# Colorado's Risk-Limiting Tabulation Audits:

# Accomplishments and Proposed Improvements

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- Software developer
- Consultant
- Poll worker
- Working on election audits and integrity since 2003
- Pioneered RLAs in Colorado with my own code in 2010, Boulder County
- Served on teams that wrote the software for Colorado's current state-wide audit
- Verified Voting board member
- Co-author of LWV Colorado Election Security position, 2022
- Speaking for myself

# Introduction

Outline

- Motivation
- Highlights
- Priority improvemen

My goal: digging relatively deeply and precisely, for practitioners

Don't have time here to do overview for the public

See references at the end for more background

Always happy to talk about audits!

Thanks to Chris for overview!

As you see, there are some limitations that haven't been addressed yet in the software

# Importance, Scale of the Challenge

- Long-standing widespread, transpartisan consensus on need for both voter verified paper ballots and audits.
- Voting systems are vulnerable, simply put
- "Assume breach"! as CISA and the DoD put it

- Only robust auditing can protect us from cyber threats

- How can we give elected officials the tools to protect our elections?

- How can we provide convincing evidence to the public?

- Need "Evidence-Based Elections": audits to cover all the contests (+ more aspects of election)

- Only ballot-level audits will do that (given long ballots in our US coordinated elections)

# Robust auditing is much harder than it seems

- Elections are increasingly complicated
- You can't easily audit the data you've got
- You can't easily get the data you need
- Ballot anonymity must be maintained (but ballots aren't "secret")
- Legal and practical hurdles, e.g. transparency
- Political hurdles
- COVID....

# Auditability around the country

- Huge steps forward in auditability since 2006
- Many states with 100% voter-verifiable paper ballots (VVPB)
- Many others are all-VVPB except for overseas or print-disabled voters
- Beware risky places where voters are required to rely on machine marking (BMDs), or unauditable return of voted ballots over the Internet

# Audits around the country

- Many states doing some audits or learning about them
- Many pilots, gaining experience

- Typically only focus on top-of-the-ticket races

- No coverage of vast majority of the contests

  - Mistaken notion of auditing the whole "election" that way
    - An audit of one contest does NOT limit risk for other contests
  - Local bond issues or powerful local offices are often the most compelling target

- Needs more focus on transparency, robustness

- Very few which publicize data to be audited before a public random selection

# Colorado: best tabulation audits in the country?

- Risk-limiting: designed to focus more on close contests, save resources on landslides
- ColoradoRLA software: open-source by Free & Fair in 2017; Democracy Works in 2018
  - Now maintained by the state, still open-source!
- Designed and implemented with many nationally recognized expert participants
- Ballot-level comparison audit: the most efficient
- Actually matches each paper ballot with corresponding Cast-Vote Record (CVR)
  - Only easy when all ballots are scanned centrally, not with voter-facing scanners

- Auditors interpret and report votes for ALL contests

  - Not as much data for small contests which weren't selected for auditing

- Goal of verifiably public random selection across all ballots per contest

# Colorado Election Officials

I'm honored to have gotten to collaborate with

- Many forward-looking county clerks past and present, collaborating regardless of party

- The Department of State, past and present, also driving innovation

They work under tremendous pressure, on strict deadlines, with a seasonal labor force and tight budgets doing work that is critical for democracy

Thank you!

# Risk limits

Thanks to Chris Beall for explaining many of the details in his presentation

Note that the risk limit is statistically "conservative"

For a 3% risk limit, at least 97 times out of 100 any tabulation error would be uncovered

