



The Antrim County 2020 Election Incident: An Independent Forensic Investigation

J. Alex Halderman, *University of Michigan*

<https://www.usenix.org/conference/usenixsecurity22/presentation/halderman>

This paper is included in the Proceedings of the
31st USENIX Security Symposium.

August 10–12, 2022 • Boston, MA, USA

978-1-939133-31-1

Open access to the Proceedings of the
31st USENIX Security Symposium is
sponsored by USENIX.

The Antrim County 2020 Election Incident: An Independent Forensic Investigation

J. Alex Halderman*
University of Michigan

Abstract

In November 2020, Antrim County, Michigan published unofficial election results that misstated totals in the presidential race and other contests by up to several thousand votes. Antrim subsequently issued a series of corrections, and the certified presidential results were confirmed by a hand count. Nevertheless, Antrim was cited by the President of the United States as evidence of widespread fraud, and it remains a centerpiece of conspiracy theories about the 2020 election. At the request of the Michigan Secretary of State and Attorney General, I performed a forensic investigation of the incident. Using data from the election system, I precisely reproduce the major anomalies, explain their cause, and verify that they have been corrected. I also uncover other errors affecting specific down-ballot contests that have *not* been corrected, despite the unusual attention focused on the results, one of which may have changed the outcome of a local contest. Based on this analysis, I refute misinformation about the incident, concluding that it was not the result of a security breach but rather a series of operator errors compounded by inadequate procedures and insufficiently defensive software design. These events offer lessons for improving election administration and highlight the value of rigorously investigating election technology incidents for enhancing accuracy and public trust.

1 Introduction

On the night of the November 3, 2020, general election, Antrim County, Michigan, published wildly inaccurate results. Totals in the presidential race and other contests were initially misreported by up to several thousand votes [40], and over the next three weeks, the county restated its results *four times* to correct this and other errors (see Table 1). Antrim’s presidential results have since been confirmed by a county-wide hand count of the paper ballots [32] and affirmed by a state-wide risk-limiting audit pilot [35]. Nevertheless, they remain a centerpiece of conspiracy theories about the 2020 election [12].

*This paper is derived from a report that the author produced as an expert witness under contract to the Michigan Department of Attorney General, available at https://www.michigan.gov/documents/sos/Antrim_720623_7.pdf.

Shortly after the election, a state court authorized Russell J. Ramsland, Jr.’s Allied Security Operations Group (ASOG) [14] to conduct a forensic analysis of Antrim’s election technology [16]. ASOG purported to find that “the Dominion Voting System is intentionally and purposefully designed with inherent errors to create systemic fraud and influence election results” [24]. ASOG’s report was repeatedly cited by President Trump as evidence of widespread fraud against him [42], and it was the basis for a draft executive order, recently obtained by the Congressional committee investigating the events of January 6, 2021, that would have directed the Secretary of Defense to seize voting machines [43].

Michigan’s Secretary of State and Attorney General asked me to perform an independent technical investigation and respond to the ASOG report. I sought to answer several questions: What caused the errors? Were they evidence of an attack or other foul play? Had they been fully corrected? Could similar problems affect other localities? What should be done to prevent such issues in the future?

By analyzing data from Antrim County’s election management system (EMS) and the memory cards from its ballot scanners, I was able to reconstruct the events that led to the initial erroneous results, precisely account for the known discrepancies, and identify the underlying causes. I determined that:

- Initial explanations provided by the county [2] and the state [34] were correct that the inaccurate results were a consequence of human error, but the problems were more complex than was at first understood. A chain of human errors was compounded by gaps in election procedures and their adherence. The election software also could have done more to help election staff avoid mistakes.
- Although vulnerabilities in election technology are well documented (see, e.g., [23, 38]), the Antrim incident was not caused by a security breach, and there is no credible evidence that it was caused deliberately. Nevertheless, I note several places where security should be improved.
- The major discrepancies in Antrim’s results have been fully corrected. The final results match the poll tapes

printed by the individual ballot scanners, and there is no indication that the poll tapes are inaccurate, except for in specific precincts where particular circumstances I explain affected small numbers of votes or down-ballot contests. These residual errors affect too few votes to change any outcome except in one local contest, the Central Lake Village Marihuana Retailer Initiative, which was potentially decided incorrectly due to a one-vote error.

