



Technological Audit of Memory Cards for the April 24, 2012 Connecticut Primary Elections

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Summary

The University of Connecticut Center for Voting Technology Research (VoTeR Center) performed pre-election and post-election audit of the memory cards for the Accu-Vote Optical Scan (AV-OS) tabulators that were used in the April 24, 2012 elections. The cards were programmed by LHS Associates of Salem, New Hampshire, and shipped to Connecticut districts.

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

For the pre-election audit, the Center received 124 memory cards from 110 districts. Among these 124 cards, 81 (65.3%) fall into category (a). All of these 81 cards were correct. There are 43 cards (34.7% of all cards) that were found to be unusable by the AV-OS, thus falling into category (b). In particular, 42 cards contained apparently random (or ‘junk’) data, 1 card was unusable by AV-OS, but did not contain random data (this requires further investigation). All these cards were unreadable by the tabulators and could not have been used in an election. Given that such cards were not selected randomly, we estimate that for pre-election audit the percentage of unusable cards is between 1.6% and 9.8% and this is consistent with prior audits.

For the post-election audit, the Center received 155 memory cards from 105 districts. Out of these cards 49 cards were used on Election Day. Among 155 cards, 104 (67.1%) fall into category (a). All of these 104 cards were correct. There are 51 cards (32.9% of all cards) that were found to be unusable by the AV-OS, thus falling into category (b). In particular, 48 contained apparently random (or ‘junk’) data, 2 cards were unusable by AV-OS, but did not contain random data (this requires further investigation), 1 card was formatted using AV-OS utility, however, it was not programmed. Given that such cards were not selected randomly, we estimate that for post-election audit the percentage of unusable cards is between 1.8% and 12.1% and this is consistent with prior audits.

Cards that fell into category (a), for both pre-election and post-election audit, 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 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.

Lastly, a limited pilot deployment of the new non-volatile memory cards was successfully performed in Vernon. There were no reported malfunctions among the 12 cards used. A broader pilot is planned for the near future.

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

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1 Preface

The University of Connecticut Center for Voting Technology Research (VoTeR Center) conducted pre-election and post-election audit of the memory cards used in the Accu-Vote Optical Scan (AV-OS) tabulators in the April 24, 2012 primary elections in the State of Connecticut. The audit was performed at the request of the Office of the Secretary of the State of Connecticut.

The memory cards were programmed by LHS Associates of Salem, New Hampshire, and provided by LHS to the districts in Connecticut. The pre-election audit was performed on the set of 124 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 April, 2012. If noteworthy irregularities that might affect integrity or security of ballot tabulation are detected, they are reported to the SOTS Office without delay. Preliminary results were reported to the SOTS Office during the audit.

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

In this report, we present the objectives of the pre-election and 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. This report is a high-level, non-technical presentation of the audit results and it omits technical details. We also note that we did not use any vendor documentation regarding the design and the internals of the AV-OS terminal.

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

2 Introduction

We start by briefly describing the electronic election system used in Connecticut. We then review the goals of the pre-election and 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:

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

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

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

- 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. 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 Memory Card Audit

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 audit.

2.2.1 Goals of the pre-election audit

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

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

Prior to the election, each polling center receives four programmed memory cards from the external contractor, LHS Associates. According to the instructions from the SOTS Office, each district is supposed to perform pre-election tests of the four cards. After the testing is complete, they are asked to select randomly one memory card per district and send it to VoTeR Center for the pre-election technological audit. The procedure for random selection of memory cards applies to district-based tabulators and does not include central absentee ballot tabulation. (Sometimes the

cards are submitted for the audit before the pre-election test, and sometimes after the pre-election test this should be made consistent in the future). When the cards are submitted for the audit after they undergo pre-election testing and preparation for the election, such memory cards should be in “election mode” with all counters set to zero.

As the cards arrive from the districts at the Center, the contents of each card is examined to determine whether the data and code on the cards 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, and any deviations in the bytecode (executable). Additionally the state of the counters and the content of the event logs are analyzed for consistency with the expected election procedures. The event logs contain significant events in the life of a card since the last time it was formatted, allowing for such an analysis to be performed.

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

2.2.2 Goals of the post-election audit

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 Pre-Election and Post-Election Audit Results

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

For the pre-election audit we received 124 memory cards. These cards correspond to 110 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. For the pre-election audit, 15 out of 124 memory cards, were received prior to the Election Day.

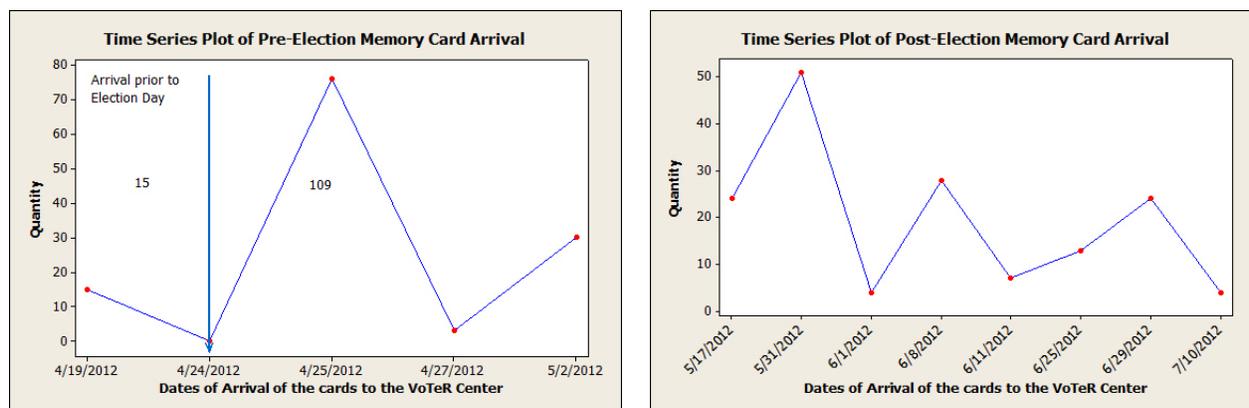


Figure 1: Arrival of the memory cards for pre-election and post election audit

For the post-election audit we received 155 memory cards. These cards correspond to 105 distinct districts in Connecticut. Figure 1 graphs the arrival of these cards.

