OMB Control # 3265-0024. Expires: 9/30/2025



Voting System Anomaly Root Cause Analysis Template v2.0

Root Cause Analysis for:

VV40ECT-99: Undervote Appeared in VxScan - Rev. 2 VxSuite, Version 4.0 and EAC Certification #VXS4

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May 13, 2025

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Introduction

This RCA documents a single undervote anomaly detected during the standard 104 hour test of continuous operation with Element and SLI Compliance, according to test requirements VVSG 2.7-B and 2.7-C. No undervotes were expected, since the pre-filled ballots used in the test were known to have no undervotes. It was important to investigate the rare issue, because it was originally hypothesized to be connected to a VxCentralScan test methodology anomaly involving rescanning imprinted ballots but then was shown to be a separate issue with VxScan. Identifying the root cause would prevent similar tallying issues arising in elections.

Anomaly Description

Complete all sections. Descriptions must be as detailed as possible, while being clear and concise since the anomaly is the source of the entire RCA. This detail should include a complete list and/or description of the "symptoms" of the anomaly and the conditions present which the symptoms occurred.

Date of Anomaly: April 10, 2025	Time of Anomaly: 9:29pm
Place of Anomaly: Element, Longmont, CO	Person identifying Anomaly: Tabitha Lehman, VotingWorks

Expected Results of actions leading up to anomaly:

The 104 hour test was to be set up according to standard procedures, including a VxScan unit for scanning hand-marked paper ballots individually and two VxCentralScan units for rapidly scanning batches of these ballots. All test reports and vote tallies each hour were expected to align exactly with pre-determined counts using this methodology. No undervotes were expected at any time if following appropriate procedures for use and maintenance.

<u>Detailed description of the event / anomaly:</u>

A single undervote was identified in a tally report on the fourth day of testing. Investigation revealed it came from a VxScan scan, and it was not reproducible using the same ballots or scanner in the test environment at Element.

If the anomaly is repeatable, provide step by step instructions to recreate it:

Although this is not easily repeatable, separate investigations outside the 104 hour test chamber revealed that this anomaly could be reproduced somewhat more reliably by intentionally introducing skew into the ballot scan via hardware, such that it will not be rejected but also will sometimes cause an undervote. This can be done by either of the following, without taking the machine apart:

- Simultaneously press down on one side of the top of the scanner (e.g. left) and pull up on the other side of the top of the scanner (e.g. right), while feeding in a ballot. This would alter and disturb the infeed gap during feeding. Attempt multiple times until the ballot is both accepted and an undervote is detected.
- Intentionally miscalibrate the scanner hardware against manufacturer recommendations by undoing bolts unevenly securing the scanner in place. This would make the infeed gap change from production, where the gap size on the left of the infeed is different from the gap on the right. Feed ballots into the scanner multiple times until it is both accepted and an undervote is detected.

Chronology of Events / Timeline

Provide a detailed chronology of the events leading up to, and following, the anomaly. Add additional events if necessary.

ID	Date/Time	Description	Entity	Result / Notes
			Org/person	
1	4/7/25,	104-hour continuous	Chris	No tally issues or overvote problems detected at
	8am	operation test begins, starting	Pedersen,	the start. VxCentralScan had no reported issues.
	Mountain	according to original plans,	VotingWorks	Issues were reported with VxMark ballots not
	Time	including VxCentralScan units		being scanned properly with VxScan, which was
		scanning and imprinting the		resolved and is covered in another Root Cause
				Analysis document. The 104-hour test