The incident in Antrim arose due to the county’s mishandling of last-minute ballot design changes, a circumstance that is unlikely to have occurred widely during the 2020 election. Nevertheless, several layers of protections that are supposed to ensure accuracy broke down due to human errors on multiple levels, including mistakes by county staff and poll workers while operating the election technology, procedural missteps while processing ballots in some localities, and the failure of the county canvassers to detect lingering discrepancies. These failings suggest a need for greater oversight of county and local election administration. I also recommend several changes to election technology and procedures in order to better guard against similar problems in future elections.

Beyond explaining the incident, this investigation offers a template for technical analysis of future election mishaps. Problems involving election technology gain public attention in nearly every election cycle, but they are rarely formally investigated. This makes such problems more likely to reoccur and leaves fertile ground for misinformation. Normalizing postmortem investigations is an opportunity for election officials to display rigor, transparency, and a drive for continuous improvement, and it would enhance accuracy and public trust.

Organization In Section 2, I describe Antrim County’s voting system and the data from it that I examined. In Section 3, I investigate and explain the discrepancies that occurred during county-level reporting. In Section 4, I uncover and explain discrepancies that occurred on poll tapes from individual scanners. In Section 5, I refute false claims in the ASOG report. I conclude in Section 6 and offer recommendations for preventing and responding to problems in future elections.

2 Background

Antrim uses Dominion Voting Systems ImageCast Precinct (ICP) ballot scanners and the Dominion Democracy Suite election management system (EMS). The EMS software runs on a single PC and manages election preparation and reporting. Antrim uses version 5.5 of the Dominion system, which is federally certified by the U.S. Election Assistance Commission (EAC) [44]. Elections in Antrim typically operate as follows:

1. *Preparation.* Workers design the ballots using the EMS software [17]. They create an “election project” (a database corresponding to the election) and define contests and choices for each precinct. The EMS generates ballot designs for printing and “election definition” files for use by the scanners. Like most Michigan counties,

	Results published on:					Difference:				
	11/4 (a)	11/5 (b)	11/6 (c)	11/16 (d)	11/21 (e)	<i>b</i> − <i>a</i>	<i>c</i> − <i>b</i>	<i>d</i> − <i>c</i>	<i>e</i> − <i>d</i>	
President	Biden	7769	7289	5960	5960	5960	−480	−1329	0	0
	Trump	4509	9783	9748	9748	9748	5274	−35	0	0
	Jorgensen	93	197	189	189	189	104	−8	0	0
	Blankenship	20	22	16	16	16	2	−6	0	0
	De La Fuente	12	8	8	8	8	−4	0	0	0
	Hawkins	20	28	28	28	28	8	0	0	0
U.S. Senator	Peters	7863	6807	5441	5758	5758	−1056	−1366	317	0
	Squier	47	81	79	83	86	34	−2	4	3
	James	4484	9345	9340	9924	9924	4861	−5	584	0
	Willis	91	960	81	82	82	869	−879	1	0
	Dern	19	26	26	27	27	7	0	1	0
U.S. Rep.	Ferguson	7745	6603	5235	5235	5235	−1142	−1368	0	0
	Bergman	4794	10344	10292	10292	10292	5550	−52	0	0
	Boren	125	266	263	263	263	141	−3	0	0
State Rep.	Burke	7697	6143	4800	4800	5578	−1554	−1343	0	778
	Borton	4529	8772	8761	8761	9936	4243	−11	0	1175

Table 1: Election Results. Antrim published five sets of results, each with widespread differences [3–7]. Some totals more than doubled, and many gained or lost over 1,000 votes. The first four contests are shown above, but most of the others were at least initially in error too. My analysis shows that report (a) was badly incorrect due to the use of mismatched election definitions; (b) added results entered by hand but failed to remove all bad data; (c) fixed this, but the manual inputs contained data entry errors, which were corrected in (d) and (e).

Antrim outsources these steps to a service provider, ElectionSource, which sends the county an “election package” containing the election project, ballot designs, and election definitions. The county imports these into its EMS and loads the election definitions onto memory cards [17]. Townships insert the cards into their scanners and perform logic and accuracy (L&A) testing by scanning marked ballots and confirming the results [27, 30].