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

Additional details concerning pre-election and post-election audit are given in Sections 4 and 5 respectively.

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.

For the pre-election audit, among the 124 cards received, 81 (65.3%) were correct. That is, these cards contained correct election data. This category includes both 78 (62.9%) cards programmed according to the correct procedure, and also the 3 (2.4%) 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.

For the post-election audit, among the 155 cards received, 104 (67.1%) were correct. That is, these cards contained correct election data. This category includes both 99 (63.9%) cards programmed according to the correct procedure, and also the 5 (3.2%) 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 *pre-election* audit identified forty three (43) cards, 34.7%, that were unusable by the tabulators. The *post-election* audit identified fifty one (51) cards, 32.9%, that were unusable by the tabulators. Consulting the summary⁴ of pre-election audits performed since 2007, we note that on the average there are about 9.0% of unusable cards encountered in elections.

We estimate that for the pre-election audit the percentage of unusable cards is between 1.6% and 9.8%, while for the post-election audit the percentage of unusable cards is between 1.8% and 12.1%, within the overall card population. This is consistent with prior observations and represents a high failure rate. These calculations are given in Sections 4.1 and 5.3.1 correspondingly.

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

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

Table 1: Audit log action types

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

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

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

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 result in erroneous reporting of the election results.

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

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

4 Pre-Election Audit Results: Additional Details

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

- 124 were received for the pre-election audit
- 81 were correct (this includes 3 cards that were involved in duplication)
 - 34 were set to be used in the elections
 - 47 were not set to be used in the elections
- 43 cards were unusable (by AV-OS)
 - 42 cards contained apparently random data ('junk' data)
 - 1 card was unusable (but the data was not random)

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

Table 2 shows the frequency of various states observed on the 124 audited memory cards.

(a) Card Format: Among the 124 audited cards, 81 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 81 cards, 78 cards (62.9%) were programmed directly using GEMS and contained data matching the baseline. These involved no duplication. 3 cards (2.4%) were involved in duplication, otherwise they contained correct data, matching the baseline.

43 cards (34.7%) 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 (33.9%) contained

| All Cards (124) | | |
|----------------------|--------|---------|
| (a) Card Format | Number | % Total |
| Correct Cards | 81 | 65.3% |
| Unusable (Junk) Data | 42 | 33.9% |
| Unusable (not Junk) | 1 | 0.8% |
| Totals: | 124 | 100% |

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

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. 1 card (0.8%) was 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.

Estimation of Unusable Cards Percentage: Given that unusable (unreadable by AV-OS for the purpose of elections) cards were not selected randomly, we estimate that for pre-election audit the percentage of unusable cards is between 1.6% and 9.8%. This estimate is made on the basis of the following calculation. We received cards from 110 districts out of the total 690 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 43. Thus the minimum percentage is calculated as $43/(690 \cdot 4) = 1.6\%$, given that unusable card data does not contain district information. Performing similar calculation for the 110 participating districts, we obtain the maximum percentage as $43/(110 \cdot 4) = 9.8\%$. This range is consistent with the results from prior audits.

Lastly, there were 12 new, non-volatile cards used in this election. There were no such cards among the 43 unusable cards, and none of the 12 cards experienced failures.

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

We now present the details of the audit for the 81 cards (among the 124 audited cards) that could be used in the elections.

(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.

34 cards (42.0%) were in Set For Election state. This is the appropriate status for cards intended to be used in the elections.

47 cards (58.0%) were in Not Set for Election state. This status would be appropriate prior to preparation for an election, but not prior to an election. This suggests that the corresponding districts sent these cards for the audit without first finalizing the preparation for the election. This is not a security concern, but an indication that not all districts submit cards at the right time (that is, after the completion of pre-election testing and preparation of the cards for the elections).

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

All of the 34 cards (42.0%) 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.

| Usable Cards 81 | | |
|--------------------------------------|--------|---------|
| | Number | % Total |
| (b) Card Status Summary | | |
| Not Set for Election | 47 | 58.0% |
| Set for Election | 34 | 42.0% |
| Totals: | 81 | 100% |
| (c) Card & Counter Status | | |
| Set For Elections, Zero Counters | 34 | 42.0% |
| Not Set, Non-Zero Counters | 44 | 54.3% |
| Not Set, Zero Counters | 3 | 3.7% |
| Totals: | 81 | 100% |
| (d) Card Duplication (3) | | |
| Master Card | 2 | 66.7% |
| Copy Card | 1 | 33.3% |
| Totals: | 3 | 100% |

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

44 cards (54.3%) 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.

3 cards (3.7%) were found to be in Not Set for Elections state with Zero Counters. This is similar to the 44 cards above. Manual examination of audit logs of these cards revealed that all 3 underwent pre-election testing. Two cards were most likely tested at the district, while the remaining one card was most likely tested at LHS, since the date of the testing is the same as the initialization date. For all 3 cards counters were re-set to 0 after testing. This situation would have been detected and remedied if such cards were to be used on the election day.

Taking the above percentages together, it appears that almost all districts ($42.0\% + 54.3\% + 2.5\% = 98.8\%$) 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 3 cards involved in duplication. 2 of these cards (66.7%) were *master* cards used for duplication. 1 card (33.3%) was a *copy* card 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 all 3 cards were most likely

involved in duplication at LHS. 1 out of 3 was involved in duplication two days after the initialization. The remaining 2 cards arrived to the VoTeR Center for pre-election testing directly from LHS.