		same ballots up to 4x in different orientations.		procedure was then updated to scan VxMark ballots with VxCentralScan 1x each, while continuing to scan the other pre-filled hand-marked paper ballots 4x each. Later an overvote anomaly would be detected on VxCentralScans, also discussed in another RCA, but unrelated to the anomaly in this RCA.
2	4/10/25, 9:29pm	A single undervote anomaly was reported by testing staff on the fourth day of tests. Ballots were inspected for causes.	Tabitha Lehman, VotingWorks	An undervote was found in a tally report for a proposition ("Proposition 2"). Inspecting the ballots found nothing wrong with the physical ballot or their print patterns. The VxCentralScan units were cleaned. Further investigation found that VxCentralScan did not misread any ballots, but that the undervote was scanned by VxScan. The CVRs were obtained and shared with VotingWorks staff to analyze.
3	4/11/25, 7:26am	The ballots, CVRs, and test reports around when the undervote occurred were analyzed.	Tabitha Lehman, Matt Roe, VotingWorks	The timeline when the undervote occurred was narrowed down to between two reports on 4/10 between 6:34pm and 8:18pm. The CVR for the individual undervote was identified as the ballot scan with ID number 92cd4414-fb5d-4a62-9c5e-701e651c8b75. An interpretation debugger reproduced the same behavior on the CVR image. Plans to attempt to reproduce and analyze the issue were made, intentionally applying skew via any known means during ballot insertion: by hand, or by hardware adjustment.
4	4/21/25	VotingWorks hardware team staff release a revised scanner mounting strategy that avoids the need to remove the factory-installed bottom mounting plate of the PDI scanner.	Jesse DeWald, Don Chu, VotingWorks	The new mounting revision prevents any change in factory calibration of the PDI scanner. Previously the original mounting strategy and instructions could lead to accidental removal of the bottom plate of the PDI scanner, potentially causing a change in scanner gap calibration, before reattaching the plate.
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Investigative Team and Method

This section shall describe how the investigative team is assembled by the voting system manufacturer, who it consists of, and how it gathers the data to be used in the analysis. Include the RCA method employed by the manufacturer in conducting the analysis and why this method was used.

Names and Positions of members of the investigation team:

Tabitha Lehman - Customer Success Manager

Matt Roe - Head of Product

Brian Donovan - Software Engineer

Jesse DeWald - Head of Hardware

Don Chu - Lead Design Engineer

Describe the data gathering process:

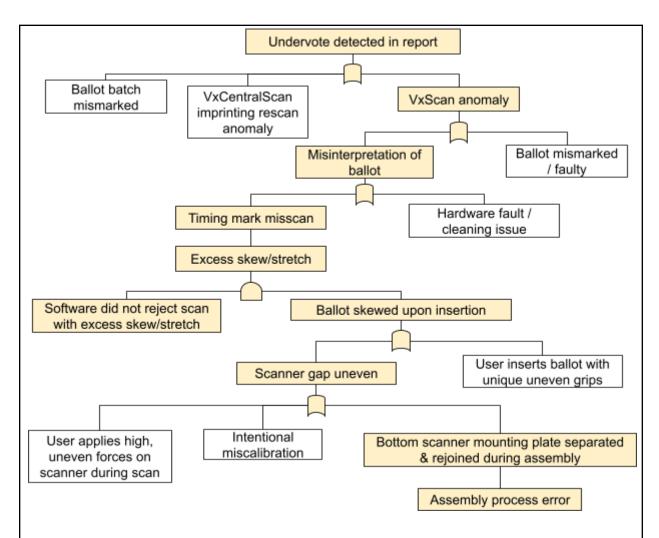
Tabitha Lehman was present in-person at Element with SLI Compliance during the 104-hour test when this undervote anomaly was reported. She initially analyzed ballots, CVRs, and tally reports, and shared data with the remote VotingWorks team, narrowing down causes related to specific scans on VxScan rather than the ballot sheets themselves.

Matt Roe joined the investigation to analyze logs and CVRs with specialized debugging tools, identifying the single undervote scan in question and tying it to interpretation of an unusually skewed scan. After reproducing the issue in a separate test system by forcing improper amounts of skew via scanner hardware miscalibration, he coordinated plans to continue mitigations with the wider VotingWorks team. Brian Donovan also joined at this point to discuss the skew/stretch measurement capabilities of the current production app software and Hardware Test Utility, and discussed plans to adjust both.

