Determining the Causes of AccuVote Optical Scan Voting Terminal Memory Card Failures

Tigran Antonyan, Nicolas Nicolaou,

Alexander A. Shvartsman, Thérèse Smith

Center for Voting Technology Research (VoTeR)
University of Connecticut

http://voter.engr.uconn.edu

Presented by Tigran Antonyan

Work funded by the Connecticut Secretary of the State Office

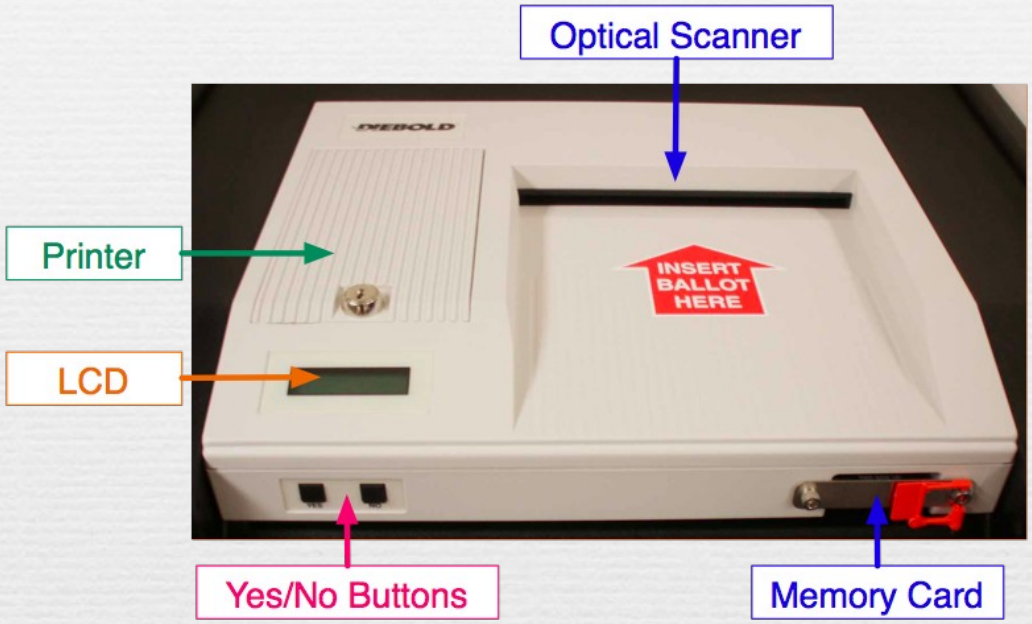
Optical Scan Voting Systems

- Play increasing role in the US elections
- Over 40 states deploy Optical Scan systems
  - 55% of all counties in 2008 elections
- AccuVote Optical Scan tabulators
  - ES&S (formerly Premier, formerly Diebold)
  - Over 20% of all optical scan systems
  - Use removable media (cards) that store election-specific programming & counters
  - Reports indicate that up to 15% of cards are failing during preparation and elections

The Consequences of Card Failures

- Memory card failures typically result in complete loss of data stored on the cards
- Such failures can occur
  - Before or during an election:
    - Delays and interruptions (have backup, best case)
    - Impossible to tabulate ballots (worst case)
  - After an election:
    - Complete loss of electronic election results
    - Impossible to perform central aggregation of election results using Election Management System (EMS)
    - Impossible to audit – results and audit logs are lost

AccuVote Optical Scan (AV-OS) Terminal



- As is typical with electronic voting systems, AV-OS uses a removable memory medium (card)
  - Provides election-specific programming to the tabulator,
  - Stores results,
  - Used to convey election results to EMS for aggregation.