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

4.3 Event Log Analysis Results

Here we present the result of the event log analysis for all the usable cards. Out of the 81 correct⁶ cards, 15 (18.5%) cards were flagged because their event logs did not match our sequence rules.

The event log analysis produced 30 notifications. Note that a single card may yield multiple notifications. Also recall that not all notifications necessarily mean that something went wrong – a notifications simply means that the sequence of events in the audit log did not match our (not-all-inclusive) rules. We next present the details of the analysis.

4.3.1 Out-Of-Bounds Dates

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

The notification statistics for each stage appear in Table 4.

| Out-of-Bounds Dates | Cards Usable for the Election | | | |
|---------------------------------|-------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| Sequence: Initialization | 1 | 3.3% | 1 | 1.2% |
| Sequence: Test Elections | 13 | 43.3% | 11 | 13.6% |
| Sequence: Prepare For Elections | 7 | 23.3% | 7 | 8.6% |

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

(a) Initialization: 1 card contained unexpected initialization times.

Card initialization is performed by LHS. We expect this process to start and complete no more than two months and no less than two weeks respectively before the election day. Thus, for these elections we expected initialization to be performed between 02/24/2012 and 04/10/2012. Our assumptions for the sequencing of events are based on the SOTS documentation⁷.

Only one card fell outside of our assumed initialization period, but it was initialized prior to the Election Day, so this is not a security issue.

The card that appeared to have initialization date that differed from our assumption is given in Table 5 for completeness.

Note that only the listed card is outside of our specified range, and only by one day.

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

⁷For example, “Marksense Voting Tabulator”, Section 9-242a-5, states that memory cards should be tested “as soon as ballots and ballot cards are available and not later than the tenth day before the election or primary”. Hence, the testing of the cards must be completed no later than the tenth day before the election, and the initialization at least two weeks in advance. The document can be found at http://www.ct.gov/sots/lib/sots/legislativeservices/regulations/12_opscanusereg.pdf.

| Card Name | Initialization | |
|---------------------------------|----------------|-------|
| | Date | Time |
| WATERBURY-DISTRICT_73-1-0005580 | 04/11/12 | 13:53 |

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

(b) **Test Elections: 11 cards were tested at unexpected times.**

Test elections are performed after the cards are delivered to the districts. Here the districts test the usability of the memory cards they receive. Thus, we expect Test Elections to be performed two weeks after the beginning of card Initialization and ten days before the election day ⁸.

For this election we expect this process to be completed between the dates 03/01/2012 and 04/14/2012. Table 6 lists districts that show unexpected test dates.

| Card Name | Test Election | |
|---------------------------------|---------------|-------|
| | Date | Time |
| ANSONIA-DISTRICT_6-0001637 | 04/16/12 | 10:32 |
| COLUMBIA-DISTRICT_1-0001407 | 04/17/12 | 15:51 |
| FRANKLIN-DISTRICT_1-0002941 | 04/18/12 | 16:34 |
| RIDGEFIELD-DISTRICT_3-0001937 | 04/16/12 | 08:02 |
| WATERBURY-DISTRICT_73-1-0005580 | 04/16/12 | 08:26 |
| WATERBURY-DISTRICT_74-3-0004126 | 04/16/12 | 07:57 |
| WATERBURY-DISTRICT_74-5-0005250 | 04/16/12 | 08:13 |
| WATERBURY-DISTRICT_75-1-0004388 | 04/16/12 | 10:23 |
| WATERBURY-DISTRICT_75-2-0004752 | 04/16/12 | 10:29 |
| WATERBURY-DISTRICT_75-3-0004397 | 04/16/12 | 10:37 |
| WATERBURY-DISTRICT_75-4-0004401 | 04/16/12 | 10:45 |

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

(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 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 7 lists districts that show preparation for elections on unexpected dates.

| Card Name | Prepare for Election | |
|---------------------------------|----------------------|-------|
| | Date | Time |
| WATERBURY-DISTRICT_73-1-0005580 | 04/16/12 | 08:31 |
| WATERBURY-DISTRICT_74-3-0004126 | 04/16/12 | 08:01 |
| WATERBURY-DISTRICT_74-5-0005250 | 04/16/12 | 08:17 |
| WATERBURY-DISTRICT_75-1-0004388 | 04/16/12 | 10:28 |
| WATERBURY-DISTRICT_75-2-0004752 | 04/16/12 | 10:33 |
| WATERBURY-DISTRICT_75-3-0004397 | 04/16/12 | 10:41 |
| WATERBURY-DISTRICT_75-4-0004401 | 04/16/12 | 10:49 |

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

⁸Ibid.

The event log for all but one of these cards shows preparation for elections at least eight days before the election. As the preparation dates are still prior to the election, this should not be a cause for concern. However, according to the SOTS regulations⁹ the cards should have been prepared for election no later than the tenth day before the election.

4.3.2 Many Instances of Events

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

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.

| Event Name | Expected No. | Suggested Max. | Description |
|-------------------|--------------|----------------|---|
| SESSION START | ≥ 3 | 30 | Tabulator is turned on (e.g., 3 times: for initialization, testing, and election) |
| POWER FAIL | 0 | 10 | Tabulator switches to backup battery as the result of a main power failure |
| 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.

| Flagged Number of Instances | Cards Usable for the Election | | | |
|----------------------------------|-------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| DUPLICATE (none allowed) | 3 | 10% | 3 | 3.7% |
| MEMORY CARD RESET (none allowed) | 1 | 3.3% | 1 | 1.2% |

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

- (a) **3 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.
- (b) **1 card contained event “MEMORY CARD RESET”:**

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

| Card Name | Observed |
|---------------------------------|----------|
| BARKHAMSTED-DISTRICT_62-0001143 | 1 |

⁹Tbid.

| Card Name | Observed |
|---------------------------------|----------|
| VERNON-DISTRICT_1-1268 | 1 |
| VERNON-DISTRICT_1-1432 | 1 |
| WATERBURY-DISTRICT_75-4-0004401 | 3 |

Table 10: Cards involved in duplication.