Jesse DeWald and Don Chu joined the investigation to investigate and mitigate the hardware root cause of physical ballot skew. Going back into assembly records, they identified that the units tested had followed a scanner mounting procedure that unintentionally could have caused some misalignment of the PDI scanner gap. They revised the mounting strategy and set up processes with the scanner supplier PDI to completely bypass this error in the future.

Describe which methodology(s) is used to conduct the root cause analysis:

The investigation began with a basic fault tree analysis, analyzing potential fault branches across the different scanner devices under test (VxScan, VxCentralScans). Test methodology was investigated first due to another anomaly previously arising involving test methodology with VxCentralScan, but this was eliminated as a possibility as only VxScan reports were identified as involved. As fault paths were eliminated as possibilities, the logs and CVRs associated with the undervote were analyzed and led to a focus on interpretation of unusually skewed ballots in VxScan. A simplified version of the fault tree analysis diagram is shown below, with the identified root cause fault path highlighted:



Drilldown into these fault paths using the "5 Why's" technique further led to identifying root causes, detailed in the key findings below. The question "Why did the software not reject a scan with excess skew/stretch?" in this case led to further questions that pointed to a need for more data to better define and identify such ballots with excess skew/stretch.

In conjunction with making the software more selective regarding skew, the question "Why would the ballot skew upon insertion?" led to exploration of several potential physical or hardware causes of skew in the first place. Only one cause was confirmed to apply to the tested units: an assembly error that was overlooked, where the bottom mounting plate from the internal PDI scanner was temporarily separated from the scanner and then reattached.

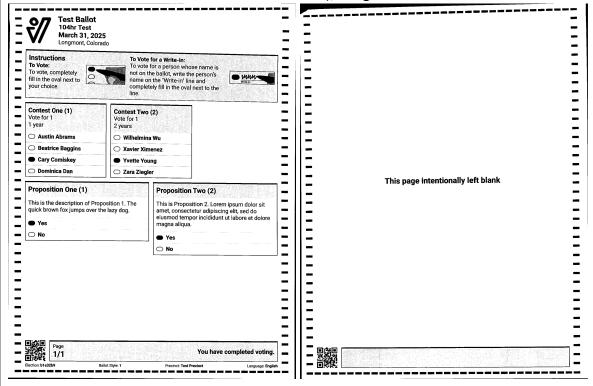
Findings and Root Cause

Describe the findings of the investigation and explain the root cause(s) based on these findings. If the RCA results in findings that are not directly related to the root cause of the anomaly, these should also be captured as manufacturer product/process improvement steps in an effort to improve the voting system.

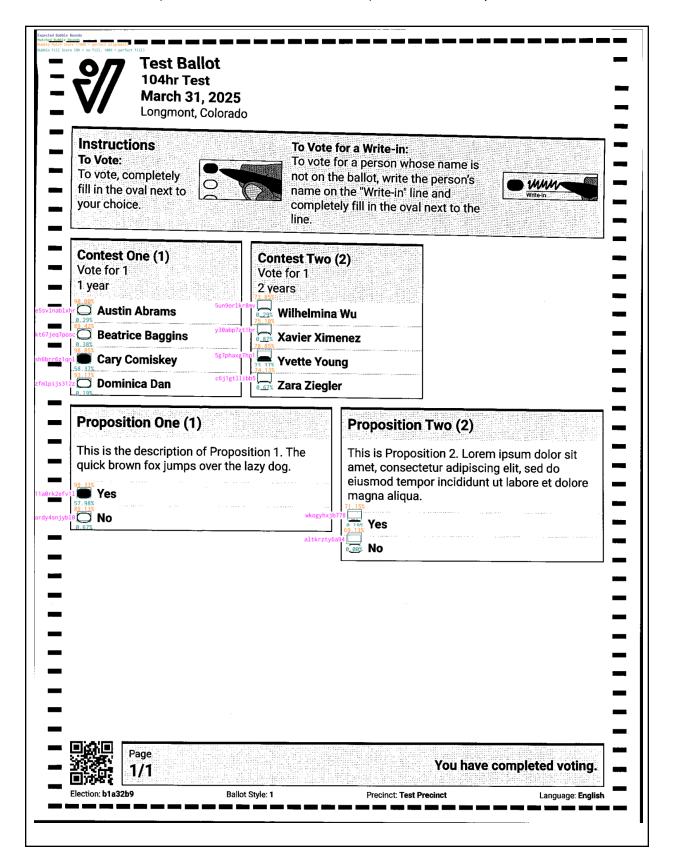
Key findings in the investigation fell under software and hardware categories, as follows:

Findings for causes in Software:

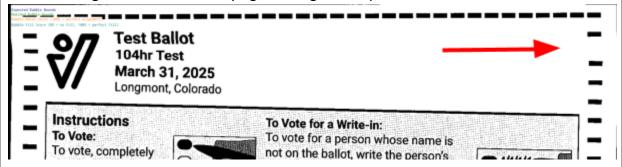
 One single ballot scan was identified as causing the undervote (Ballot ID number: 92cd4414-fb5d-4a62-9c5e-701e651c8b75), images of both sides shown below:



- The marked ballot paper itself was not a contributor to the issue, as rescanning it did not reproduce the issue.
- Debugging tools showed that this set of scan images had detected bubbles offset from the actual bubble positions. (See image below, "Proposition Two," green rectangles overlaid on top of ballot bubbles.) This led to an incorrectly detected undervote for the single contest, as a bubble was misidentified as empty.



• The underlying problem causing the bubble misalignment was a missing timing mark near the upper right corner of the front side. Note that the 3rd row of timing marks in the image was misscanned with a gap on the right side (see image below). This led to misalignment of the underlying bubble grid interpretation.



- The misscanned timing mark was due to uneven skew and stretching, which can happen rarely when ballots are inserted skewed or gripped unevenly, or if the scanner itself fell out of manufacturer's calibration of the infeed gap to grip ballots evenly. The lack of reproducibility rescanning ballots pointed to unique ballot handling causing the skew.
- Software is also expected to reject ballots with excess skew, stretching, or misscanned timing marks.

Findings of causes in Hardware:

- It was previously known that uneven gripping or handling of a paper ballot during feeding into the scanner can lead to skew, but testing with this strategy alone did not reproduce this anomaly. Software would appropriately reject improperly gripped scans for being too skewed.
- Forcing miscalibration of the scanner infeed gap via hardware stresses could reproduce the anomaly, although the skewed scan leading to an undervote would not happen all the time. Many repeated scans while disturbing the infeed gap were necessary to reproduce the issue. The infeed gap should not ever fall out of the manufacturer's calibration if the component is installed properly.
- Communications with the scanner component manufacturer (PDI) confirmed that factory calibration of the scanner gap never has to be adjusted except in the cases of assembly problems. This gap is set by PDI, and it can only shift if:
 - the built-in bottom mounting plate is ever removed, or
 - the scanner is not mounted using all three provided mounting points.
- Investigations of assembly logs showed that some of the VxScan units under test at Element/SLI had the bottom plate of the scanner components removed completely during assembly, then reattached. This is because VotingWorks was installing a secondary mounting bracket to the PDI scanner bottom plate during assembly; this required removing two screws only, and not all four. However, in some cases, the assembly team removed all four in error, leading to the separation of the bottom plate

from the scanner, before it was reattached. During this separation, the scanner infeed gap may have come misaligned.

The root cause of the undervote was a combination of factors:

- Excess skew and stretch of the ballot scan image, due to a combination of:
 - o the internal scanner mounting strategy needing to be improved,
 - o preventable assembly error
- Software acceptance of the ballot scan with the misscanned timing mark.

Corrective Action(s)

Corrective actions were identified in software and hardware:

- Prevent the issue at the hardware assembly level by (1) having PDI install the
 mounting bracket directly before factory calibration, and (2) using all three
 PDI-recommended mounting points for the scanner to further hold the factory
 calibration. This entirely avoids VotingWorks assemblers having to adjust any scanner
 mounting plate fasteners, as recommended by PDI. It also avoids assemblers
 accidentally separating parts calibration.
- Prevent the issue at the **software** level by more reliably rejecting misscanned ballots with excess stretch/skew, and logging stretch/skew characteristics for diagnostic or maintenance purposes.

