A Statistical Method For Auditing Vote-Counting:

Whereby Counting a Relatively Small Number of Ballots Can Yield a High Degree of Statistical Confidence

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How to effectively audit ballot interpretation machines

Paul Walmsley, Margit Johansson / April 8, 2005

1. Boulder County relies on computerized ballot interpretation machines to determine elector intent.
2. We use these machines under the assumption that they determine voter intent with roughly the same results that human election judges would.
3. But this assumption is never effectively tested.
4. Existing logic and accuracy tests are statistically insufficient to assess the accuracy of these devices.
5. Furthermore, the LATs are done on test ballots – not live ballots. The accuracy of the count of live election ballots is not effectively tested at all.
6. To test these machines, we need to hand-count a portion of the live ballots and compare that information to what the ballot interpreting machines produce.
7. Unfortunately, most existing audit plans count a large number of ballots, but still result in a low degree of statistical significance – because they are comparing their totals to machine totals.
8. We can fix those problems by applying a unique serial number to each ballot, and by requiring that the ballot interpretation machines generate a "Ballot Interpretation Report." This report shows the machine's interpretation of each vote on each ballot, listed by ballot serial number.
9. Under these conditions, in a county with 150,000 or more voters, a hand-count team would only need to review 921 randomly-selected ballots – less than 1% - to guarantee that the machines are interpreting at least 99.5% of the ballots correctly in 99 out of

100 elections.

10. This method protects against software and hardware errors and fraud in the ballot interpretation device – without relying on source code inspection or other techniques.

11. The ballot interpretation reports can then be used to audit the vote tabulation process by loading the reports into standard spreadsheet software and summing the columns.

12. Any difference from the results from the vote tabulation machine or process would demonstrate a problem in the tabulation process.

13. The plan is based on a well-known, peer-reviewed acceptance sampling plan written by a fellow of the American Statistical Association and the American Society for Quality Control.

14. The serial numbers can be applied when the ballots are printed, or preferably, immediately before the ballots are scanned. The latter approach helps protect voter anonymity.

15. This plan is only possible if the vote interpretation process is auditable. DREs without VVPATs, for example, are not auditable. This system would not work for those devices. This method does work for elections using optical scan systems (including opscan systems using ballot marking devices like the Vogue Automark) and also DREs with VVPATs. Fortunately, this component of Boulder County's voting system is auditable.

16. This plan is a powerful and efficient way to assess a potentially significant source of election error and fraud. But there are many other aspects of an election which require auditing and careful security, including the ballot printing process and the absentee balloting process. Therefore, although this plan is a necessary part of election security, its use alone is not sufficient to guarantee election accuracy.

Example Ballot Interpretation Report

August 2, 2004 Test Election

	Race 1				Race 2			
Ballot Seq #	Bush	Kerry	Overvote	Undervote	Coors	Salazar	Overvote	Undervote
1004	1	0	0	0	1	0	0	0
1005	0	1	0	0	0	1	0	0
1006	0	0	0	1	0	0	1	0
1007	1	0	0	0	0	1	0	0
...								

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- Define "Live Ballot"

    - The canonical legal record of one or more votes in one or more races entered by an eligible elector during an election. Contrast with "test ballot" (used for testing purposes only).

Define "Interpret (a ballot)"

    - In voting system equipment context, "Process of converting paper ballot images into cast vote records." In human context, "Process of creating a cast vote record by examining marks on a ballot."

Define "Live Auditing"

    - "Live auditing" is the process of independent testing of voting system functional units during an election, via methods that do not modify, create, or destroy votes on live ballots. Contrast with "pre-election tests," "logic and accuracy tests," and "post-election tests." Similar to "parallel testing."

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Live auditing techniques are crucial to verify voting system accuracy during the live election. The following proposed addition to the VVSG describes the use of statistical live auditing techniques to verify that paper ballots or paper audit trails match the cast vote records created by the scanning process.

6.9 Requirements for Statistical Live Auditing of Optical-Scan and VVPAT Records

When machine-scanned paper records include a unique identifier, strong auditing of the vote interpretation process is possible during the live election via well-known statistical quality control techniques. The technique described here is applicable to optical-scan ballots and voter-verified paper audit trails.