Since closer examination of the event log of this card revealed that the reset instance was recorded two weeks prior to the election date, it does not raise concerns.

4.3.3 Miscellaneous Warnings

Table 11 reports the notifications issued for 2 cards that were caused either by unexpected events appearing in some event log sequences, or when an event occurred beyond the scope of rules covered by the current audit log analysis.

| Sequence Inconsistencies | Cards Usable for the Election | | | |
|--------------------------|-------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| Action Beyond Rules' End | 5 | 16.7% | 2 | 2.5% |

Table 11: Pre-Election Event Log Analysis Results - Sequence Inconsistencies

In the latter case additional events appear in the log, after all the rules are satisfied. The following cards contained such warnings:

| Card Name | No. of Warnings |
|---------------------------------|-----------------|
| BARKHAMSTED-DISTRICT_62-0001143 | 1 |
| RIDGEFIELD-DISTRICT_2-0001935 | 4 |

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

- BARKHAMSTED-DISTRICT_62-0001143 prepared for election and then reset. Before resetting the card the zero total report was printed. The activities outlined above took place two weeks prior to the election and do not raise concerns.
- For RIDGEFIELD-DISTRICT_2-0001935 the ZERO TOTAL REPORT was reported/printed 15 days before the election day four times. This is not an issue, provided such reports are also printed on the election day.

5 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.

- 155 cards were received for the post-election audit
- 104 cards were correct (this includes 5 cards that were involved in duplication)
 - 49 cards were used in the elections

- 46 cards were set to be used in the elections
- 9 cards were not set to be used in the elections
- 51 cards were unusable (by AV-OS)
 - 48 cards contained apparently random data (‘junk’ data)
 - 2 cards were unusable (but the data was not random)
 - one card was not programmed (formatted, but blank)

5.1 Overall Card State Analysis

Table 12 shows the frequency of various states observed on the 155 audited memory cards.

| All Cards (155) | | |
|---------------------------|--------|---------|
| (a) Card Format | Number | % Total |
| Correct Cards | 104 | 67.1% |
| Unusable (Junk) Data | 48 | 31% |
| Unusable Not Junk) | 2 | 1.3% |
| Unusable (Not Programmed) | 1 | 0.6% |
| Totals: | 155 | 100% |

Table 12: Memory card analysis summary for all cards received: (a) Card Format.

5.2 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.

49 cards were used in the election.

47 cards (95.9%) 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 (4.1%) 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, 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.

5.2.1 Event Log Analysis: 49 Cards Used in the Election

Here we present the result of the audit log analysis for the cards that were used in the election. Out of the 49 cards used in the election, 45 (91.8%) cards were flagged because their audit logs did not match our sequence rules.

The audit log analysis for the cards used in the election produced 95 notifications. Note that a single card may yield multiple notifications. Also recall that not all notifications necessarily mean that something went wrong – a notifications 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.

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 13.

| Out-of-Bounds Dates | Cards Usable for the Election | | | |
|--------------------------------|-------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| Sequence: Initialization | 2 | 2.1% | 2 | 4.4% |
| Sequence: Test Election | 31 | 32.6% | 28 | 57.1% |
| Sequence: Prepare For Election | 28 | 29.5% | 28 | 62.2% |
| Sequence: Election | 32 | 33.7% | 32 | 71.1% |

Table 13: Post-Election Audit Log Analysis Results - Out-of-Bounds Dates

(a) **Initialization: 2 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 02/24/2012 and 04/10/2012. Our assumptions for the sequencing of events are based on the SOTS documentation¹⁰. 2 cards fell outside of our assumed initialization period, but they were initialized prior to Election Day, so this is not a security issue.

The cards that appeared to have initialization date that differed from our assumption is given in Table 14 for completeness.

| Card Name | Initialization | |
|-------------------------------|----------------|-------|
| | Date | Time |
| EAST_HAVEN-DISTRICT_4-0002057 | 4/16/12 | 14:11 |
| LITCHFIELD-DISTRICT_4-0001991 | 4/16/12 | 10:01 |

Table 14: Initialization dates outside of our assumed time window.

¹⁰ 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.

(b) **Test Elections: 28 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 day¹¹. For this election we expect this process to be completed between the dates 03/01/2012 and 04/14/2012. Table 15 lists districts that show unexpected test dates.

In the case of the Town of Vernon, all cards listed in Table 15 are the new non-volatile memory cards. These cards were used in Vernon as a pilot. The cards were received by the VoTeR Center on 04/19/2012 directly from LHS, examined, and then delivered to Vernon by the Center personnel on 04/20/2012. Table 15 shows that the cards were tested on the same day that they were received in Vernon.

