00/127	31:63
CHESHIRE-DISTRICT_2-0003005	00/00/127	31:63
CHESHIRE-DISTRICT_6-0003020	00/00/127	31:63
CHESHIRE-DISTRICT_7-0003024	00/00/127	31:63
DURHAM-DISTRICT_2-0002390	00/00/127	31:63
GLASTONBURY-ABSENTEES-0005619	00/00/127	31:63
GLASTONBURY-DISTRICT_2-0002746	00/00/127	31:63
GLASTONBURY-DISTRICT_3-0003120	00/00/127	31:63
GLASTONBURY-DISTRICT_4-0002727	00/00/127	31:63
GLASTONBURY-DISTRICT_5-0002730	00/00/127	31:63
GLASTONBURY-DISTRICT_7-0001616	00/00/127	31:63
GLASTONBURY-DISTRICT_9-0004750	00/00/127	31:63
GREENWICH-DISTRICT_8-0002526	00/00/127	31:63
MIDDLETOWN-DISTRICT_8-0003962	00/00/127	31:63
WESTPORT-DISTRICT_136-1-0001690	00/00/127	31:63
WESTPORT-DISTRICT_143-0005692	00/00/127	31:63

Table 4: Initialization dates outside of our assumed time window.

(b) **Test Elections: 7 cards were tested at unexpected times.**

Test elections are performed after the cards are delivered to the districts. During this stage the 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 <sup>7</sup>. For this election we expect this process to be completed between the dates 06/21/2012 and 08/04/2012. Table 5 lists districts that show unexpected test dates.

Card Name	Test Election	
	Date	Time
GLASTONBURY-ABSENTEES-0005619	8/8/12	07:15
GLASTONBURY-DISTRICT_2-0002746	8/8/12	08:24
GLASTONBURY-DISTRICT_3-0003120	8/8/12	09:19
GLASTONBURY-DISTRICT_4-0002727	8/8/12	10:07
GLASTONBURY-DISTRICT_5-0002730	8/8/12	09:08
GLASTONBURY-DISTRICT_7-0001616	8/8/12	08:36
GLASTONBURY-DISTRICT_9-0004750	8/8/12	10:00

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

These notifications do not present any concerns.

(c) **Preparation for Election: 7 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 post-election audit. Since election preparation needs to be done immediately after the cards are tested, the date boundaries are the same as for the Test Election sequence. Table 6 lists districts that show preparation for elections on unexpected dates.

<sup>7</sup>Ibid.

As the preparation dates of all but one card are still prior to the election, this should not be a cause for concern. However, according to the SOTS regulations<sup>8</sup> the cards should have been prepared for election no later than the tenth day before the election. One card was prepared for election on the election day, even though it was tested on 08/08/2012. This is a deviation from the standard procedures and this should never occur.

Card Name	Prepare for Election	
	Date	Time
GLASTONBURY-ABSENTEES-0005619	8/8/12	07:32
GLASTONBURY-DISTRICT_2-0002746	8/14/12	04:36
GLASTONBURY-DISTRICT_3-0003120	8/8/12	09:26
GLASTONBURY-DISTRICT_4-0002727	8/8/12	10:13
GLASTONBURY-DISTRICT_5-0002730	8/8/12	09:17
GLASTONBURY-DISTRICT_7-0001616	8/8/12	08:45
GLASTONBURY-DISTRICT_9-0004750	8/8/12	10:07

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

(d) **Election: 9 cards indicate minor deviations in the Election Day sequence timing.**

We expect the election to be held on the election day. According to the SOTS regulations<sup>9</sup> the zero totals report should be printed no earlier than 04:30 and the election should be closed no later than 20:01. Manual examination of the log shows that 1 out of 9 cards had printed zero total reports on the election day at 04:29. 7 out of 9 cards closed the election after 20:01, however the latest time appears to be 20:19. The remaining one card (MIDDLETOWN-DISTRICT\_8-0003962) shows an election on 7/31/12 and it has only 2 ballots cast. This card requires a follow up by the SOTS Office. It is plausible that the district used an incorrect mode to test the card. Table 7 lists districts that show minor timing deviations in the Election sequence.