To use this audit technique, a unique identifier is imprinted on the election's paper vote records, either at record creation time or during machine scanning. (The latter approach is considered superior, as it avoids anonymity concerns.) When the records are machine-interpreted, the resulting cast vote record is electronically associated with the paper record's unique identifier. A small portion of the paper records are then randomly selected for auditing, and that subset is hand-interpreted by one or more hand-count teams, resulting in a second human-compiled set of cast vote records. The human-compiled cast vote records are compared to the machine-compiled cast vote records, and any discrepancies are investigated.

Since the individual paper records are linked to the electronic cast vote records by the unique identifier, this auditing method is very efficient. Medium-to-large counties can be 99% confident that the electronic cast vote records differ from the results of a hypothetical full hand count by less than 1%, by only hand-counting 1,000 ballots. The number of ballots to randomly select to achieve a particular confidence level can be determined by reference to [1], below.

The unique identifier may be applied when the paper record is scanned by a scanner equipped with an imprinter. The unique identifier also may be printed on the paper record when the record is initially created.

6.9.1 The paper record interpretation function should be decoupled from other voting system functions to facilitate auditing.

6.9.2 In paper ballot systems, it is desirable that the unique identifier is applied to the ballot when the ballot is scanned.

Discussion: This is intended to preserve voter anonymity, and can be implemented by use of scanners with imprinters. This will not apply to VVPAT systems.

6.9.3 The list of record unique identifiers to hand-count shall be determined in a manner that is extremely difficult to predict prior to the audit, yet which generates a repeatable and publicly verifiable list of record unique identifiers.

Discussion: This can be done by cryptographically hashing several subseeds, provided by election judges, lottery results, party observers, election officials, and other sources[2], and using the resulting number to seed a PRNG.

6.9.4 Any algorithms used to generate the list of record unique identifiers shall be FIPS-approved.

6.9.5 Any algorithms, input data, and output data used to generate the

list of record unique identifiers shall be published openly.

Discussion: This includes the pseudocode of the algorithms, source code of the algorithms, the individual subseeds, the hashed seed, the PRNG output, and the derived list of record unique identifiers to count.

6.9.6 The number of paper records to hand-interpret and any necessary process details shall be determined by a peer-reviewed statistical quality control method.

Discussion: One such procedure is the Lot-Sensitive Sampling Plan (LSP) [1].

6.9.7 The confidence intervals of the plan should be set such that it can accurately audit very close elections where the margin of victory is 1% or less.

Discussion: If LSP is used, p*, the maximum percent of ballots allowed to be inaccurately interpreted, should be 1% or less. pa, the probability that the audit would miss an inaccurately interpreted ballot, should be 1% or less.

6.9.8 The hand-count teams shall interpret the paper records and create a set of cast vote records by hand to compare with the subset of machine-generated cast vote records.

References

[1] Schilling, Edward G. _A Lot Sensitive Sampling Plan for Compliance Testing and Acceptance Inspection._ Journal of Quality Technology, Vol. 10, No. 2 (April 1978), pp. 47-51.

[2] Eastlake, D. E. _RFC 3797 - Publicly Verifiable Nominations Committee (NomCom) Random Selection._ Internet Society, June 2004.

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Walmsley, Paul. _Overview of Live Auditing Procedures for Incorporation in the Voluntary Voting System Guidelines._ September 30, 2005.

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Live auditing techniques can be used to verify the accuracy of the cast vote record tabulation process during the live election. The following proposed addition to the VVSG describes one method for doing so.

6.10 Requirements for Live Auditing of Vote Tabulation

The vote tabulation process, as defined in this section, takes as its input a set of cast vote records and possibly some election metadata, and generates as its output a set of vote totals. Some modern voting systems decouple this process from other election processes, allowing it to be independently live audited.

To live audit the tabulation process, the cast vote records used as input to the vote tabulation system are also tabulated using a second computer system (the "audit tabulation system"), using different tabulation software that is open-source and publicly distributed. Any difference between the primary tabulation system and the audit tabulation system results is an indication of error or fraud.

6.10.1 The vote tabulation function should be decoupled from other voting system functions to facilitate auditing.

6.10.2 The audit tabulation system shall use the same cast vote record format as the primary tabulation system.

6.10.3 Voting system components which store or export cast vote records (such as vote interpretation components) shall have no means of determining whether the stored cast vote records are intended for primary tabulation or audit tabulation.

6.10.4 The audit tabulation system software shall be independently written from the primary tabulation system software using a "clean room" methodology.