The statistics assume a near-tie. If the actual margin was greater than 1 vote, more ballots would have had to have been incorrectly interpreted for the outcome to be incorrect,

and the chance of uncovering any tabulation error would be even greater

# Summarize Audit of 2022 Coordinated election in Colorado

- Three rounds over several days
- Most counties done in one day in Round 1
- Risk limit: 3% for selected contests
- > 2,508,830 ballots cast statewide (undervotes make exact number hard to find)
- 3,526,411 ballot cards in the state (multiple cards per ballot in some counties)
- 6,454 ballot cards selected (based on margin, 0.2% overall)
- 233,223 votes compared! (36 per card on average)
- 186 discrepancies - 0.08%, apparently mostly wrong ballot or entry error
- Audit data for 981 contests
- RLAs of 68 contests (some partial and thus artificial...)
- Many more opportunistic contest audits, below risk limit
  - Opportunistic sampling across counties is not uniformly random, so very tricky to calculate rigorous risk levels for those

| County | Contest | Vote For | Lowest Winner | Highest Loser | Contest Margin | Diluted Margin | Risk Limit | Estimated # of CVRs to audit | # of CVR | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| Colorado | United States Senator | 1 | 1,030,331 | 798,921 | 231,410 | 9.34% | 3% | 78 | 1,905,052 | Audited in all 63 counties |
| Colorado | Governor/Lieutenant Governor | 1 | 1,085,082 | 759,989 | 325,093 | 13.13% | 3% | 56 | 1,905,052 | Audited in all 63 counties |
| Colorado | Secretary of State | 1 | 1,011,329 | 810,362 | 200,967 | 8.11% | 3% | 90 | 1,905,052 | Audited in all 63 counties |
| Colorado | State Treasurer | 1 | 973,136 | 812,686 | 160,450 | 6.48% | 3% | 112 | 1,905,052 | Audited in all 63 counties |
| Colorado | Attorney General | 1 | 996,172 | 822,173 | 173,999 | 7.03% | 3% | 104 | 1,905,052 | Audited in all 63 counties |
| Colorado | State Board of Education Member - At Large | 1 | 952,164 | 811,758 | 140,406 | 5.67% | 3% | 129 | 1,905,052 | Audited in all 63 counties |
| Adams | Adams County Sheriff | 1 | 64,428 | 57,013 | 7,415 | 2.94% | 3% | 248 | 126,233 | |
| Alamosa | District Attorney - 12th Judicial District | 1 | 3,492 | 2,172 | 1,320 | 22.20% | 3% | 33 | 5,946 | Single county audit |
| Arapahoe | Arapahoe County Commissioner - District 2 | 1 | 21,917 | 17,225 | 4,692 | 2.77% | 3% | 263 | 40,889 | |
| Archuleta | Archuleta County Commissioner - District 3 | 1 | 4,494 | 2,720 | 1,774 | 22.63% | 3% | 32 | 7,839 | |
| Baca | Baca County Commissioner - District 2 | 1 | 1,144 | 569 | 575 | 16.26% | 3% | 45 | 1,768 | |