2. *Voting and counting.* Vote counting begins on election day. In-person voters insert their own ballots into the scanners, which tabulate the selections. For absentee ballots, most localities have poll workers feed them into the same scanners used for in-person voting. The scanners count votes by detecting marks in particular ballot locations (called “voting targets”) specified by the election definition. For each ballot, the scanner records on its memory card which voting targets were marked. (ICP scanners can also store a digital image of each ballot, but this capability was not enabled in Antrim.) After polls close, the scanner prints a paper “poll tape” showing the number of votes recorded for each choice, which is returned to the county along with the memory card [28]. The paper ballots are retained by the locality.
3. *Reporting.* County workers aggregate results using a second EMS application [18]. It loads vote data from the memory cards and stores it in the election project database. The EMS generates a report containing results for the entire county, which Antrim posts on its website.

4. *Post-election checks.* Before the local Board of County Canvassers certifies the results, it is supposed to manually verify that the reported totals from the EMS match the poll tapes from each scanner [29]. The state also recently began conducting risk-limiting audits, in which randomly sampled ballots are inspected to confirm the reported outcome for particular contests [33].

In the November 2020 election, Antrim used 18 scanners across 15 townships, shown in Table 2. Mancelona Township used two scanners, and Elk Rapids and Milton townships used separate scanners (“AV Boards”) for absentee ballots. Each township had up to four ballot designs, for 43 in total. There were 16,044 ballots recorded, a voter turnout of 73%.

To reconstruct what went wrong, I examined forensic images of the EMS and of the 18 scanner memory cards. Several kinds of data were valuable for my analysis. One of the most important was the EMS database. Democracy Suite uses Microsoft SQL Server, and data for each election project is maintained in a separate database. I analyzed the database for the November 2020 election using Microsoft SQL Server Management Studio and purpose-built Python scripts. In reconstructing the sequence of events, I also made repeated use of log files stored in the EMS and memory cards. For instance, the election database records the actions that users perform on the election project. Each memory card also contains a detailed log of events that occurred on the scanner.

3 Discrepancies in County-Level Reporting

The first part of my investigation concerns errors that were introduced in the course of aggregating and reporting results from precincts across the county, including the major discrepancies in the initial results posted on November 4. I reconstruct the events that led to the errors, explain their causes, and verify that they have been corrected. My analysis confirms that the final reported results match the results obtained by the individual scanners.

3.1 Preparations for the Election

The sequence of events that led to the reporting discrepancies began long before the election, during the process of designing the ballots. According to a timeline produced by the county [2], it received initial proofs of the ballot designs from ElectionSource on September 5. After a series of corrections, county staff approved the designs on September 18 and received a flash drive from ElectionSource containing the election package on September 29. County staff loaded the election package into the EMS, copied the election definition files for the scanners to memory cards, and distributed them to localities for use in the election. The memory card logs show that all townships loaded the cards into their scanners and performed L&A testing in late October (see Appendix A).

Typically, the ballot designs and election definitions would have remained unchanged from this point. However, according to Antrim’s timeline, on October 5 and 7, the county

Scanner	Election Definition	Scanner	Election Definition
Banks	Revised (a)	Jordan	Initial
Central Lake *	Revised (b)	Kearney	Initial
Chestonia	Initial	Mancelona 1 *	Revised (c)
Custer	Initial	Mancelona 2 *	Revised (c)
Echo	Initial	Milton 1	Initial ✗
Elk Rapids 1	Initial ✗	Milton AV	Initial
Elk Rapids AV	Initial	Star	Initial
Forest Home	Initial	Torch Lake	Initial
Helena	Initial	Warner *	Initial ✗

Table 2: Scanner Election Definitions. Memory cards from only 4 of the 18 scanners matched the revised election definitions when I examined them. *Notes:* * Ballot design changed after initial definition; (a) Initial and revised definitions identical; (b) Used initial definition Nov. 3 but rescanned Nov. 6 with revised definition; (c) Revised definition loaded before Nov. 3; ✗ EMS unable to load results from card.

alerted ElectionSource about errors that had been identified in three of the ballot designs. ElectionSource corrected them and provided a revised election package on October 23, which Antrim loaded into its EMS that day.

At this point, county staff *should have* updated the memory cards for every scanner to ensure that their election definitions matched the EMS’s. In fact, the only scanners that were updated before election day were the two in Mancelona Township. This would prove to be a consequential mistake.