Card Name	Election Sequence	
	Date	Time
CHESHIRE-ABSENTEES-0005045	8/14/12	20:11
CHESHIRE-DISTRICT_2-0003005	8/14/12	20:10
CHESHIRE-DISTRICT_6-0003020	8/14/12	20:02
CHESHIRE-DISTRICT_7-0003024	8/14/12	20:07
GLASTONBURY-DISTRICT_9-0004750	8/14/12	04:29
GREENWICH-DISTRICT_8-0002526	8/14/12	20:19
MIDDLETOWN-DISTRICT_8-0003962	7/31/12	18:55
WESTPORT-DISTRICT_136-1-0001690	8/14/12	20:05
WESTPORT-DISTRICT_143-0005692	8/14/12	20:05

Table 7: Election date/time outside of the assumed time window.

### 4.3 Analysis of Cards Not Used in the Election

The VoTeR Center received 86 cards for the post-election audit. This number includes 16 cards used in the election, with the analysis results presented in the previous section. Here we present the audit results for the remaining 70 cards.

<sup>8</sup>Ibid.

<sup>9</sup>Ibid.

The high level breakdown of the cards not used in the election is as follows.

- 70 cards were not used in the election.
- 28 cards were correct (this includes 2 cards that were involved in duplication)
  - 26 cards were set to be used in the elections
  - 2 cards were not set to be used in the elections
- 42 cards were unusable (by AV-OS)
  - 42 cards contained apparently random data ('junk' data)

### 4.3.1 Overall Card State Analysis (Part a)

Table 8 shows the frequency of various states observed on the 70 audited memory cards not used in the election.

<b>Cards (70) Not Used in the Election</b>		
<b>(a) Card Format</b>	Number	% Total
Correct Cards	28	40.0%
Unusable (Junk) Data	42	60.0%
Totals:	70	100%

Table 8: Memory card analysis summary: (a) Card Format.

**(a) Card Format:** Among the 70 cards not used in the election, 28 cards were readable by AV-OS and usable for elections. These cards were correctly formatted, and contained correct data and code for the specific districts for which they were prepared.

Among these 28 cards, 26 cards (37.1%) were programmed directly using GEMS and contained data matching the baseline. These involved no duplication. 2 cards (2.9%) were involved in duplication, otherwise they contained correct data, matching the baseline.

42 cards (60.0%) 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. 42 cards (60.0%) 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.

**Estimation of Unusable Cards Percentage:** Given that unusable (unreadable by AV-OS for the purpose of elections) cards were not selected randomly, we estimate that for post-election audit the percentage of unusable cards is between 1.4% and 15.9%. This estimate is made on the basis of the following calculation. We received cards from 66 districts out of the total 754 districts that participated in this election (this includes absentees), where there are four cards per district. The number of unusable cards in the audit is 42. Thus the minimum percentage is calculated as  $42 / (754 \cdot 4) = 1.4\%$ , given that unusable card data does not contain district information. Performing similar calculation for the 66 participating districts, we obtain the maximum percentage as  $42 / (66 \cdot 4) = 15.9\%$ . This range is largely consistent with the results from prior audits.

### 4.3.2 Analysis of the Readable/Usable Cards Not Used in the Election

We now present the details of the audit for the 28 cards (among the 86 audited cards) that could have been used in the elections.

<b>Usable Cards (28) Not Used in the Election</b>		
	Number	% Total
<b>(b) Card Status Summary</b>		
Set for Election	26	92.9%
Not Set for Election	2	7.1%
Totals:	28	100%
<b>(c) Card &amp; Counter Status</b>		
Set For Elections, Zero Counters	26	92.9%
Not Set, Non-Zero Counters	2	7.1%
Totals:	28	100%
<b>(d) Card Duplication (2)</b>		
Master Card	2	100%
Totals:	2	100%

Table 9: Summary of the analysis for memory cards not used in the election: (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.

26 cards (92.9%) were in Set For Election state. This is the appropriate status for cards intended to be used in the elections.

2 cards (7.1%) were in Not Set for Election state. This status would be appropriate prior to preparation for an election, but not prior to an election. This suggests that the corresponding districts sent these cards for the audit without first finalizing the preparation for the election. This is not a security concern, but an indication that not all districts follow the pre-election testing procedure.

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

26 cards (92.9%) were found in Set For Election state and had Zero Counters. This is the appropriate status for cards intended to be used in the elections.

2 cards (7.1%) 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.

Taking the above percentages together, it appears that almost all districts (92.9% + 7.1% = 100%) 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. Lastly, if the data on the card being duplicated is erroneous, the same error will be reproduced on the copy.

Among the usable cards not used in the election 2 cards were involved in duplication. All of these cards (100%) were *master* cards used for duplication.