| Bent | Bent County Sheriff | 1 | 800 | 402 | 398 | 27.93% | 3% | 26 | 1,425 | |
| Boulder | City of Boulder Ballot Question 2C | 1 | 16,196 | 8,324 | 7,872 | 3.75% | 3% | 194 | 30,460 | |
| Broomfield | Boulder Valley School District RE-2 Ballot Issue 5A | 1 | 8,378 | 5,039 | 3,339 | 8.92% | 3% | 82 | 15,091 | Single county audit |
| Chaffee | Chaffee County Commissioner - District 3 | 1 | 5,592 | 3,853 | 1,739 | 14.82% | 3% | 49 | 11,731 | |
| Cheyenne | Amendment D (CONSTITUTIONAL) | 1 | 487 | 332 | 155 | 17.26% | 3% | 42 | 898 | Single county audit |
| Clear Creek | Clear Creek County Commissioner - District 1 | 1 | 2,726 | 1,654 | 1,072 | 23.05% | 3% | 32 | 4,650 | |
| Conejos | Conejos County Sheriff | 1 | 2,169 | 1,210 | 959 | 27.76% | 3% | 26 | 3,454 | |
| Costilla | Costilla County Ballot Issue 1A | 1 | 853 | 663 | 190 | 11.09% | 3% | 66 | 1,714 | |
| Crowley | Proposition FF (STATUTORY) | 1 | 756 | 562 | 194 | 14.08% | 3% | 52 | 1,378 | Single county audit |
| Custer | Custer County School District C-1 Ballot Question 4A | 1 | 1,650 | 1,060 | 590 | 17.61% | 3% | 41 | 3,350 | |
| Delta | Amendment D (CONSTITUTIONAL) | 1 | 7,745 | 6,327 | 1,418 | 8.89% | 3% | 82 | 15,948 | Single county audit |
| Denver | City and County of Denver Initiated Ordinance 305 | 1 | 72,599 | 48,322 | 24,277 | 6.39% | 3% | 114 | 126,682 | |
| Dolores | Dolores County Ballot Issue 1B | 1 | 784 | 460 | 324 | 24.94% | 3% | 29 | 1,299 | |
| Douglas | State Senator - District 30 | 1 | 44,260 | 38,645 | 5,615 | 3.04% | 3% | 239 | 88,076 | |
| Eagle | Eagle County Ballot Issue 1A | 1 | 7,018 | 4,766 | 2,252 | 10.22% | 3% | 71 | 20,965 | |
| El Paso | City of Colorado Springs Ballot Issue 301 | 1 | 71,678 | 64,470 | 7,208 | 3.37% | 3% | 216 | 150,185 | |
| Elbert | Proposition 125 (STATUTORY) | 1 | 3,533 | 3,209 | 324 | 4.66% | 3% | 156 | 6,950 | Single county audit |
| Fremont | Proposition FF (STATUTORY) | 1 | 10,175 | 8,935 | 1,240 | 6.29% | 3% | 116 | 19,707 | Single county audit |
| Garfield | Garfield County Clerk and Recorder | 1 | 10,818 | 10,135 | 683 | 3.12% | 3% | 234 | 21,900 | |
| Gilpin | Gilpin County Assessor | 1 | 1,853 | 1,440 | 413 | 12.14% | 3% | 60 | 3,401 | |
| Grand | Grand County Commissioner - District 3 | 1 | 3,983 | 3,456 | 527 | 6.83% | 3% | 107 | 7,715 | |
| Gunnison | Proposition 125 (STATUTORY) | 1 | 4,844 | 3,859 | 985 | 10.68% | 3% | 68 | 9,221 | Single county audit |
| Hinsdale | Amendment D (CONSTITUTIONAL) | 1 | 249 | 172 | 77 | 14.75% | 3% | 49 | 522 | Single county audit |

