VoTeR Center

UConn Voting Technology Research Center

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Post-Election Audit of Memory Cards
for the February 2008 Connecticut Primary Elections

Version 0.3, July 17, 2008

Summary

The UConn VoTeR Center performed a post-election audit of the memory cards for the Accu-Vote Optical Scan tabulators that were used in the February 2008 Connecticut Primary Elections. The cards were programmed by LHS Associates of Methuen, Massachusetts, and shipped to Connecticut districts for use in the elections. For the purpose of the post-election audit, the VoTeR Center received 215 memory cards from a number of districts after the elections. The audit was performed on 210 of these memory cards. (Five of the 215 cards were examined separately: three contained data from special election held in March, different from the primary elections; one card contained a referendum, and one card was from the 2007 municipal elections.)

This document reports on the findings obtained during the audit. Among the 210 cards received and tested by the VoTeR Center, 200 cards (95%) were found to have been properly programmed for election. These cards contained valid ballot data and the executable code on these cards was the expected code, with no extraneous data or code on the cards. The remaining 10 cards, or 5% were found to contain "junk" data, that is, they were unreadable, which is easily detected by the tabulators as such, and could not have been used in the election. This is a high percentage of faulty cards.

137 of the cards were used for the actual election (the rest where backup cards). All cards were properly programmed and contained no unexpected code. 126 cards, or 92%, of the 137 cards were in the "election closed" state with non-zero counters which is the intended state. 10 cards (7.3%) indicated that printing was aborted, which suggests that election officials turned off the machine before the printing of the election results was completed.

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

1   Preface

The Voting Technology Research (VoTeR) Center at the University of Connecticut conducted post-election audit of the memory cards used in the AccuVote Optical Scan (AV-OS) tabulators in the primary elections of February 2008. The audit was performed on request of the Office of the Secretary of the State of the State of Connecticut.

The memory cards were programmed for the February 2008 election by LHS Associates of Methuen, Massachusetts, and provided by LHS to the districts in Connecticut. The audit was performed on a set memory cards that were shipped after the elections by the individual districts to the VoTeR Center at the University of Connecticut in Storrs.

The memory cards were subject to several integrity tests and this report presents a comprehensive overview of the procedures taken by the VoTeR Center personnel in conducting the audit. In this report, we present the objectives of the post-election audit, the audit process, and the audit results. The process included testing, comparison, and analysis of the data collected during the audit. We also outline the safekeeping steps taken in dealing with the memory cards after receiving them from the districts. These include a strict chain of custody policy with regard to handling the cards, maintaining a log of all transactions and activities, and safekeeping (both physical and electro-magnetic) of the memory cards.

We conclude the report with several observations based on what was learned during the post-election audit process, and we offer recommendations aimed at enhancing the integrity of our elections. These include recommendations to poll workers and election officials regarding making and managing relevant policies, safely and efficiently handling memory cards, voting terminals, and other equipment associated with an election. We include comments on the importance of clear and unambiguous instructions in dealing with the electoral apparatus and following such directions diligently. We believe that technological audits are crucial in providing valuable feedback and maintaining the integrity of the electoral process.

This report is a high-level, non-technical overview of the procedures taken by the VoTeR Center and to this end omits several technical details. We also note that we had no access to, and we did not use any vendor documentation regarding the design and the internals of the AV-OS terminal. The technical basis for conducting the audit and our procedures are documented in our previous report that can be found at URL http://voter.engr.uconn.edu/voter/Reports_files/audit07mc.pdf [1].

About the UConn VoTeR Center

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

The work of VoTeR Center in the State of Connecticut is funded by the Office of the Connecticut Secretary of the State (SOTS), and we function in close contact with the SOTS Office personnel. We offer the State an independent, objective analysis of the voting technologies offered by several vendors, we advise the State on selecting and administering the voting equipment for its election needs, and we are not associated with any of the voting technology vendors. The evaluations of the voting technology are performed at the VoTeR Center Lab at the University of Connecticut. These include hands-on evaluations, exploration of possible attack vectors, physical integrity checks of the terminals and memory cards, and mitigation strategies. It is worth pointing out that the VoTeR center is not involved in the State's policies for choosing a vendor to procure the voting technology,

but limited to evaluating these technologies before deployment and use by the State. In this sense the VoTeR center is a third party independent technical consulting resource for the State of Connecticut.

