



Partial Post-Election Audit of Memory Cards for the November 2007 Connecticut Elections

Version 1.0, January 27, 2008

Summary

The UConn VoTeR Center performed a partial post-election audit of the memory cards for the Accu-Vote Optical Scan tabulators that were to be used in the November 2007 Connecticut Elections. The cards were programmed by LHS Associates of Methuen, Massachusetts, and shipped to the towns in Connecticut. The research and development required to perform the audit and the methodology and procedures used to conduct the audit are essentially identical to what was used to perform the pre-election memory card audit, and we refer the reader to our earlier report to avoid a complete restatement¹.

In this partial memory cards audit, the total of 100 cards were received and tested by the VoTeR Center. This represents the total number of cards made available (the cards were not selected randomly), and covers over 5% of the cards actually used in the election. Among these, 8% of the cards (8 cards) contained “junk data”, that is, they were unreadable, which is easily detected by the tabulators, and such cards could not have been used in the election. One card (1.1%) was not programmed for elections. Among the usable cards, about 40% of the cards (36 cards) were used in the election according to the card status. About 47% of the cards were set for election, but not used in the election (these are most likely the cards from the second machine in each district and the “back up” cards). One card was found in the state set for election but with non-zero counters, indicating that the district tested the card in election mode and did not reset the card. This is a detectable situation, since proper procedures require that the “zero counter” report is produced at the start of the election. All of the above (usable) 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 audit was performed on request of the Office of the Secretary of the State.

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

1 Preface

The Voting Technology Research (VoTeR) Center at the University of Connecticut conducted pre-election audit and partial post-election audit of the memory cards to be used in the AccuVote Optical Scan (AV-OS) tabulators in the municipal elections of November 2007. The audits were performed on request of the Office of the Secretary of the State of Connecticut.

The memory cards were originally programmed for the November 2007 election by LHS Associates of Methuen, Massachusetts, and provided by LHS to the districts in Connecticut. The pre-election audit was performed on the randomly selected memory cards (one out of four) that were selected and shipped by the individual districts to the VoTeR Center at the University of Connecticut in Storrs.

The results of the pre-election audit are documented in the report “Pre-Election Audit of Memory Cards for the November 2007 Connecticut Elections,” UConn VoTeR Center, Version 1.0, January 24, 2008, and it is available online at <http://voter.engr.uconn.edu/voter/Reports.html>.

Once the feasibility of performing a memory card audit was established during the pre-election audit, it was opportune to take advantage of the availability of the memory cards that were actually used in the election, and to test them for integrity and consistency. This partial post-election audit served two purposes: (1) to examine the available memory cards that actually were used in the November 2007 election; and (2) to use the experience gained in the audit to formulate recommendations about how to conduct such audits in conjunction with the future elections.

This document contains the results of the post-election audit of memory cards, discussion, and recommendations. This post-election audit was partial. For the audit, with the assistance of the Office of the Secretary of the State, we were able to obtain 100 cards from various districts. However the available set of cards does not represent a randomly drawn sample.

The memory cards in both pre-election audit and post-election audit were subject to several integrity tests and our pre-election audit report mentioned above presents a comprehensive overview of these procedures taken by the VoTeR Center personnel in conducting the audit. We do not repeat here the description of the engineering that was performed to enable the audit and the technical setup used in the tests.

Finally we note that in the performance of the audit we had no access to, and we did not use any vendor/manufacture documentation regarding the specification, design and the internals of the Accu-Vote Optical Scan terminal or the memory cards.

2 Brief Description of the AV-OS System

We start by overviewing the AV-OS based election system used in Connecticut. 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 system 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.

The GEMS system can be used for centralized tabulation of the election results. However, in Connecticut the results are reported at the precincts, and the overall tabulation does not involve GEMS, thus it is eliminated as a source of uncertainty in the tabulation.

- 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 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, ballot layout, and bytecode corresponding to the precincts of the State of Connecticut for use during elections.

3 Overview of the Post-Election Memory Card Audit

VoTeR Center was asked by the CT SOTS Office to perform a partial audit of the memory cards used in the November 2007 election. The primary goal of the 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 precinct. (The district then shipped one of the cards chosen randomly to VoTeR Center for the pre-election audit; see our earlier audit report.) Among the remaining three cards, two were secured in AV-OS systems for election. Normally one of these two systems is used in the election, while the second is used as a backup.

After the election, a selection of the cards is made available to the VoTeR Center. The contents of the cards are 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.

4 Results of the Post-Election Memory Card Data Audit

We now present the results of the post-election audit. We have received and examined 100 memory cards from several districts. Most of the cards used in the election were shipped to LHS for reprogramming, and the VoTeR Center received the remaining cards that were still in the possession of the districts. Thus these cards do not represent a random sample of the cards used in the election. However examining these 100 cards allowed us to collect meaningful data that we present here. The audit covered more than 5% of all cards actually used in the election.