| Contest Margin | Diluted Margin | Risk Limit | Estimated # of CVRs to audit | # of CVR | Remarks |
|---|---|---|---|---|---|
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| 7,415 | 2.94% | 3% | 248 | 126,233 | |
| 1,320 | 22.20% | 3% | 33 | 5,946 | Single county audit |
| 4,692 | 2.77% | 3% | 263 | 40,889 | |
| 1,774 | 22.63% | 3% | 32 | 7,839 | |
| 575 | 16.26% | 3% | 45 | 1,768 | |
| 398 | 27.93% | 3% | 26 | 1,425 | |
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| 194 | 14.08% | 3% | 52 | 1,378 | Single county audit |
| 590 | 17.61% | 3% | 41 | 3,350 | |

Public data from Audit Center

CVR to audit board interpretation comparison (CSV)

| | county_ | contest_name | imprinted_id | choice_per_voting_computer | audit_board_selection | timestamp |
|---|---|---|---|---|---|---|
| 2 | Adams | Adams County Assessor | 101-110-55 | "Hieu Truong Nguyen" | "Hieu Truong Nguyen" | 2022-11-19 10:52:35 |
| 3 | Adams | Adams County Assessor | 101-128-3 | "Hieu Truong Nguyen" | "Hieu Truong Nguyen" | 2022-11-19 11:08:52 |
| 4 | Adams | Adams County Assessor | 101-130-61 | "Hieu Truong Nguyen" | "Hieu Truong Nguyen" | 2022-11-19 11:10:36 |
| 5 | Adams | Adams County Assessor | 101-16-52 | "Ken Musso" | "Ken Musso" | 2022-11-19 10:34:03 |
| 6 | Adams | Adams County Assessor | 101-176-13 | "Hieu Truong Nguyen" | "Hieu Truong Nguyen" | 2022-11-19 11:20:22 |
| 7 | Adams | Adams County Assessor | 101-210-39 | "Ken Musso" | "Ken Musso" | 2022-11-19 11:22:10 |
| 8 | Adams | Adams County Assessor | 101-241-5 | "Ken Musso" | "Ken Musso" | 2022-11-19 11:30:00 |
| 9 | Adams | Adams County Assessor | 101-246-16 | "Ken Musso" | "Ken Musso" | 2022-11-19 11:33:15 |
| 10 | Adams | Adams County Assessor | 101-270-38 | "Ken Musso" | "Ken Musso" | 2022-11-19 11:40:24 |
| 11 | Adams | Adams County Assessor | 101-333-63 | "Hieu Truong Nguyen" | "Hieu Truong Nguyen" | 2022-11-19 12:28:47 |
| 12 | Adams | Adams County Assessor | 101-335-75 | "Hieu Truong Nguyen" | "Hieu Truong Nguyen" | 2022-11-19 12:30:38 |
| 13 | Adams | Adams County Assessor | 101-355-16 | "Ken Musso" | "Ken Musso" | 2022-11-19 12:33:04 |
| 14 | Adams | Adams County Assessor | 101-43-37 | "Hieu Truong Nguyen" | "Hieu Truong Nguyen" | 2022-11-19 10:36:49 |
| 15 | Adams | Adams County Assessor | 101-444-65 | "Ken Musso" | "Ken Musso" | 2022-11-19 12:41:48 |
| 16 | Adams | Adams County Assessor | 101-460-62 | "Ken Musso" | "Ken Musso" | 2022-11-19 12:47:01 |
| 17 | Adams | Adams County Assessor | 101-487-80 | | | 2022-11-19 12:48:42 |

Note unique ID for ballot card (County name, imprinted_id)

Note audit board entry timestamps

233223 lines of data, one per vote comparison

# Discrepancy breakdown (tentative)

186 Discrepancies between interpretations of a vote by the voting system vs auditors

By Type:

- 116 Wrong Ballot
- 44 Audit Board Error
- 16 Adjudication Error
- 6 Voting System Limitation
- 3 Voter Mistake
- 1 Ambiguous Voter Intent

The most common voting system error is during adjudication

# What does Colorado's RLA accomplish?

Voter-verifiable paper ballots interpreted by multi-partisan audit boards

Applies to all contests, though not necessarily achieving risk limit

One of the few places in the country where election officials get such a robust independent line of evidence supporting the results of tabulation

Great protection from cyber attack, voting system malfunction, human error

Drives good practices for ballot management (keeping them in sequence), reconciliation

A significant step towards Evidence-Based Elections

# Next goal: allowing Public to fully verify the audit

Currently rolling the dice before people know which ballots would be selected by which rolls

Improvement 1: verifiable public random selection

- Need to resume publishing manifests before random selection
- Dice rolls were originally conducted in person, but recently via Zoom
- No longer convincing to outside observer - could be pre-recorded
- Easy to fix that: e.g. invite variety of stakeholders to pick next die color live during rolling
- Also need Audit Center to report imprinted IDs selected, like it did in 2017

# Improvement 2: Explain audits better!

We surface a gold mine of data to provide confidence and help improve processes, but need better analysis, presentation of it, engagement with it

CO doesn't emphasize how our approach yields reassuring data on so many contests

When extra rounds are needed, explain why on the AuditCenter

Report on the prior accounting and reconciliation of the ballot sheet counts vs CVRs

Publish images of samples which were found discrepant

We can seek free, savvy implementation help from US Digital Response (USDR), as we do for signature verification audits

# 2023 Audit Data for Arvada Mayor contest

Arvada Mayor race was close, of interest to many observers

- About a 1% margin of victory, small subset of the county, thus quite hard to audit
- We're still able to describe relevant audit data

- 98.4% in Jefferson county, where 46 ballots for mayor were audited

- Audit found zero discrepancies - 46 for 46!

