Evidence-Based Elections
Colorado's Future?

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Election Audits: Compliance and Materiality

Compliance audit

Determine whether the audit trail is trustworthy enough to determine who won.

Materiality audit

Use the audit trail to confirm that the outcome is correct, or to correct the outcome if it is wrong.

Requires intact audit trail–need to pass compliance audit first.
Might require counting the entire audit trail by hand.

Risk-Limiting Audits
(Required by Colorado Revised Statutes 1-7-515)

Risk-limiting Audit

Large, known chance of a full hand count if the outcome is wrong, in which case the hand count corrects the outcome.

Risk is maximum chance of failing to correct an apparent outcome that is wrong, no matter what caused the outcome to be wrong.

Gives statistical assurance that voting system found the right winner(s).

RLA

- Requires an audit trail: voter-marked paper ballots or voter-verifiable paper records.
- Doesn't absolutely guarantee the electoral outcome is right, but guarantees a large chance of correcting the outcome if the outcome is wrong.
- "Intelligent" incremental recount: stops only when there is convincing evidence that a full hand count won't change the outcome.
- Until the evidence is strong, counting continues, possibly to a full hand count.
- Absent a full hand count, will not alter election outcomes: Can correct wrong outcomes, but can't harm correct outcomes.

Current Situation in Colorado

- CRS 1-7-515 is best audit law in the world, effective 2014. (Some details to flesh out—I'm happy to help.)
- Heterogeneous mix of equipment and systems, including unauditable (no paper) and obsolescent.
- Compliance with the law with no change to current systems will be expensive: need to audit at the ballot level to be efficient.
- No deployed vote-tabulation system (VTS) makes ballot-level auditing possible on its own.

Three Options for Colorado

1. Upgrade voting systems to next-next.
   (Systems currently in review for certification won't do it).
   Expensive.
   Many jurisdictions can't afford to replace current systems.
2. Scan ballots a second time and base the audit on CVRs extracted from that scan.
   Time-consuming. Have to touch ballots twice.
   Workable in small jurisdictions but hard in Jefferson or Denver.
   (However, talk to Clear Ballot Group, TrueBallot, TEVS.)
3. Replace the system of record with an alternative system that makes auditing easy.
   Colorado does not require federal certification—well situated.

VTS Certification and Risk-Limiting Audits

Question 1

In the lab, can the vote-tabulation system—as delivered from the manufacturer—count votes with a specified level of accuracy?

Question 2

As maintained, deployed, and used in the current election, did the vote-tabulation system find the true winners?

Only care about Q1 insofar as it matters for Q2.

Certification addresses Q1. Risk-limiting audits address Q2.

Claim

If elections create an accurate, durable audit trail and the vote tabulation is checked with a risk-limiting audit, there is little harm—and much benefit—from abandoning certification of vote-tabulation systems.

- Makes ballot-level auditing easy.
- Drastically reduces costs.
- Speeds development/improvement cycle.
- Can be based on COTS scanners—cheap to lease or buy.
- Can capture voter intent better, improve accuracy.
  (cf Merced, San Luis Obispo, Stanislaus, Ventura).
- Puts incentives in the right place: more accurate CVRs means less hand counting in the audit.
  LEOs gain by using the most accurate and economical system.

Single Vendor, or No Vendor?

With soon-to-be-available open-source VTS (tested in 5 elections),

- Far, far cheaper than any commercial system.
- Auditable at the ballot level, unlike current commercial systems—better for election integrity.
- Not locked into contracts, maintenance, etc.; easy upgrades: “agile.”
- Still can share expertise and equipment across counties, etc.

Bottlenecks

Biggest problem: getting ballot style information from the EMS, so VTS knows where to look for voters' marks.

Options:

- Some systems (e.g. DFM) make it easy to export ballot descriptions.
- Work with vendors as part of state certification of EMSs.
- Reverse engineer. (Icky.)
- Extract automatically from image, like TEVS or Clear Ballot.
- Do it by hand. (Not workable in big jurisdictions.)
- Provide free tools for ballot design. It's not that hard a problem.