| Card Name | Test Election | |
|-------------------------------------|---------------|-------|
| | Date | Time |
| COLCHESTER-DISTRICT_1-0004443 | 4/16/12 | 09:20 |
| COLCHESTER-DISTRICT_3-0004448 | 4/16/12 | 10:30 |
| EAST_HAVEN-DISTRICT_4-0002057 | 4/16/12 | 13:26 |
| FAIRFIELD-DISTRICT_10-0005321 | 4/17/12 | 11:54 |
| GLASTONBURY-DISTRICT_1-0005152 | 4/18/12 | 07:28 |
| GLASTONBURY-DISTRICT_3-0002735 | 4/18/12 | 07:42 |
| GLASTONBURY-DISTRICT_4-0002726 | 4/18/12 | 07:43 |
| GLASTONBURY-DISTRICT_5-0002731 | 4/18/12 | 07:59 |
| GLASTONBURY-DISTRICT_7-0005154 | 4/18/12 | 08:05 |
| GLASTONBURY-DISTRICT_9-0002747 | 4/18/12 | 08:00 |
| LITCHFIELD-DISTRICT_4-0001991 | 4/16/12 | 11:08 |
| NAUGATUCK-DISTRICT_1-1-0003462 | 4/16/12 | 15:21 |
| NORTH_BRANFORD-DISTRICT_1-0005097 | 4/16/12 | 18:03 |
| NORTH_STONINGTON-DISTRICT_1-0002620 | 4/16/12 | 10:23 |
| NORWALK-DISTRICT_143A-0004049 | 4/18/12 | 12:45 |
| OLD_LYME-DISTRICT_1-0004577 | 4/16/12 | 14:16 |
| ROCKY_HILL-DISTRICT_1-0004871 | 4/18/12 | 09:41 |
| SOUTHURY-DISTRICT_2-0002211 | 4/17/12 | 10:29 |
| SOUTHINGTON-DISTRICT_9-0002800 | 4/18/12 | 11:49 |
| STAMFORD-DISTRICT_11-0004179 | 4/19/12 | 10:33 |
| VERNON-DISTRICT_1-1268 | 4/20/12 | 17:51 |
| VERNON-DISTRICT_2-1841 | 4/20/12 | 18:01 |
| VERNON-DISTRICT_3-1301 | 4/20/12 | 18:16 |
| VERNON-DISTRICT_4-1890 | 4/20/12 | 18:22 |
| VERNON-DISTRICT_5-1269 | 4/20/12 | 18:35 |
| VERNON-DISTRICT_5-2145 | 4/20/12 | 18:06 |
| VERNON-DISTRICT_6-1767 | 4/20/12 | 18:48 |
| VOLUNTOWN-DISTRICT_1-0005831 | 4/18/12 | 08:01 |

Table 15: Test Election dates outside of the assumed time window.

(c) **Preparation for Election: 28 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

¹¹Ibid.

the same as for the Test Election sequence. Table 16 lists districts that show preparation for elections on unexpected dates.

As the preparation dates are still prior to the election, this should not be a cause for concern. However, according to the SOTS regulations¹² the cards should have been prepared for election no later than the tenth day before the election.

In the case of the Town of Vernon, again all cards listed in Table 16 are the new non-volatile memory cards used in the pilot. These cards were delivered to Vernon on 04/20/2012. Table 16 shows that the cards were prepared for election on the same day that they were received.

| Card Name | Prepare for Election | |
|-------------------------------------|----------------------|-------|
| | Date | Time |
| COLCHESTER-DISTRICT_1-0004443 | 4/16/12 | 09:27 |
| COLCHESTER-DISTRICT_3-0004448 | 4/16/12 | 10:35 |
| EAST_HAVEN-DISTRICT_4-0002057 | 4/23/12 | 11:13 |
| FAIRFIELD-DISTRICT_10-0005321 | 4/17/12 | 13:56 |
| GLASTONBURY-DISTRICT_1-0005152 | 4/18/12 | 07:31 |
| GLASTONBURY-DISTRICT_3-0002735 | 4/18/12 | 07:45 |
| GLASTONBURY-DISTRICT_4-0002726 | 4/18/12 | 07:45 |
| GLASTONBURY-DISTRICT_5-0002731 | 4/18/12 | 08:01 |
| GLASTONBURY-DISTRICT_7-0005154 | 4/18/12 | 08:07 |
| GLASTONBURY-DISTRICT_9-0002747 | 4/18/12 | 08:03 |
| LITCHFIELD-DISTRICT_4-0001991 | 4/17/12 | 10:10 |
| NAUGATUCK-DISTRICT_1-1-0003462 | 4/16/12 | 15:28 |
| NORTH_BRANFORD-DISTRICT_1-0005097 | 4/16/12 | 18:21 |
| NORTH_STONINGTON-DISTRICT_1-0002620 | 4/16/12 | 10:31 |
| NORWALK-DISTRICT_143A-0004049 | 4/18/12 | 12:47 |
| OLD_LYME-DISTRICT_1-0004577 | 4/16/12 | 14:28 |
| ROCKY_HILL-DISTRICT_1-0004871 | 4/18/12 | 11:16 |
| SOUTHURY-DISTRICT_2-0002211 | 4/17/12 | 10:33 |
| SOUTHINGTON-DISTRICT_9-0002800 | 4/18/12 | 11:51 |
| STAMFORD-DISTRICT_11-0004179 | 4/19/12 | 10:34 |
| VERNON-DISTRICT_1-1268 | 4/20/12 | 17:59 |
| VERNON-DISTRICT_2-1841 | 4/20/12 | 18:06 |
| VERNON-DISTRICT_3-1301 | 4/20/12 | 18:21 |
| VERNON-DISTRICT_4-1890 | 4/20/12 | 18:28 |
| VERNON-DISTRICT_5-1269 | 4/20/12 | 18:39 |
| VERNON-DISTRICT_5-2145 | 4/20/12 | 18:11 |
| VERNON-DISTRICT_6-1767 | 4/20/12 | 18:52 |
| VOLUNTOWN-DISTRICT_1-0005831 | 4/18/12 | 08:10 |

Table 16: Prepare for Election dates outside of the assumed time window.

(d) **Election: 32 cards appeared to have some abnormalities in the Election sequence.**

We expect the election to be held on the election day. According to the SOTS regulations¹³ 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 revealed that 7 out of 32 cards had printed zero total reports on the election day in the time window 4:13–4:29. 16 of those cards closed the election after 20:01, however the latest time appears to be 20:23. For 7 cards a zero report was

¹²Ibid.