We manually examined the event logs of all duplicated cards and compared the initialization date of the card against the date of the duplication. We observed that these cards (as well as all other usable cards) submitted for post-election audit have an invalid initialization date: this date is 00/00/127. Thus we could not establish whether the cards were involved in duplication at LHS or at the districts. It is extremely important that both LHS and the districts set the AV-OS date/time correctly.

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

### 4.3.3 Event Log Analysis: 28 Cards Not Used in the Election

Here we present the result of the event log analysis for the usable cards that were not used in the election. All 28 cards (100%) were flagged because their event logs did not match our sequence rules.

The event log analysis for the cards not used in the election produced 34 notifications. Note that a single card may yield multiple notifications. Also recall that not all notifications mean that something went wrong — a notification simply means that the sequence of events in the event log did not match our (not-all-inclusive) rules. Such notifications are subsequently examined to determine their significance. We next present the details of the analysis.

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

The notification statistics for each stage appear in Table 10.

Out-of-Bounds Dates	Cards Not Used in the Election			
	# Warn.	% Warn.	# Cards	% Usable
Sequence: Initialization	28	82.4%	28	100%
Sequence: Test Election	3	8.8%	2	7.1%
Sequence: Prepare For Election	1	2.9%	1	3.6%

Table 10: Post-Election event log Analysis Results - Out-of-Bounds Dates

(a) **Initialization: 28 cards were initialized at unexpected times.**

Card initialization is performed by LHS. We expect this process to start and complete no more than two months and no less than two weeks respectively before the election day. Thus, for these

Card Name	Initialization	
	Date	Time
CHESHIRE-DISTRICT_1-0003031	00/00/127	31:63
CHESHIRE-DISTRICT_3-0003030	00/00/127	31:63
CHESHIRE-DISTRICT_4-0003013	00/00/127	31:63
FRANKLIN-DISTRICT_1-0002943	00/00/127	31:63
GREENWICH-DISTRICT_8-0002525	00/00/127	31:63
MIDDLETOWN-DISTRICT_11-0005559	00/00/127	31:63
WATERBURY-DEM_ABS_71-73-0004108	00/00/127	31:63
WATERBURY-DISTRICT_71-1-0004068	00/00/127	31:63
WATERBURY-DISTRICT_71-2-0004064	00/00/127	31:63
WATERBURY-DISTRICT_71-3-0004069	00/00/127	31:63
WATERBURY-DISTRICT_72-1-0004105	00/00/127	31:63
WATERBURY-DISTRICT_72-2-0004076	00/00/127	31:63
WATERBURY-DISTRICT_72-3-0004082	00/00/127	31:63
WATERBURY-DISTRICT_72-5-0004759	00/00/127	31:63
WATERBURY-DISTRICT_73-1-0004094	00/00/127	31:63
WATERBURY-DISTRICT_73-2-0004098	00/00/127	31:63
WATERBURY-DISTRICT_73-4-0004130	00/00/127	31:63
WATERBURY-DISTRICT_74-1-0004120	00/00/127	31:63
WATERBURY-DISTRICT_74-2-0004123	00/00/127	31:63
WATERBURY-DISTRICT_74-3-0004128	00/00/127	31:63
WATERBURY-DISTRICT_74-4-0004132	00/00/127	31:63
WATERBURY-DISTRICT_75-1-0004395	00/00/127	31:63
WATERBURY-DISTRICT_75-3-0004399	00/00/127	31:63
WATERBURY-DISTRICT_75-4-0004403	00/00/127	31:63
WATERBURY-REP_ABS_71-73-0004114	00/00/127	31:63
WESTBROOK-DISTRICT_2-0002660	00/00/127	31:63
WESTPORT-DISTRICT_136-1-0001692	00/00/127	31:63
WESTPORT-DISTRICT_143-0005693	00/00/127	31:63

Table 11: Initialization dates outside of our assumed time window.

elections we expected initialization to be performed between 06/14/2012 and 07/31/2012. Our assumptions for the sequencing of events are based on the SOTS documentation<sup>10</sup>.

The initialization date of all correct cards fell outside of the assumed period. This is apparently due to the fact that the AV-OS machine used for initializing these cards at LHS does not have its date/time set correctly. Instead, the date of initialization appears as 00/00/127 in the event log of all correct cards. We reiterate that it is important that all AV-OS tabulators have the date/time set correctly.