In order to achieve these corrective actions, the following actions have been taken:

- Manufacturing agreements have been made with scanner supplier PDI to attach the VotingWorks mounting bracket before factory calibration. The VxScan assembly process no longer requires modifying the PDI scanner mounting plates, and the PDI scanner is optimally mounted to the rest of the VxScan assembly.
- Procedures for more reliably reproducing and analyzing the issue were defined, given the initial rarity. This involves purposely mis-calibrating scanner hardware in a testing environment to induce skew/stretch similar to that seen in this anomaly.
- Hardware Test Utility software updates were defined, to better analyze skew and stretch characteristics of scans more efficiently than in the production app.
- Test plans have been made to measure ballot skew/stretch characteristics at different states of scanner hardware calibration. The production app will be updated to better reject ballot scans with excess stretch/skew based on this data, and from adjusting a feature that could introduce misinterpretation of the timing marks. Details on this are below.

Software Mitigation Plans

The undervote was due to misidentifying the timing mark grid, causing the interpreter to look for the bubbles in the wrong location. The grid was incorrectly identified and accepted as valid because the interpreter will attempt to infer missing timing marks, and inferred a timing mark in the stretch gap between the real timing marks on the right side near the top of the sheet's front side. This essentially caused all the timing marks below the 2nd timing mark on the right side to be off by one, causing greater alignment errors in bubble finding the farther to the right the bubbles were.

Inferring timing marks was necessary on the top (for inverted ballots) and bottom edges of the scanned sheets because of our support for interpreting AccuVote ballots which use the

presence & absence of bottom timing marks as bits for encoding ballot configuration. To prevent this issue in the future, the software will stop inferring timing marks on the left and right edges and likely stop inferring them at all. We intend only to support ballots with a complete timing mark grid and using a QR code to encode ballot configuration. Had this mitigation been in place, the gap between the 2nd and 3rd timing marks would have remained and the ballot would have been rejected due to being overly stretched according to our existing thresholds for measuring stretch

Solution Management

The purpose of this section is to manage the corrective action(s) moving forward. This should detail all process changes to manage those corrective actions, and steps taken to ensure the actions eliminate the anomaly over time.

Management of the corrective actions spans three areas:

Testing and Product Quality:

- A dedicated cross-functional team was formed to further investigate and monitor the issue across software and hardware.
- Skew and stretch metrics that are already collected in the production software app will be incorporated into an updated Hardware Test Utility. The required materials and procedures for using this utility will be defined, including the appropriate test ballots.
- Research is planned to collect more data to inform product design. Data will be
 collected to measure how different factors influence the stretch/skew characteristics
 of ballot scans. These factors include various states of scanner hardware calibration
 (i.e. scanner infeed gap calibration), vibration, hardware manufacture batch, scan
 numbers, time, etc. Further analysis will link the resulting stretch/skew characteristics
 to how often they lead to tallying anomalies, such as undervote anomalies.

Hardware Design and Production:

- An agreement has been made with the scanner component supplier PDI to attach the VxScan mounting bracket before factory calibration, then supply the scanner to VotingWorks. The VxScan production process has been revised to account for this, avoiding disassembling any part of the original PDI scanner hardware, and avoiding any need to change factory calibration of the infeed gap.
- Users never have to consider scanner gap calibration, as it is handled during manufacturing/assembly. VotingWorks still has the option internally to adjust calibration for testing and R&D purposes following PDI-supplied instructions.

Software Design and Maintenance:

 Production software will be updated in the next version v4.0.2 to stop inferring timing marks on the left and right, preventing the misscan anomaly here if this specific type of skew still occurs. The software will also incorporate better data-driven rejection of ballots with excess stretch/skew.