¹³Ibid.

printed prior to the election day, however the report was re-printed on the election day, hence it is not a security concern. The remaining one card run election on 04/12/12 and it has 165 ballots cast. This card requires further investigation, and we present it in Table 17 for convenience:

| Card Name | Election Sequence | |
|---------------------------------|-------------------|-------|
| | Date | Time |
| WESTPORT-DISTRICT_136-2-0005693 | 4/12/12 | 09:58 |

Table 17: Election date/time 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 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 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 18.

| Flagged Number of Instances | Cards Used in the Election | | | |
|-----------------------------|----------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| DUPLICATE (none allowed) | 2 | 1.4% | 2 | 4.1% |

Table 18: Event Log Analysis Results - Many Instances of Events

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 established that both cards were most likely involved in duplication at LHS, since one of them was duplicated a day after it was initialized, while the second one was sent for the pre-election testing to the VoTeR Center from LHS directly, and the same duplication event was noted on that card during the pre-election audit.

Miscellaneous Notifications. Miscellaneous notifications are caused either by unexpected events appearing in some audit log sequences, or when an event occurred beyond the scope of rules covered by the current audit log analysis.

No miscellaneous notifications were issued for the cards used in the election.

5.3 Analysis of Cards Not Used in the Election

The VoTeR Center received 155 cards for the post-election audit. This number includes 49 cards used in the election, with the analysis results presented in the previous section. Here we present the audit results for the remaining 106 cards.

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

- 106 cards were not used in the election.
- 55 were correct (this includes 3 cards that were involved in duplication)

– 46 were set to be used in the elections

- 9 were not set to be used in the elections
- 51 cards were unusable (by AV-OS)
 - 48 cards contained apparently random data (‘junk’ data)
 - 2 cards were unusable (but the data was not random)
 - 1 card was not programmed (formatted, but blank)

5.3.1 Overall Card State Analysis (Part a)

Table 19 shows the frequency of various states observed on the 106 audited memory cards not used in the election.

| Cards (106) Not Used in the Election | | |
|--------------------------------------|--------|---------|
| (a) Card Format | Number | % Total |
| Correct Cards | 55 | 51.9% |
| Unusable (Junk) Data | 48 | 45.3% |
| Unusable (not Junk) | 2 | 1.9% |
| Unusable (Not Programmed) | 1 | 0.9% |
| Totals: | 106 | 100% |

Table 19: Memory card analysis summary: (a) Card Format.

(a) Card Format: Among the 106 cards not used in the election, 55 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 55 cards, 52 cards (49.1%) were programmed directly using GEMS and contained data matching the baseline. These involved no duplication. 3 cards (2.8%) were involved in duplication, otherwise they contained correct data, matching the baseline.

51 cards (48.1%) 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. 48 cards (45.3%) contained apparently random (‘junk’) data and are readily detected through pre-election testing by poll workers, thus they could not have been used in the election. 2 cards (1.9%) 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. One card (0.9%) was not programmed. Such cards contain no data about the election, and this is not an intended state of the card. It is possible that this card was (inadvertently) reformatted after testing; else it may have arrived not programmed.

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 1.8% and 12.1%. This estimate is made on the basis of the following calculation. We received cards from 105 districts out of the total 690 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 51. Thus the minimum percentage is calculated as $51/(690 \cdot 4) = 1.8\%$, given that unusable card data does not contain district information. Performing

similar calculation for the 105 participating districts, we obtain the maximum percentage as $51/(105 \cdot 4) = 12.1\%$. This range is consistent with the results from prior audits.

5.3.2 Analysis of the Readable/Usable Cards Not Used in the Election

We now present the details of the audit for the 55 cards (among the 155 audited cards) that could have been used in the elections.

| Usable Cards (55) Not Used in the Election | | |
|---|--------|---------|
| | Number | % Total |
| (b) Card Status Summary | | |
| Not Set for Election | 9 | 16.4% |
| Set for Election | 46 | 83.6% |
| Totals: | 55 | 100% |
| (c) Card & Counter Status | | |
| Set For Elections, Zero Counters | 45 | 81.8% |
| Set For Elections, Non-Zero Counters | 1 | 1.8% |
| Not Set, Non-Zero Counters | 8 | 14.6% |
| Not Set, Zero Counters | 1 | 1.8% |
| Totals: | 55 | 100% |
| (d) Card Duplication (3) | | |
| Master Card | 3 | 100% |
| Copy Card | 0 | 0% |
| Totals: | 3 | 100% |

Table 20: 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.

46 cards (83.6%) were in Set For Election state. This is the appropriate status for cards intended to be used in the elections.

9 cards (16.4%) 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.

One card (1.8%) was found in Set For Election state and had Non Zero Counters. This is not the appropriate status. Manual examination of the audit log of this card revealed that this card was used on the election day (April 24, 2012) and had 93 ballots cast on it. Audit Log analysis showed that the machine was restarted twice during the election day, hence we suspect a machine malfunction. The last event recorded in the audit log is a POWER FAIL at 19:33 and the ENDER CARD was never cast. As a result, the election was never closed and no total report was printed. Follow-up

investigation by the SOTS Office revealed that the district in question encountered an equipment failure at 19:30. The tabulator stopped accepting ballots and a backup tabulator was used instead. All ballots cast on the failed machine were put through the backup tabulator for the final count.

45 cards (81.8%) 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.

8 cards (14.6%) 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.

One card (1.8%) was found to be in Not Set for Elections state with Zero Counters. This is similar to the 8 cards above. This situation would have been similarly detected and remedied if such cards were to be used on the election day. Manual examination of the audit log of this card showed that two test elections were run on this card. However, the dates of the testing suggest that the card was tested at LHS rather than at the district.

Taking the above percentages together, it appears that almost all districts ($83.6\% + 14.6\% = 98.2\%$) performed pre-election testing before submitting the cards for the audit.

(d) Card Duplication: Among the usable cards not used in the election 3 cards were involved in duplication. All of these cards (100%) were *master* cards used for 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 two cards were most likely involved in duplication at LHS, since they were duplicated the same day as they were initialized. The remaining one card could have been involved in duplication in the district, since the duplication was done 8 days after the card was initialized.