AV-OS Memory Card

- Specifications
  - Seiko-Epson style 40-pin card
  - 128KB (as used in CT)
  - Hynix RAM (volatile -- at 2V guaranteed to retain data)
  - Powered by CR2016 3V Battery
- Symptoms of memory card failure
  - Arbitrary content, near random sequence of bytes
  - AV-OS recognizes failed cards as invalid (i.e., not containing valid data)

Observed Card Failure Rates in CT

Audit Type	Election Name	% Failed Cards
Post-election	November 2009 election	12%
Pre-election	November 2009 election	9%
Post-election	November 2008 election	8.9%
Pre-election	November 2008 election	8.9%
Post-election	August 2008 primary	15.4%
Pre-election	August 2008 primary	5.4%
Post-election	February 2008 primary	4.8%
Post-election	November 2007 election	8%
Pre-election	November 2007 election	3.4%

Main Suspects

- Battery that powers the memory card
  - Depletion can lead to data loss
- Physical condition of the memory card
  - Loose connections can lead to data loss
- AV-OS low battery warning system
  - Inadequate warning time can lead to depleted batteries during electoral process
- Hardware failure of the memory card
  - Defective memory card components

Our Work

- Experimental observation of AV-OS memory card failures
  - Timed tests on known failed memory cards
    - With original batteries
    - With new batteries (where failures were observed)
  - Contrasted the results with a control set
  - Strong evidence that depleted batteries cause memory card failures
- Analytical determination of the causes of failures
  - Analysis of AV-OS memory card design
  - Analysis of AV-OS low-battery warning function
  - Calculation of the time interval between the low-battery indication and data loss due to battery discharge
- Recommendations

Experimental Setting

- Each memory card involved in the study was subjected to a timed test
  - At least four weeks long (or until card failure)
- Experimental procedure
  - Programming and initial testing
    - Program the card with valid election data
    - Series of “cold” and “hot” tests
  - Repeated validation of card data
    - Extract card contents
    - Compare card contents with valid data

Test Details

Three dependent tests (+ control test)

- **Test 1**
  Timed experiment performed on the 55 cards that failed during November 2008 electoral process
- **Test 2**
  Timed experiment performed on 20 cards that lost their data within 2 days into Test 1
- **Test 3**
  Timed experiment performed on 17 cards that lost their data within 2 days into Test 2, but this time using fresh batteries
- Control test with 50 cards that were not known to fail

Test Details: Results

	Total Cards	Failed	Passed	Duration
Test 1:	55 (100%)	34 (62%)	21 (38%)	38
Test 2:	20 (100%)	18 (90%)	2 (10%)	31
Test 3:	17 (100%)	4 (24%)	13 (76%)	29
Control:	50 (100%)	0 (0%)	50 (100%)	31

- **Test 2**: worst performing 20 cards from Test 1. 18 cards failed, with 17 cards losing their data within the first 2 days.
- **Test 3**: worst performing 17 cards from Test 2, *new batteries*.
  - 13 cards, or 76%, were "cured" by the new batteries
  - 4 failed cards had hardware problems or showed signs of physical damage.

Other Failure Causes

There were 4 cards that failed with new batteries

- 2 cards had internal problems
  - 1 card appeared to have an internal short
  - 1 card failed for unknown reasons (other problems?)
- 2 cards were found to be physically damaged

Summary of Experimental Observations

- Strong evidence that the causes of data loss are:
  - Depleted or improperly seated batteries
  - Physical damage and wear of the cards
- Additional observations
  - Renewing batteries makes the cards more reliable (unless they are damaged)
  - Low battery indicator symbol was displayed only intermittently for cards that lost data
- Although the experiments involved a modest number of cards, it motivates taking a deeper look into AV-OS low-battery warning function, since it does not appear to be a reliable predictor of card data longevity

Analysis of the Causes

- Motivated by the experimental observations, we analyze:
  - Memory card design
  - Battery characteristics & the depletion curve
  - AV-OS low-battery function
- Consider normal election timeline
- For the AV-OS system, estimate:
  - Service lifetime for typical batteries
  - Time from low-battery warning to battery depletion (end of useful service life)

Memory Card, Briefly

- Seiko-Epson style 40-pin card that includes:
  - **Hynix HY628100B RAM (volatile)**
    - 128KB model requires about 10 µA standby current
    - 2V is sufficient to maintain data
  - **DS1312 chip controls power to RAM**
    - Two voltage inputs:
      - VCCI, 5V when inserted into powered AV-OS
      - VBAT, when running on battery only
    - Provides continuous power to the memory
    - Battery must be at 2.2V or higher to deliver 2V to RAM
    - Signals low-voltage when voltage falls below factory set threshold of 2.5V – 2.7V
      (routed to pin 2 of the memory card)