VoTeR Center personnel assisted the State in developing safe use procedures for the Optical Scan terminals. The procedures in place for the election includes strict physical custody policy, tamper-resistant protection of the equipment, and audits.

2   Introduction

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

2.1   Brief Description of the AV-OS

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

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

- The GEMS software is installed on a conventional PC (or a laptop). It includes a ballot design system and a tabulation system.

- Once the election data is entered into the GEMS system, the specifications of the election are downloaded into a memory card via an AV-OS system connected to GEMS by a serial line cable.

- The memory cards are the 40-pin 128KB Epson cards. The memory card is installed into to the 40-pin card slot (J40 connector) of the AV-OS. It is worth mentioning that Epson has discontinued this memory card some time ago, and reader/writers for this memory card are not readily available.

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

2.2   Goals of the Post-Election Memory Card Audit

The VoTeR Center was asked by the CT SOTS Office to prepare for and implement memory card audits. The primary goal of the post-election audit was to perform an integrity check of the contents of the memory cards that were used in the elections.

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 on the memory cards are loaded on to the memory card using the AV-OS terminal from the GEMS database. The GEMS database to be used as the baseline for the election data was provided by LHS Associates prior to the election. Each district was given

four identical memory cards containing the election information for that district. After the elections, a number of districts shipped memory cards to the VoTeR Center for the audit. The contents of the cards were then extracted and compared with the intended contents using the GEMS database as the reference. The audit process was automated to the extent possible. Any discrepancies or deviations from the baseline were then logged and analyzed. Specifically, the memory cards were audited for any deviations in the ballot data/layout, bytecode, the state of the counters, and to some extent the audit logs on the memory card. The remainder of this report describes each of these steps in detail.

2.3   Preview of the Audit Results

A total of 215 cards, including 137 used in the primary election, were received and tested by the VoTeR Center. Among these cards three contained a special election conducted on March 11, 2008. One card contained a referendum, and one card was from the 2007 municipal elections. Those 5 cards were not considered in this report. This report focuses on the 137 cards used in the elections and on the 210 cards pertaining to the 2007 primary elections.

Among the 137 cards used in the elections 98.5% (135 cards) were properly programed, contained no unexpected code, and were in the state consistent with proper usage. 1.5% of the cards (2 cards) contained a few bytes of noise (or "specks") that apparently do not interfere with proper usage; these cards otherwise were properly programmed. 7.3% of the cards (10 cards) were in the "result print aborted" state. This is an undesired condition, although, provided results were in fact printed, this does not present a problem. Better communication to poll workers should eliminate such situations in the future.

Among all 210 cards examined, 10 cards, or 4.8% were found to contain "junk" data, that is, they were unreadable, which is easily detected by the tabulators as such, and could not have been used in the election. The rest of the cards, or 95.3%, were found to have been properly programmed for election. These cards contained valid ballot data and the executable code on these cards was the expected code, with no extraneous data or code on the cards.

22% of the cards were in Set for Election mode, this is the intended state for back-up cards that were not used in the elections. 9.5% were Not Set for Election. Those cards are apparently back-up cards that were not used in the election. This is not the desired state for such cards, and it suggests that poll workers did not follow the proper procedure while handling those cards. Finally three cards had flags set that indicated that they had been duplicated. There is no procedure that requires card duplication to our knowledge, and thus those incidents require a follow up.

3   Audit Results

We now present the results of the post-election audit. For the February 2008 Primary elections we received and examined 215 cards. These cards were received during the months of February through May. Among these cards 137 were used in the primary election. The rest of the cards we used in non-primary elections (5 cards), the remainder of the cards were (back-up) cards not used in the elections. Thus this report deals with total of 210 cards that pertain to the primary elections, and more specifically with 137 cards that were actually used in the elections.

3.1   Memory Card Data Audit Results: 137 Cards Used in the Election

Table 1 shows the frequency of various states observed on the audited memory cards for the 137 cards used in the election. The data is presented in two parts:

(a) Card Format: About 98.5% of the cards were properly formatted and contained good data. The rest 1.5% of cards were properly formatted and contained good data, but also included a

few "specks", that is a few isolated bytes with unexpected values. The specks are not detected by AV-OS, and it does not appear that they interfere with normal AV-OS operation.

(b) Card & Counter Status: About 92% of the cards 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.