Given the SOTS policies, 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.

5.3.3 Event Log Analysis: 55 Cards Not Used in the Election

Here we present the result of the audit log analysis for the usable cards that were not used in the election. Out of the 55 cards, 24 (43.6%) cards were flagged because their audit logs did not match our sequence rules.

The audit log analysis for the cards not used in the election produced 52 notifications. Note that a single card may yield multiple notifications. Also recall that not all notifications necessarily mean that something went wrong – a notification simply means that the sequence of events in the audit log did not match our (not-all-inclusive) rules. We next present the details of the analysis.

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 21.

(a) Initialization: one card was 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 02/24/2012 and 04/10/2012. Our

| Out-of-Bounds Dates | Cards Not Used in the Election | | | |
|--------------------------------|--------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| Sequence: Initialization | 1 | 1.9% | 1 | 4.2% |
| Sequence: Test Election | 20 | 38.5% | 20 | 83.3% |
| Sequence: Prepare For Election | 20 | 38.5% | 20 | 83.3% |
| Sequence: Election | 3 | 5.8% | 3 | 12.5% |

Table 21: Post-Election Audit Log Analysis Results - Out-of-Bounds Dates

assumptions for the sequencing of events are based on the SOTS documentation¹⁴. One card fell outside of our assumed initialization period. However, this card is not programmed. It is possible that the card was formatted at the district and never initialized.

This card is given in Table 22 for completeness.

| Card Name | Initialization | |
|-------------------------------|----------------|-------|
| | Date | Time |
| MIDDLETOWN-DISTRICT_2-0003938 | 4/12/12 | 11:31 |

Table 22: Initialization dates outside of our assumed time window.

(b) **Test Elections: 20 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 day¹⁵. For this election we expect this process to be completed between the dates 03/01/2012 and 04/14/2012. Table 23 lists cards that show unexpected test dates.

(c) **Preparation for Election: 20 cards were prepared for elections at unexpected times.**

Cards should be prepared for elections after the testing is completed but before the election date. This is the expected state for the cards submitted for the pre-election audit. Since election preparation needs to be done immediately after the cards are tested, the date boundaries are the same as for the Test Election sequence. Table 24 lists districts that show preparation for elections on unexpected dates.

As the preparation dates are still prior to the election, this should not be a cause for concern. However, according to the SOTS regulations¹⁶ the cards should have been prepared for election no later than the tenth day before the election.

(d) **Election: 3 cards appeared to have some abnormalities in the Election sequence.**

We expect the election to be held on the election day. according to the SOTS regulations¹⁷ the zero total report should be printed no earlier than 04:30 and the election should be closed no

¹⁴ 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.

¹⁵Ibid.

¹⁶Ibid.

¹⁷Ibid.

| Card Name | Test Election | |
|----------------------------------|---------------|-------|
| | Date | Time |
| CHESTER-DISTRICT_1-0002342 | 4/17/12 | 11:39 |
| FAIRFIELD-DISTRICT_10-0005320 | 4/17/12 | 11:54 |
| GLASTONBURY-DISTRICT_1-0002714 | 4/18/12 | 07:41 |
| GLASTONBURY-DISTRICT_3-0002722 | 4/18/12 | 07:30 |
| GLASTONBURY-DISTRICT_4-0002720 | 4/18/12 | 07:30 |
| GLASTONBURY-DISTRICT_5-0002730 | 4/18/12 | 07:51 |
| GLASTONBURY-DISTRICT_7-0002739 | 4/18/12 | 08:24 |
| GLASTONBURY-DISTRICT_9-0004750 | 4/18/12 | 07:53 |
| NAUGATUCK-DISTRICT_1-1-0003460 | 4/16/12 | 15:13 |
| NAUGATUCK-DISTRICT_1-1-0003461 | 4/16/12 | 04:52 |
| NEW_CANAAAN-DISTRICT_2-3-0001501 | 4/20/12 | 14:19 |
| NEWINGTON-DISTRICT_3-0002438 | 4/19/12 | 09:18 |
| ROCKY_HILL-DISTRICT_2-0004603 | 4/18/12 | 09:46 |
| ROCKY_HILL-DISTRICT_3-0004605 | 4/18/12 | 10:44 |
| SOUTHBURY-DISTRICT_1-0002207 | 4/17/12 | 10:56 |
| SOUTHBURY-DISTRICT_2-0002209 | 4/17/12 | 10:34 |
| SOUTHBURY-DISTRICT_3-0002214 | 4/17/12 | 09:17 |
| SOUTHBURY-DISTRICT_4-0002217 | 4/17/12 | 09:27 |
| SOUTHBURY-DISTRICT_5-0002222 | 4/17/12 | 11:34 |
| STAMFORD-DISTRICT_11-0004180 | 4/19/12 | 11:42 |

Table 23: Test Election dates outside of the assumed time window.

| Card Name | Prepare for Election | |
|----------------------------------|----------------------|-------|
| | Date | Time |
| CHESTER-DISTRICT_1-0002342 | 4/17/12 | 11:45 |
| FAIRFIELD-DISTRICT_10-0005320 | 4/17/12 | 13:56 |
| GLASTONBURY-DISTRICT_1-0002714 | 4/18/12 | 07:57 |
| GLASTONBURY-DISTRICT_3-0002722 | 4/18/12 | 07:33 |
| GLASTONBURY-DISTRICT_4-0002720 | 4/18/12 | 07:33 |
| GLASTONBURY-DISTRICT_5-0002730 | 4/18/12 | 07:55 |
| GLASTONBURY-DISTRICT_7-0002739 | 4/18/12 | 08:26 |
| GLASTONBURY-DISTRICT_9-0004750 | 4/18/12 | 07:55 |
| NAUGATUCK-DISTRICT_1-1-0003460 | 4/16/12 | 15:18 |
| NAUGATUCK-DISTRICT_1-1-0003461 | 4/16/12 | 04:56 |
| NEW_CANAAAN-DISTRICT_2-3-0001501 | 4/20/12 | 14:27 |
| NEWINGTON-DISTRICT_3-0002438 | 4/19/12 | 09:22 |
| ROCKY_HILL-DISTRICT_2-0004603 | 4/18/12 | 11:19 |
| ROCKY_HILL-DISTRICT_3-0004605 | 4/18/12 | 11:01 |
| SOUTHBURY-DISTRICT_1-0002207 | 4/17/12 | 10:59 |
| SOUTHBURY-DISTRICT_2-0002209 | 4/17/12 | 10:39 |
| SOUTHBURY-DISTRICT_3-0002214 | 4/17/12 | 09:23 |
| SOUTHBURY-DISTRICT_4-0002217 | 4/17/12 | 09:32 |
| SOUTHBURY-DISTRICT_5-0002222 | 4/17/12 | 11:37 |
| STAMFORD-DISTRICT_11-0004180 | 4/19/12 | 11:44 |