AV-OS Warning Function Implementation

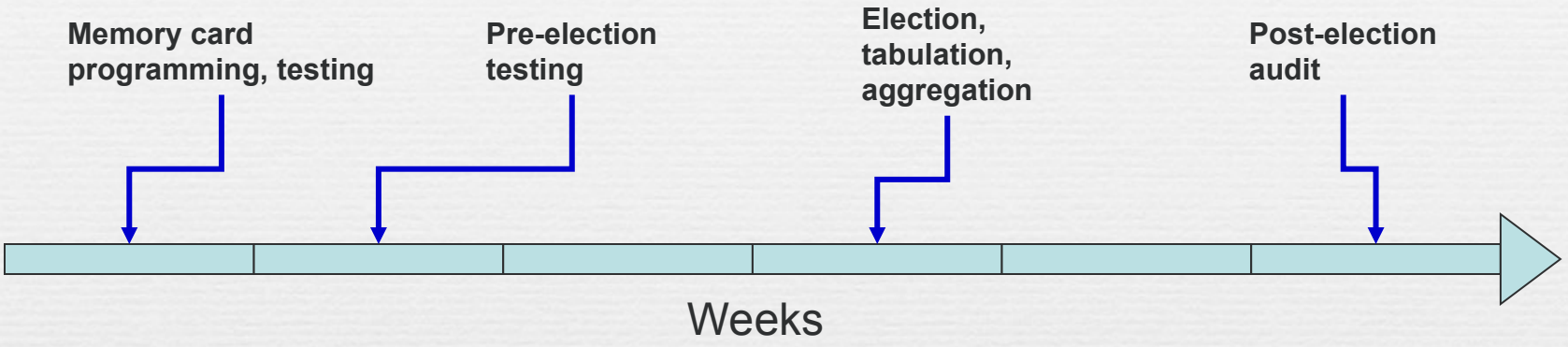
- Memory card
  - When 5V power is available, DS1312 chip periodically compares battery voltage to a pre-set threshold (in the range 2.5V – 2.7V; for Dallas Semiconductor DS1312 this is 2.5V)
  - DS1312 sets an output (routed to pin 2 on the card):
    - High, when battery voltage is above the threshold
    - Low, when battery voltage is below threshold
- AV-OS terminal
  - Pin 2 signal of the card is delivered to a comparator
  - AV-OS software displays low-battery warning when the signal on pin 2 is low

Battery Discharge Characteristics

- Typical CR2016 battery
  - Estimation based on a manufacturer's data, adjusted by scaling to 300 KΩ load at 10 μA

  - Design maximizes the period of time at higher voltage after which voltage declines sharply