Ballot Design Changes I extracted the initial and revised election packages from the EMS image. Among other files, each package contains a PDF of each ballot design. I confirmed that there were differences in exactly three ballot designs, as illustrated in Figure 1. They are:

Central Lake, Precinct IV. On the ballot for Central Lake Village, the school board contest changed from Ellsworth School District to Central Lake School District. The number of choices remained the same, but the contest changed from vote-for-two to vote-for-three, necessitating an added write-in blank. This shifted the position of the contest below, State Proposal 20-1, down by one row.

Mancelona, Precinct IV. On the Mancelona Village ballot, a candidate (Eugene K. Kerr) was added to the Village Trustee contest. This contest changed from vote-for-three to vote-for-two, so there was one fewer write-in blank and no change to the position of any contest.

Warner, Precinct 1BF. In part of Warner Township, a contest was added for the Boyne Falls Public Schools Sinking Fund Millage Proposal. The new contest appears at the end of the second column on the final page of the ballot, so no other contest changed position.

Scanner Election Definitions The election packages also contain election definition files to be copied to each scanner’s memory card. I compared the election definition files that

Ballot Package	Local School District	Proposal Section	State
Initial	<p>Board Member Ellsworth Smith</p> <p>Incumbent Position Vote for not more than 1</p> <p>Michael J. Kelly Any Nonpartisan Candidate Vote for not more than 1</p> <p>Mark Edward Smith Christopher Welton</p>	<p>Proposal 20-1</p> <p>A proposed constitutional amendment to allow money from oil and gas mining on state-owned lands to continue to be collected in state funds for land protection and creation and maintenance of parks, nature areas, and public recreation facilities, and to describe how money in those state funds can be spent</p> <p>Impose a fee to help defray administrative and enforcement costs for the state permit and each subsequent permit, but not to exceed \$25,000 each</p> <p>Allow acceptance or suspension of an issued permit by the Village Clerk for any violation of the ordinance, after written notice and public hearing</p> <p>Make a violation of the ordinance a misdemeanor infraction, subject to a fine of not more than \$500</p> <p>Should this ordinance be enacted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>	<p>Proposal 20-1</p> <p>A proposed constitutional amendment to allow money from oil and gas mining on state-owned lands to continue to be collected in state funds for land protection and creation and maintenance of parks, nature areas, and public recreation facilities, and to describe how money in those state funds can be spent</p> <p>Impose a fee to help defray administrative and enforcement costs for the state permit and each subsequent permit, but not to exceed \$25,000 each</p> <p>Allow acceptance or suspension of an issued permit by the Village Clerk for any violation of the ordinance, after written notice and public hearing</p> <p>Make a violation of the ordinance a misdemeanor infraction, subject to a fine of not more than \$500</p> <p>Should this ordinance be enacted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>
Revised	<p>Board Member Central Lake Schools</p> <p>Incumbent Position Vote for not more than 1</p> <p>Michael J. Kelly Any Nonpartisan Candidate Vote for not more than 1</p> <p>Mark Edward Smith Keith Stuber</p>	<p>Proposal 20-1</p> <p>A proposed constitutional amendment to allow money from oil and gas mining on state-owned lands to continue to be collected in state funds for land protection and creation and maintenance of parks, nature areas, and public recreation facilities, and to describe how money in those state funds can be spent</p> <p>Impose a fee to help defray administrative and enforcement costs for the state permit and each subsequent permit, but not to exceed \$25,000 each</p> <p>Allow acceptance or suspension of an issued permit by the Village Clerk for any violation of the ordinance, after written notice and public hearing</p> <p>Make a violation of the ordinance a misdemeanor infraction, subject to a fine of not more than \$500</p> <p>Should this ordinance be enacted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>	<p>Proposal 20-1</p> <p>A proposed constitutional amendment to allow money from oil and gas mining on state-owned lands to continue to be collected in state funds for land protection and creation and maintenance of parks, nature areas, and public recreation facilities, and to describe how money in those state funds can be spent</p> <p>Impose a fee to help defray administrative and enforcement costs for the state permit and each subsequent permit, but not to exceed \$25,000 each</p> <p>Allow acceptance or suspension of an issued permit by the Village Clerk for any violation of the ordinance, after written notice and public hearing</p> <p>Make a violation of the ordinance a misdemeanor infraction, subject to a fine of not more than \$500</p> <p>Should this ordinance be enacted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>