Table 24: Prepare for Election dates outside of the assumed time window.

later than 20:01. Manual examination of these cards showed that after preparing the cards for election the machine was turned on and the zero total report was printed. For two of the cards it was printed a few days prior to the election day. This is not a security concern, since zero total report is printed every time the machine is turned on. For the remaining one card the zero total report was printed on the election day, however no ballots were cast, and hence this card was not considered as a card used in the election. We present those cards in Table 25 for completeness.

| Card Name | Election Sequence | |
|---------------------------------|-------------------|-------|
| | Date | Time |
| GLASTONBURY-DISTRICT_5-0002730 | 4/18/12 | 08:04 |
| NEW_CANAAN-DISTRICT_2-3-0001501 | 4/20/12 | 14:29 |
| ROCKY_HILL-DISTRICT_2-0004603 | 4/18/12 | 11:31 |

Table 25: Election date/time 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 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 26.

| Flagged Number of Instances | Cards Not Used in the Election | | | |
|--------------------------------|--------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| DUPLICATE (none allowed) | 3 | 5.8% | 3 | 5.5% |
| COUNT RESTARTED (none allowed) | 2 | 3.8% | 1 | 1.8% |

Table 26: Audit Log Analysis Results - Many Instances of Events

- (a) **3 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 27. We already discussed card duplication in Section 5.3.2.

| Card Name | Observed |
|---------------------------------|----------|
| NEW_CANAAN-DISTRICT_2-3-0001501 | 1 |
| PLAINVILLE-DISTRICT_4-0002334 | 2 |
| STRATFORD-BALDWIN-0004621 | 1 |

Table 27: Cards involved in duplication.

- (b) **1 card contained event “COUNT RESTARTED”:** This event is recorded when the tabulator is restarted while in election mode and the ballot counting started. Such event may be raised if the machine is restarted while it is set for elections and the ballot counting has started. As discussed earlier, the SOTS Office confirmed that there was a tabulator malfunction in this district. The card appears below:

| Card Name | Observed |
|-----------------------------|----------|
| SIMSBURY-DISTRICT_4-0005925 | 2 |

Miscellaneous Notifications. Table 28 reports the notifications issued for 2 cards that were caused either by unexpected events appearing in some audit log sequences, or when an event occurred beyond the scope of rules covered by the current audit log analysis.

| Sequence Inconsistencies | Cards Not Used in the Election | | | |
|--------------------------|--------------------------------|---------|---------|----------|
| | # Warn. | % Warn. | # Cards | % Usable |
| Action Missing | 3 | 5.8% | 2 | 3.6% |

Table 28: Pre-Election Audit Log Analysis Results – Sequence Inconsistencies

The following cards contained such warnings:

| Card Name | No. of Warnings |
|-------------------------------|-----------------|
| MIDDLETOWN-DISTRICT_2-0003938 | 1 |
| SIMSBURY-DISTRICT_4-0005925 | 2 |

The manual examination of these audit logs of these cards revealed the following issues:

- MIDDLETOWN-DISTRICT_2-0003938 card is not programmed. It is possible that the card was formatted at the district and as a result not initialized.
- For SIMSBURY-DISTRICT_4-0005925 BAL COUNT START event appears twice in Election sequence when ender card is expected. This was caused by the tabulator being restarted while in election mode. We already noted above that the SOTS Office investigated the matter and confirmed that there was a tabulator malfunction in the district and a backup tabulator was used instead of the failed one. All the ballots cast on the failed tabulator were put through the backup tabulator and were included in the final count.

6 Addressing Memory Card Reliability

We estimated the overall percentage of the cards that are not usable in the election to be between 1.6% and 9.8% for the pre-election audit, while for the post-election audit 1.8% and 12.1%. 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 observations¹⁸, 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.

¹⁸ 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 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 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. 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 to report to the SOTS Office any unexpected behavior of the tabulators that seem to necessitate a restart or a memory card reset. It would be helpful if moderators' logs contained records of machine restarts, perceived causes, and reasoning for the restart or reset. There was at least one documented case of a tabulator malfunction during this primary election. In such cases it is strongly recommended that the problematic tabulator is tested by the Center personnel (either at the district or in our laboratory).
- The current number of cards with unreadable data (junk data) continues to be high. We have determined that weak batteries are the primary cause of this. The vendor developed a new non-volatile, battery-less memory card, and our ongoing evaluation continues to confirm their compatibility with the AV-OS machines used in Connecticut. A limited pilot using the new cards was successfully performed in Vernon. It is expected that a broader pilot deployment of the new cards by the SOTS Office will occur in the near future. The use of the new card should eliminate the major cause of memory card failures.
- It is important that cards sent for the pre-election audit are selected at random. One card randomly selected from four cards in each district is to be randomly selected for the audit. While the districts are encouraged to submit all malfunctioning cards to 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, 155, out of which only 49 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.

[End]