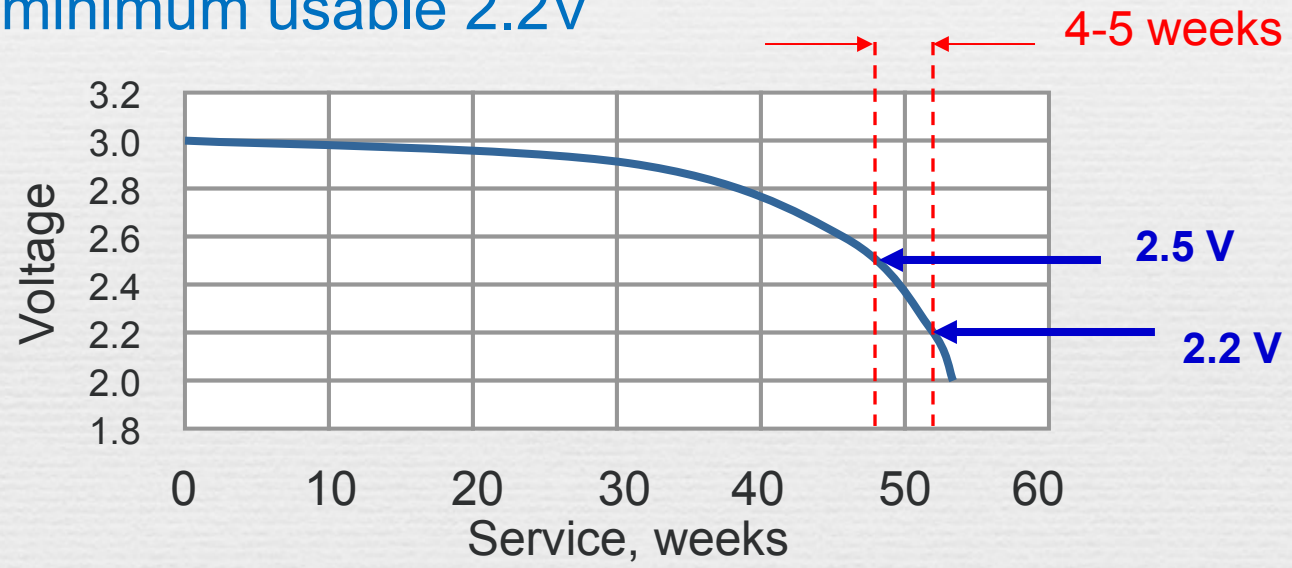
Timeline of an Election



- The latest time when battery is changed is prior to programming if low-battery warning is issued by AV-OS
- Cards are programmed at least 3 weeks prior to the election day
- Cards are tested and locked into the tabulators at least 2 weeks prior to the election day
- After the elections are closed, cards need to remain locked in the tabulator for at least 2 weeks
- Minimum of 6 weeks warning time is required

AV-OS Low-Battery Warning

- Consider again the example battery depletion curve
  - Measure the duration from the instant when voltage drops below 2.5V to the instant when voltage reaches minimum usable 2.2V



  - This is about 4-5 weeks (your mileage *may* vary depending on the battery vendor; could be less!)
- Too close for comfort!

Your Mileage *Will* Vary!

- CR2016 spec (IEC) batteries
  - Not all brands of batteries are equal
  - Not all batteries from the same vendor follow the same smooth discharge pattern
- Experiments with three different vendor batteries
  - Time interval from 2.5V to 2.2V:
    - Vendors A, B, C: < 1 week
  - Time interval from 2.7V to 2.2V:
    - Vendor A: at most 2.5 weeks
    - Vendor B: at most 2 weeks
    - Vendor C: at most 4 weeks

General Implications

- Given the discharge pattern of batteries it is difficult to qualitatively improve the observed landscape
  - The steep drop in voltage towards the end of battery service life allows only a modest warning interval based on voltage
  - Increasing the voltage threshold to lengthen the warning interval will invariably lead to numerous false warnings
- Similar observations are likely to apply to electronic voting systems that use battery backed RAM, e.g.,
  - ES&S Model 100 (OS)
  - AVC Advantage (DRE)

Lessons

- Absence of low-voltage warning is not a guarantee that data will be retained for long
  - When using removable media with battery-backed RAM, scheduled renewing of batteries is recommended
- When choosing replacement batteries
  - Consider vendor battery specification
  - Consider removable media/memory card current load and minimum required voltage
  - Evaluate low-battery warning function implementation (if any)
  - Assess warning interval in the context of the duration of the electoral process
- In jurisdictions that require digital data to be retained for a long time (cf. 22 months), consider backing-up all removable media

Conclusions

- Primary cause of data loss in AV-OS memory cards is battery depletion
- Memory cards can fail (lose data) even if the AV-OS does not issue a low-battery warning
- Memory cards with older batteries may retain data only for a few weeks or even days following successful programming
- Any jurisdiction that encounters memory card failures when using battery-powered cards should develop mitigating procedures (e.g., implement scheduled renewal of batteries, audits, backups)
- Election officials should inspect the cards for physical wear and damage, focusing on loose or damaged enclosures
- Longer term migration to non-volatile media should be considered

Thank You.

Questions?