For completeness we list all cards with incorrect initialization dates in Table 11.

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

Test elections are performed after the cards are delivered to the districts. During this stage the 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

<sup>10</sup> 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](http://www.ct.gov/sots/lib/sots/legislativeservices/regulations/12_opscanusereg.pdf).

day <sup>11</sup>. For this election we expect this process to be completed between the dates 06/21/2012 and 08/04/2012. Table 12 lists cards that show unexpected test dates.

Card Name	Test Election	
	Date	Time
FRANKLIN-DISTRICT_1-0002943	8/13/12	09:36
MIDDLETOWN-DISTRICT_11-0005559	8/8/12	15:11

Table 12: Test Election dates outside of the assumed time window.

- (c) **Preparation for Election: one card was prepared for elections at unexpected times.** Cards should be prepared for elections after the testing is completed but before the election date. This is the expected state for the cards submitted for the pre-election audit. Since election preparation needs to be done immediately after the cards are tested, the date boundaries are the same as for the Test Election sequence. Table 13 lists a district that shows preparation for elections on unexpected date.

As the preparation date is still prior to the election, this should not be a cause for concern. However, according to the SOTS regulations<sup>12</sup> the cards should have been prepared for election no later than the tenth day before the election.

Card Name	Prepare for Election	
	Date	Time
FRANKLIN-DISTRICT_1-0002943	8/13/12	09:49

Table 13: Prepare for Election dates outside of the assumed time window.

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

Table 14 lists such events along with the expected number of appearances and suggested maximums. The statistics for all such notifications appear in Table 15.

- (a) **2 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 16. We already discussed card duplication in Section 4.3.2.

**Miscellaneous Notifications.** No miscellaneous notifications were issued for the usable cards not used in the election.

## 5 Addressing Memory Card Reliability

We estimated the overall percentage of the cards that are not usable in the election to be between 1.4% and 15.9%. None of these cards are readable by the tabulators, and as such they do not pose

<sup>11</sup>Ibid.

<sup>12</sup>Ibid.

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

Table 14: Events in an election timeline that may indicate a problem.

Flagged Number of Instances	Cards Not Used in the Election			
	# Warn.	% Warn.	# Cards	% Usable
DUPLICATE (none allowed)	2	5.9%	2	7.1%

Table 15: event log Analysis Results - Many Instances of Events

Card Name	Observed
CHESHIRE-DISTRICT_4-0003013	1
WATERBURY-DISTRICT_74-3-0004128	2

Table 16: Cards involved in duplication.

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<sup>13</sup>, is a reliability issue.

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

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

A broader pilot is being planned by the SOTS Office to occur in the near future. The use of the

<sup>13</sup> 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>.

new card should eliminate the major cause of memory card failures.

## 6 Conclusions and Recommendations

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

- The SOTS Office should continue publicizing proper procedures and continue offering training. In particular, to reinforce the need to prepare all cards for election prior to the election day and prior to the pre-election audit.
- Fewer cards are being duplicated at the districts, and it is important to continue reiterating that cards must never be duplicated. Any cases of duplication should be recorded in the moderators' logs and be brought to the attention of the SOTS Office with a documented explanation of why this is necessary.
- It is important for the districts to report any problems during pre-election testing (and any card problems) to the SOTS Office as soon as possible upon completion of the tests.
- 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. There was at least one documented case of a tabulator malfunction during this primary election. In such cases it is strongly recommended that the problematic tabulator is tested by the Center personnel (either at the district or in our laboratory).
- The current number of cards with unreadable data (junk data) continues to be high. We have determined that weak batteries are the primary cause of this. The vendor developed a new non-volatile, battery-less memory card, and our ongoing evaluation continues to confirm their compatibility with the AV-OS machines used in Connecticut. A limited pilot using the new cards was successfully performed in Vernon. It is expected that a broader pilot deployment of the new cards by the SOTS Office will occur in the near future. The use of the new card should eliminate the major cause of memory card failures.
- It is important that cards sent for the pre-election audit are selected at random. One card randomly selected from four cards in each district is to be randomly selected for the audit. While the districts are encouraged to submit all malfunctioning cards to VoTeR Center, all such cards need to be identified separately from the cards randomly selected for the audit. (This has been addressed in a recent newsletter from the SOTS Office.)

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, 86, out of which only 16 were used in the election. This is a very low number. It would be extremely important in the future to obtain substantially larger numbers of cards from the actual use in the elections.

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

[End]