- Measured risk of about 80% (disappointing, but less scary than it seems)

- That's far more evidence than most states have on most contests

- Yet we'd like to do better!

# Auditing small or close contests

- For a municipal or district contest, or multi-card ballots, style-based sampling is much more efficient

    - Boulder did that for their 2023 IRV (mayor) audit, with new software
    - Would DRAMATICALLY increase diluted margin, and decrease CVRs to audit

- We focus too much on a low risk limit, and not enough on choosing contests of interest to audit

- Definition of risk is very conservative, assumes that the actual outcome was a win by 1 vote, and a perfect attack.

- I'd much rather see close contests selected, even if manageable sample size requires large risk limit

# Improvement 3: Timely CVRs

Allow public, canvass board to verify ballot comparisons

- Publish cast-vote records before random selection
  - We should really design districting and election to avoid need for redaction
  - In the meantime: anonymization (redaction / aggregation), straightforward to automate

# Improvement 4: Better Contest Selection

- Now typically picking just one local contest per county

- Before contest selection, publish data on potential contests to audit to help public provide input

- Best to guarantee a risk limit for all contests

  - ... Or at least all those that presumably wouldn't require a larger sample
  - Focus on auditing the close, interesting contests, not on artificially low risk limit
  - Avoid unmanageable auditing effort by increasing risk limit
  - Better to audit a close contest at a 50% risk limit, than an landslide one at 3%

- At least report measured risk for each contest

- Explore recent auditing innovations like Non(c)euch and ONEAudit

# Improvement 5: Minimum Ballot Count to Audit per County

Often there is no suitable county-level contest with a contest close enough to drive a good audit

- Might require just 20 ballots, need more for quality control
- So SoS often audits statewide contests using county margin
- But there's no meaningful contest outcome to audit there!
- Sometimes results in auditing the wrong outcome

E.g. 2022 Republican Primary, audited local Senate margins in 16 counties

- Statewide winner was O'Dea
- Within some counties, winner was Hanks
- Audit would escalate if O'Dea was gaining votes, increasing real margin - backwards!

=> Establish minimum ballot count to audit per county for opportunistic audits, quality control

# Improvement 6: Avoid Need for Extra Rounds

- Audit sometimes has a single discrepancy, and requires whole audit team to return to audit just a few more ballots
- Avoid those extra rounds via a small amount of oversampling

# Improvement 7: Promote Public Engagement

- Update Audit Center in a timely manner to facilitate observation; annotate Audit Center to provide simple understandable indication of status

- Publish real time control panel data to facilitate observation; publish schedules for audit process in advance

# Improvement 8: Leverage Ballot Images

Publish hashes of each image ASAP after scanning

- During audit, after audit board enters interpretation based on paper, check ballot image also
- Invaluable for protecting the chain-of-custody
- Ask me for details

Releasing images themselves would also allow independent tabulations

- Not software-independent, thus not suitable for cyber-secure audit
- But good for finding a variety of issues

# Summary

Bottom Line

- Colorado has the best tabulation audits around
- They help election officials protect against a wide variety of problems
- They need improvement to help the public verify the results
- Most suggestions should have minimal impact on audit workload
- Some other improvements are very worthwhile
  - Principles and Best Practices for Post-Election Audits
- Besides tabulation audits, we all need much more work on Evidence-Based Elections
  - Transparent audits of voter eligibility, chain-of-custody, etc.
- Hoping to kick off further discussions in coming months

# Acknowlegements

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- Matt Crane
- Election Verification Network
- Colorado Legislators
- Free & Fair Team beyond the call of duty
- Galois support
- Democracy Works team
- Michael Raisch

# Supporting information

- Overview and History (updated):
  - The Colorado Risk-Limiting Audit Project (CORLA)

Slides: http://bcn.boulder.co.us/~neal/elections/corla-beac/