6.10.5 The audit tabulation system software source code shall be publicly distributed to facilitate peer review.

6.10.6 The audit tabulation system shall reside on a separate computer system than the primary tabulation system.

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Voluntary Voting System Guidelines._ September 30, 2005.

Walmsley, Paul. _Requirements for Statistical Live Auditing of

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Overview of Live Auditing Procedures for Incorporation in the Voluntary Voting System Guidelines

The proposed Voluntary Voting System Guidelines are missing guidelines for live auditing, and should include them.

"Live auditing" is the process of independent testing of voting system functional units during an election, via methods that do not modify, create, or destroy votes on live ballots. Live auditing is similar to the 'parallel testing' process described in [1] and [2]; however, modern auditable voting system designs enable live auditing to take place without having to take voting machines out of service or to otherwise affect the voting process.

Existing voting system test approaches are inadequate to verify voting system reliability. Currently, election officials perform "logic and accuracy tests" before, and in some cases after, the election. However, even if these tests are successful, they disclose nothing about the functionality of the system _during_ the election. Logic and accuracy tests also generally do not use live ballots, and are often run in a 'test' mode on the voting systems.

Some examples of live audit applications:

1. Live auditing can be used to verify the accuracy of the 'ballot scanning and interpretation' component of some optical scan systems and VVPAT scanners. With modern auditable voting systems, very high accuracy tests can be implemented with a minimum of additional work. One such technique is described in [4].

2. Live auditing can also be used to verify the accuracy of the vote tabulation component, when it is decoupled from the rest of the voting process (as it is in several current voting systems). One such technique is described in [5].

The components are tested as "black boxes." Inputs and outputs are defined, and an independent process must be able to verify to a high degree of confidence that the black boxes are producing valid outputs given particular inputs. In our first example, the inputs to the process are paper ballots or audit trail records, and the outputs are a set of cast vote records. Similarly, in the second example, the input is a set of cast vote records, and the output is the vote total across those records.

One important prerequisite for live auditing is that the voting system components must themselves be auditable to independent observers. DREs without VVPATs generally do not possess this property, as there is no independent, non-computer-corruptible record of voter intent that can be compared to the machine-stored record. The Voluntary Voting System Guidelines should discourage the development and use of voting systems which cannot be live audited.

Similarly, some voting systems are difficult to live audit

efficiently, even though they may technically be live auditable. One example would be a paper-based optical scan system without unique identifiers. Live auditing the ballot scanning and interpretation component of such a system to a reasonable degree of confidence would involve the independent interpretation of a large number of ballots, and therefore make live auditing practically infeasible for this system. The Voluntary Voting System Guidelines should discourage the use of voting systems with components that are practically infeasible to live audit.

Another requirement for live auditing is that the systems under audit must not have any means of detecting that they are under audit. The system must be auditable without putting it into any "test modes" or other modes of operation that are not used during a live election.

Live auditing is not a new concept for election administrators. Many jurisdictions use teams of election judges, composed of citizens with different party affiliations, at various points in the voting process, including ballot box unsealing and questionable vote interpretation. In these teams, each judge is live auditing the decisions of the other judges. This basic philosophy - that decisions made by one observer must be verified by at least one other independent observer - should also be used to test the voting system equipment used during an election. The Voluntary Voting System Guidelines should promote the incorporation of peer-reviewed live audit techniques in voting system design and election official best practices.

[1] Jones, Douglas W. _Testing Voting Systems._

[2] Jones, Douglas W. _Parallel Testing: a menu of options._

[3] Jones, Douglas W. _Auditing Elections._ Communications of the ACM, 47, 10 (October 2004) 46-50.

[4] Walmsley, Paul. _Requirements for Statistical Live Auditing of Optical-Scan and VVPAT Records._ September 30, 2005.

[5] Walmsley, Paul. _Requirements for Live Auditing for Vote Tabulation._
September 30, 2005.

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A random sample of the VVPAT records should be hand-interpreted and tested against the cast vote records during the election to verify the accuracy of the CVRs and the VVPAT, using live audit methodology.

6.8.6.12 A random sample of the paper records should be hand-interpreted and compared against the electronic records during the live election using the procedure outlined in proposed section 6.9 (see [1]).

References

[1] Walmsley, Paul. _Requirements for Statistical Live Auditing of Optical-Scan and VVPAT Records._ September 30, 2005.