Simplest incarnation

- Paper ballots designed by current EMSs.
- CCOS using COTS high speed scanners.
  $16k scanner can image about 3,500 ballots per hour.
- Scanner prints identifier on the ballots as they are scanned.
- Open-source software interprets images.
- Open-source software lets LEOs inspect images, resolve hard cases. (Sort on mark density, undervotes, over votes, etc.; images could be deleted after this step.)
- Post results at whatever level of geography statutes require.
- “Commit” cast vote record for each ballot.
- Compliance audit to ensure audit trail is complete.
- Risk-limiting audit at the ballot level using simple tools.

Hot-Button Issue

Perceived conflict between transparency and voter anonymity.

Who is allowed to see the ballots, and under what circumstances?

- Audit requires the LEO to “commit” to the CVRs, but does not require publishing CVRs or ballot images.
- However, easiest way to commit to the CVRs is to publish them, which also allows the public to confirm that the votes add up. Improves transparency.
- If that’s not politically feasible, there are alternatives that maintain most of the transparency and still let the public verify the sums. Harder to explain.

Evidence-Based Elections

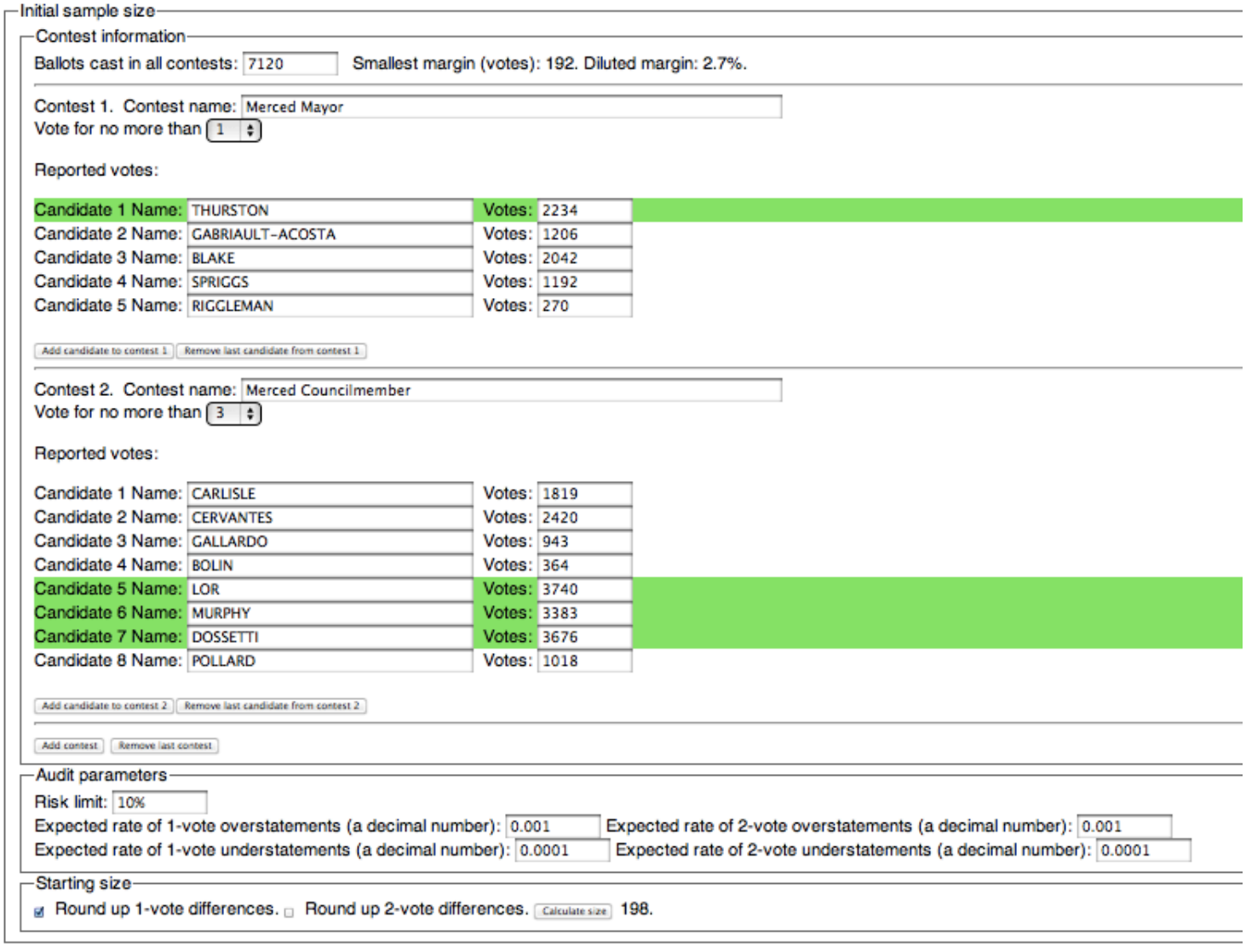
- Law should require LEOs to give convincing evidence outcomes are right.
- Certifying equipment isn't enough: How was the equipment used?
- Election should generate hard evidence, checked for integrity.
- Audit trail is key. Needs to be created, curated, and scrutinized to confirm or correct the outcome.
- "I'm good at my job" is widely true, but stuff happens. Need better evidence than "trust me."
- Why regulate equipment but not curation of the audit trail?