One card (0.7%) was found in in Election Closed state with Zero counters. This is unexpected. Either nobody voted in the election in that precinct, or someone accidentally closed the election during pre-election testing using a "back-up" card.

7.3% of the cards were in Results Print aborted state with non-Zero counters. Such cards, are expected to have non zero counters, however this is an undesired state, indicating that poll workers shut the machine during the printing of the results (perhaps unintentional second printing).

No cards with uploaded results were found. No cards with audit report printed were found. These are the expected results.

	Cards Used in the Election	
	Number	% Total
(a) Card Format		
Good Data, Clean Card	135	98.5%
Good Data, Some "Specks"	2	1.5%
Totals:	137	100%
(b) Card &Counter Status		
Election Closed, Non-Zero Counters	126	92.0%
Election Closed, Zero Counters	1	0.7%
Results Print aborted, Non-Zero Counters	10	7.3%
Results Sent/Uploaded	0	0.0%
Audit Report Printed	0	0.0%
Totals:	137	100%

Table 1: Memory card analysis summary for cards used in the election: (a) card format, (b) card & counter status.

3.2 Memory Card Data Audit Results: All 210 Cards

Table 2 shows the frequency of various states observed on the audited memory cards for all 210 cards examined, including the 137 cards ath were used in the election. The data is presented in three parts:

(a) Card Format: About 93.8% of the cards were properly formatted and contained good data. Another 1.4% of cards were properly formatted and contained good data, but also included a few "specks", that is a few isolated bytes with unexpected values. The specks are not detected by AV-OS, and it does not appear that they interfere with normal AV-OS operation. The rest 4.8% of cards contained "junk" data, that is the card format is unrecognizable and appears to contain arbitrary noise. Such cards are not readable by AV-OS and they are readily detected through pre-election testing by poll workers, thus they could not have been used in the election.

In the rest of the analysis the percentages are computed for the 200 cards (95.2%) that were properly formatted and contained good data, i.e., the cards that did not contain junk data.

(b) Card Status: This refers to the current state of the memory card, such as loaded with an election, set for election, running an election, or closed election, and others.

No blank/unprogrammed but properly formatted cards were found. No cards with uploaded results were found. No cards with audit report printed were found. These are the expected results.

The majority of the cards, about 64% were in Election Closed state, which is the desired memory card state for cards that were used in the elections.

5% of the cards were found to be in the Results Print aborted state, suggesting that the printing of the results, after the election was closed, was interrupted by turning-off the AV-OS machine, before the printing was completed. This is not the intended procedure. The above suggest that those cards were used in the actual election. The results must eventually be printed and signed by post officials, according to election procedures, which suggests that the results were printed and signed, but election officials did not wait for the printing to complete, and turned-off the machine prematurely. It should be recommended that the poll workers must allow the printing of results to complete, before turning off the AV-OS machines, indeed this is the intended procedure.

22% of the cards were in Set For Election state. Such cards, were not used in the election. They were back-up cards. This is the intended state for such cards.

Finally 10% of the cards were in Not Set state. These cards were not used in the election. This is not the intended state. Still if they were to be used in the election, they should first be "Set for election", which would result in the counters of the card being set to zero, and the state changing to "Set For Election". Although harmless, this suggests that poll workers did not fully understand or follow the procedures.

(c) Card & Counter Status: 22% of the cards were Set For Election state and had Zero counters. This is the intended state, for memory cards that were not used in the elections.

63% of the cards 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.

One card (0.5%) was found in in Election Closed state with Zero counters. This is unexpected. Either nobody voted in the election in that precinct, or someone accidentally closed the election in a back-up card, which is not the intended procedure.

5% of the cards were in Results Print aborted state. (This was discussed above.)

9% of the cards were in Not Set state with non-Zero counters. This is not the expected state, still it is not a problematic one as discussed above.

One card (0.5%) was in Not Set state with Zero counters. This is not the expected state, but like the case presented above, does not create any problems in the election procedure.

These observations indicate that proper pre-election testing and post-election reporting procedures are either not uniform, or are not communicated effectively.