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

Recall that each district received 4 memory cards. Most of the districts sent one of the cards to the VoTeR Center for pre-election audit, leaving 3 cards in the possession of each district. Among these, it is expected that one card was used in the election. Thus about 33.3% of the cards should

	Number of Cards	% Total Cards
(a) Card Format (all cards)		
Good Data, Clean Card	92	92.0%
Good Data, Some "Specks"	0	0.0%
Junk Data	8	8.0%
Total:	100	100%
(b) Card Status (well-formatted cards)		
Not Programmed (Blank)	1	1.1%
Not Set for Election	11	12.0%
Set for Election	44	47.8%
Results Print Aborted	4	4.3%
Election Closed	32	34.8%
Results Sent/Uploaded	0	0.0%
Audit Report Printed	0	0.0%
Totals:	92	100%
(c) Counter Status (usable cards)		
Not Set for Election, Non Zero Counters	11	12.1%
Set for Election, Zero Counters	43	47.3%
Set for Election, Non Zero Counters	1	1.1%
Election Closed, Non Zero Counters	32	35.2%
Print Aborted, Non Zero Counters	4	4.4%
Totals:	91	100%
Total number of cards used in the election:	36	39.6%

Table 1: Memory card analysis summary: (a) card format for all cards, (b) card status for well-formatted cards, (c) counter status for usable cards.

have been used in the election. Among the post-election cards we examined, 36% of the cards (36 cards) were used, which is close to what was anticipated. (Some of the audited cards turned out to be unusable, so among the usable cards 39.6% were used.)

We present the rest of the results in three parts:

- (a) **Card Format:** Among the 100 cards, 92% of the cards were properly formatted and were found to contain consistent data (these cards contained no “specks”, that is a few isolated bytes with unexpected values, as were found during the pre-election testing). The remaining 8% of cards (8 cards) contained “junk” data, that is the card format is unrecognizable and appears to contain random noise. Such cards are not readable by AV-OS and they are readily detected through pre-election testing by poll workers.

In the rest of the analysis the percentages are computed for the 92% of the cards that were properly formatted, 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 blank (not programmed), loaded with an election, set for election, running an election, or closed election, and others.

One blank/unprogrammed but properly formatted card was found. This means, most probably, that LHS did not program the card, and they shipped it without testing.

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

Of the usable cards, 12% were not set for election. These cards were not used in the election, but they should have been set for election, suggesting that some pre-election protocols were not completely followed.

The plurality of the cards, over 47% were Set for Election, which is the desired memory card state for cards that were not used in the election.

Almost 35% of the usable cards (32 cards) were found to be in the Election Closed state. These are the majority of the cards that were used in the election.

Another 4.3% (4 cards) were used in the election, but indicate that the printing of the results was aborted. This suggests that the machine was turned off before the complete paper tape was printed. (Perhaps poll workers waited just for the counters to be printed, then turned off the machine. Alternatively, it is possible that the printing of a duplicate tape was aborted.)

- (c) **Counter Status:** This part of the results deals with the state of the counters for the 91 cards that were found to be usable in the election.

Over 12% of the usable cards were not set for election, and had non-zero counters. Such cards indicate that they were tested by poll workers prior to the election, but not set for election. These were not used in the election.

Over 47% of the cards were set for election and had zero counters. This is the intended state of the cards that were not used in the election.

About 35% of the cards (32 cards) indicated that election was closed and had non-zero counters. These cards were used in the election.

Over 4% of the cards (4 cards) had non-zero counters and indicated that the printing of the results was aborted (see above). These cards were used in the election.

One card (1.1%) was found in the state where it was set for election with non-zero counters. The counters must be 0 for such cards. This situation is detectable upon the attempt to print of the “zero count” report on the election day.

Bytecode Analysis Result. We have decompiled the Accu-Basic bytecode that is loaded into each programmed memory card. After the analysis of the decompiled Accu-Basic bytecode we conclude that the bytecode provided by LHS Associates for the elections is safe to use. The bytecode performs the expected reporting functions.

5 Discussion and Additional Recommendations

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

1. Absence of ballot data or bytecode corruption.

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

2. Election closed, but the print of results aborted.

This means that the cards were used in the election, they show non-zero counters, but the printing of the election results was aborted. Either there was a malfunction, or the poll workers turned off the machine before it finished all printing (probably as soon as the results were printed they turned the machines off). It is important to ensure in the future that all reports are properly and completely printed following an election before the machines are shut down.

3. One card was set for election with non-zero counters.

Among all the cards that were subject to the post-election audit process, one card was found to contain non-zero counters and be set for election. This card was not used in the election according to its status. This situation can be easily identified by a careful poll worker as the required zero report would not be printed in this case. Note that printing a zero total report prior the start of election is a requirement which cannot be ignored.

4. Several had non-zero counters and were not set for election.

These cards were not used in the election. Several cards had non-zero counters, which 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. We note that leaving non-zero counters after pre-election testing does not conform to the procedures that poll workers should follow. All the cards should be in “election mode” and there should not be any non-zero counters.

5. One card was not programmed at all.

This means, most probably, that LHS did not program the card, and they shipped it without testing.

6. There were a number of cards with “junk data”

By saying that the card contains “junk data” we understand that the card was not programmed correctly. When you put 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 never tested by LHS Associates. We recommend that all the programmed cards undergo the same testing procedures without any differentiation between backup and main memory cards. Among the audited cards we detected 8% of the cards containing junk data. This percentage is very big and this issue has to be resolved in the future. Specifically, quality control at LHS needs to be more effective. This should eliminate most if not all “junk data” cards and ensure that the cards are programmed prior to shipping them.

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

Among the cards not used in the election, in both audits we found the memory cards to be in a variety of different states, with large percentages of cards not being in the prescribed 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.

[End]

About the UConn VoTeR Center

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

The work of the 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.

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