Friendly Tools for Risk-Limiting Audits

The rules are not hard, and the tools can be simple:

`http://statistics.berkeley.edu/~stark/Vote/auditTools.htm`

auditTools in action



Random sampling

Pseudo-Random Sample of Ballots

Seed: 12082217
Number of ballots: 7120
Current sample number: 198
Draw this many ballots: 198 draw sample reset

Ballots selected: ☑ show sequence numbers ☐ show hash values

```
sequence_number, ballot
1,2660
2,5463
3,5334
4,2208
5,3459
6,6223
7,2407
8,5245
9,1899
```

Ballots selected, sorted:

```
35,82,98,99,197,220,241,254,256,369,389,416,422,447,501,573,638,738,760,831,932,940,964,986,1006,1
027,1067,1197,1208,1234,1285,1298,1410,1446,1464,1476,1495,1509,1548,1568,1621,1647,1745,1778,1
877,1879,1899,1947,1973,2023,2061,2133,2173,2208,2241,2318,2339,2398,2400,2407,2514,2557,2654,2
660,2666,2725,2744,2760,2847,2866,2894,3119,3123,3197,3223,3227,3232,3233,3299,3366,3370,3405,3
444,3459,3585,3588,3598,3624,3629,3637,3718,3758,3774,3802,3839,3875,3906,3977,4168,4177,4223,4
243,4261,4286,4321,4357,4382,4410,4426,4427,4429,4449,4517,4528,4536,4542,4571,4668,4712,4715,4
748,4749,4755,4779,4803,4805,4812,4814,4817,4828,4899,4922,4976,4988,5073,5116,5119,5138,5194,5
210,5240,5245,5305,5334,5414,5429,5463,5523,5534,5554,5658,5681,5691,5730,5740,5787,5854,5878,5
904,5980,5998,6001,6029,6032,6032,6043,6052,6078,6113,6161,6166,6223,6233,6258,6291,6379,6421,6
428,6446,6518,6549,6567,6599,6607,6628,6644,6697,6716,6784,6818,6853,6877,6908,6972,7001,7017,7
```

Ballots selected, sorted, duplicates removed:

```
35,82,98,99,197,220,241,254,256,369,389,416,422,447,501,573,638,738,760,831,932,940,964,986,1006,1
027,1067,1197,1208,1234,1285,1298,1410,1446,1464,1476,1495,1509,1548,1568,1621,1647,1745,1778,1
877,1879,1899,1947,1973,2023,2061,2133,2173,2208,2241,2318,2339,2398,2400,2407,2514,2557,2654,2
660,2666,2725,2744,2760,2847,2866,2894,3119,3123,3197,3223,3227,3232,3233,3299,3366,3370,3405,3
444,3459,3585,3588,3598,3624,3629,3637,3718,3758,3774,3802,3839,3875,3906,3977,4168,4177,4223,4
243,4261,4286,4321,4357,4382,4410,4426,4427,4429,4449,4517,4528,4536,4542,4571,4668,4712,4715,4
748,4749,4755,4779,4803,4805,4812,4814,4817,4828,4899,4922,4976,4988,5073,5116,5119,5138,5194,5
210,5240,5245,5305,5334,5414,5429,5463,5523,5534,5554,5658,5681,5691,5730,5740,5787,5854,5878,5
904,5980,5998,6001,6029,6032,6043,6052,6078,6113,6161,6166,6223,6233,6258,6291,6379,6421,6428,6
446,6518,6549,6567,6599,6607,6628,6644,6697,6716,6784,6818,6853,6877,6908,6972,7001,7017,7024,7
```