3.3   Bytecode Analysis Result

We have analyzed the Accu-Basic 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

	All Cards	
	Number	% Total
(a) Card Format		
Good Data, Clean Card	197	93.8%
Good Data, Some "Specks"	3	1.4%
Unusable Cards, "Junk Data"	10	4.8%
Totals:	210	100%
(b) Card Status		
Not Programmed (Blank)	0	0.0%
Not Set for Election	19	9.5%
Set for Election	44	22.0%
Results Print Aborted	10	5.0%
Election Closed	127	63.5%
Results Sent/Uploaded	0	0.0%
Audit Report Printed	0	0.0%
Totals:	200	100%
(c) Card &Counter Status		
Not Set for Election, Non-Zero Counters	18	9%
Not Set for Election, Zero Counters	1	0.5%
Set for Election, Zero Counters	44	22.0%
Results Print aborted, Non-Zero Counters	10	5.0%
Election Closed, Non-Zero Counters	126	63.0%
Election Closed, Zero Counters	1	0.5%
Totals:	200	100%

Table 2: Memory card analysis summary for all cards: (a) card format, (b) card status, (c) card & counter status.

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 Accu-Basic bytecode, as was pointed out in our earlier report [2].

3.4   Duplicated Cards

Among the analyzed cards, three were found to be duplicated, although they contained correct data and code.

    MONROE_1_74896 (MASTER)
    NEW.MILFORD_ABS_80425 (MASTER)
    NEW.MILFORD_ABS_82406 (DUPLICATE)

    This was identified from the status codes and events recorded on the cards. For New Milford we have received both the master and the duplicate card, while for Monroe we received only the master card (from which a copy was made). We are not aware of any procedure which requires duplication of any cards. Thus a follow up is necessary.

4   Discussion and Recommendations

Having performed and completed the audit, we believe that memory card audits are crucial in providing valuable and timely information necessary to ensure the integrity of our electoral system. This section contains the conclusions we draw from the post-election audit process, and some recommendations on safe-use procedures.

1. Some cards used in the election were found to be in Results Print Aborted state. Memory cards should not be in that state. Still this is not a dangerous condition, since if those cards were used in the election and all other procedures were followed, the results should have been printed and signed by the election officials. This suggests that either the results were printed until the signature space started appearing and then the machines were reset, or perhaps a duplicate results were printed unintentionally, and then the machine was shut off. This suggests that some procedures were not communicated clearly enough to poll workers.

2. Some cards that were not used in the election had non-zero counters and were not set for election. This indicates that test elections were done by either LHS Associates or the corresponding district. However, the cards were not set for election. According to the procedures provided by the State this should not be the case. However, this situation is not potentially dangerous because once the cards are set for election all the counters would be automatically nullified and the zero total report printed. In any case, this indicates that pre-election procedures were not followed. All cards not used in the election should be in "Set For Election" status with zero counters.

3. Larger then acceptable number of cards contained what we describe as "junk" data. By saying that the card is "junk" we understand that the card was not programmed correctly. When one puts the card containing the "junk" data into the AV-OS terminal it issues a prompt requesting to format the card. We do not believe these cards were damaged in shipping. Consequently, it appears that these cards were not adequately tested by LHS Associates. Among the audited cards 4.8% of the cards contained junk data. This percentage is high and this issue has to be resolved in the future.

4. Among the cards examined we found 3 duplicated cards. We are not aware of any procedure that requires duplication of any cards. It is important to understand what caused the cards

to be duplicated. Our recommendation is that all card duplication events must be logged and brought to the attention of the SOTS Office. There should be no undocumented duplication of the cards.

5. No detected ballot data or bytecode corruption.

   During the data analysis we have not detected any corruption of the ballot data or the bytecode. The ballot layout of the audit cards were identical to the ballot layout of the corresponding baseline data.

6. Improving and making more explicit instructions for the districts.

   We found the memory cards to be in a variety of different states, with large percentages of cards not being in the expected states. It may be the case that the instructions to poll workers were unclear, or that the poll workers were unable to follow the instructions. If so, we recommend holding training sessions explaining to poll workers exactly what needs to be done to prevent this situation in the future.

   We have to note here, that the percentage of cards that appear in a state different than the expected one, has been significantly reduced in comparison with the prior audits. This is a positive development and is most welcome.

References

[1] Pre-election Memory Cards Audit Report, UConn VoTeR Center, January 2008. http://voter.engr.uconn.edu/voter/Reports_files/audit07mc.pdf

[2] Security Assessment of the Optical Scan Voting Technology from LHS Associates, UConn VoTeR Center, June 8, 2007. http://voter.engr.uconn.edu/voter/Report-OS.html

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