Repeated ballots:

```
Ballot, multiplicity
6032,2
```

Finding ballots using a ballot manifest

Ballot look-up tool

Ballot manifest: (batch label, ballots) pairs separated by commas, one pair per line

```
Merced1-cvr.txt,162
Merced11-cvr.txt,284
Merced13&15-cvr.txt,423
Merced14-cvr.txt,163
Merced16-cvr.txt,257
Merced17-cvr.txt,172
Merced18-cvr.txt,237
Merced2-cvr.txt,249
Merced20&21-cvr.txt,756
Merced22&29-cvr.txt,415
Merced23&26-cvr.txt,465
Merced24&25-cvr.txt,504
Merced27&32-cvr.txt,534
Merced28-cvr.txt,484
Merced3&30-cvr.txt,257
Merced31&33-cvr.txt,312
Merced4&12-cvr.txt,394
Merced5&9&10-cvr.txt,357
Merced6&19-cvr.txt,326
Merced7&8-cvr.txt,369
```

Ballots to look up (separated by commas):

```
35,82,98,99,197,220,241,254,256,369,389,416,422,447,501,573,638,738,760,831,932,94
0,964,986,1006,1027,1067,1197,1208,1234,1285,1298,1410,1446,1464,1476,1495,1509,
1548,1568,1621,1647,1745,1778,1877,1879,1899,1947,1973,2023,2061,2133,2173,2208,
2241,2318,2339,2398,2400,2407,2514,2557,2654,2660,2666,2725,2744,2760,2847,2866,
2894,3119,3123,3197,3223,3227,3232,3233,3299,3366,3370,3405,3444,3459,3585,3588,
3598,3624,3629,3637,3718,3758,3774,3802,3839,3875,3906,3977,4168,4177,4223,4243,
4261,4286,4321,4357,4382,4410,4426,4427,4429,4449,4517,4528,4536,4542,4571,4668,
4712,4715,4748,4749,4755,4779,4803,4805,4812,4814,4817,4828,4899,4922,4976,4988,
5073,5116,5119,5138,5194,5210,5240,5245,5305,5334,5414,5429,5463,5523,5534,5554,
5658,5681,5691,5730,5740,5787,5854,5878,5904,5980,5998,6001,6029,6032,6032,6043
```

look up ballots

Sorted lookup table:

```
sorted_number, ballot, batch_label, which_ballot_in_batch
1, 35, Merced1-cvr.txt, 35
2, 82, Merced1-cvr.txt, 82
3, 98, Merced1-cvr.txt, 98
4, 99, Merced1-cvr.txt, 99
5, 197, Merced11-cvr.txt, 35
6, 220, Merced11-cvr.txt, 58
7, 241, Merced11-cvr.txt, 79
8, 254, Merced11-cvr.txt, 92
9, 256, Merced11-cvr.txt, 94
```

Should more ballots be audited?

Stopping sample size and escalation

Ballots audited so far: 198

1-vote overstatements:	0	Rate: 0
2-vote overstatements:	0	Rate: 0
1-vote understatements:	0	Rate: 0
2-vote understatements:	0	Rate: 0

Estimated stopping size

Calculate Audit complete

If no more differences are observed: 178.
If differences continue at the same rates: 178.
Estimated additional ballots if difference rates stay the same: 0.

The Future

The overall election and canvass process should correct its own errors before announcing results, or report that it can't guarantee it corrected its errors (for instance, because the audit trail can't be shown to be intact).

Resilient Canvass Framework

Known minimum chance that the overall system (human, hardware, software, procedures) gives the correct election outcome—when it gives an outcome.

- Use voting system that creates a voter-verified audit trail.
- Conduct a compliance audit to ensure that the audit trail is accurate and complete.
- If so, conduct a risk-limiting audit.
  If not, do not declare an outcome.