(a) Central Lake, Precinct 1V

Ballot Package	Local School District	Proposal Section	State
Initial	<p>Board Member Charlevoix-Emmet Intermediate School District</p> <p>Incumbent Position Vote for not more than 3</p> <p>Thelma A. Chalka Jean E. Frenze Mary P. Jason</p>	<p>Proposal 20-2</p> <p>A proposed constitutional amendment to require a search warrant in order to access a person's electronic data or electronic communications</p> <p>Prohibit unreasonable searches or seizures of a person's electronic data and electronic communications</p> <p>Require a search warrant to access a person's electronic data or electronic communications, unless the same conditions currently required for the government to obtain a search warrant to search a person's house or seize a person's things</p> <p>Should this proposal be adopted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>	<p>Proposal 20-2</p> <p>A proposed constitutional amendment to require a search warrant in order to access a person's electronic data or electronic communications</p> <p>Prohibit unreasonable searches or seizures of a person's electronic data and electronic communications</p> <p>Require a search warrant to access a person's electronic data or electronic communications, unless the same conditions currently required for the government to obtain a search warrant to search a person's house or seize a person's things</p> <p>Should this proposal be adopted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>
Revised	<p>Board Member Charlevoix-Emmet Intermediate School District</p> <p>Incumbent Position Vote for not more than 3</p> <p>Thelma A. Chalka Jean E. Frenze Mary P. Jason</p>	<p>Proposal 20-2</p> <p>A proposed constitutional amendment to require a search warrant in order to access a person's electronic data or electronic communications</p> <p>Prohibit unreasonable searches or seizures of a person's electronic data and electronic communications</p> <p>Require a search warrant to access a person's electronic data or electronic communications, unless the same conditions currently required for the government to obtain a search warrant to search a person's house or seize a person's things</p> <p>Should this proposal be adopted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>	<p>Proposal 20-2</p> <p>A proposed constitutional amendment to require a search warrant in order to access a person's electronic data or electronic communications</p> <p>Prohibit unreasonable searches or seizures of a person's electronic data and electronic communications</p> <p>Require a search warrant to access a person's electronic data or electronic communications, unless the same conditions currently required for the government to obtain a search warrant to search a person's house or seize a person's things</p> <p>Should this proposal be adopted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>

(b) Mancelona, Precinct 1V

Ballot Package	Township	Intermediate School District	State
Initial	<p>Clark Vote for not more than 1</p> <p>Treasurer Vote for not more than 1</p> <p>Trustee Vote for not more than 1</p> <p>Board Member Boyaie Falls Public Schools Vote for not more than 3</p>	<p>Charlevoix-Emmet Intermediate School District Partial Term Ending 12/31/2024</p> <p>Larry Casady</p> <p>Charlevoix-Emmet Intermediate School District Partial Term Ending 12/31/2022</p> <p>Local School District Boyaie Falls Public Schools Vote for not more than 3</p>	<p>Proposal 20-2</p> <p>A proposed constitutional amendment to require a search warrant in order to access a person's electronic data or electronic communications</p> <p>Prohibit unreasonable searches or seizures of a person's electronic data and electronic communications</p> <p>Require a search warrant to access a person's electronic data or electronic communications, unless the same conditions currently required for the government to obtain a search warrant to search a person's house or seize a person's things</p> <p>Should this proposal be adopted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>
Revised	<p>Clark Vote for not more than 1</p> <p>Treasurer Vote for not more than 1</p> <p>Trustee Vote for not more than 1</p> <p>Board Member Boyaie Falls Public Schools Vote for not more than 3</p>	<p>Charlevoix-Emmet Intermediate School District Partial Term Ending 12/31/2024</p> <p>Larry Casady</p> <p>Charlevoix-Emmet Intermediate School District Partial Term Ending 12/31/2022</p> <p>Local School District Boyaie Falls Public Schools Vote for not more than 3</p>	<p>Proposal 20-2</p> <p>A proposed constitutional amendment to require a search warrant in order to access a person's electronic data or electronic communications</p> <p>Prohibit unreasonable searches or seizures of a person's electronic data and electronic communications</p> <p>Require a search warrant to access a person's electronic data or electronic communications, unless the same conditions currently required for the government to obtain a search warrant to search a person's house or seize a person's things</p> <p>Should this proposal be adopted?</p> <p>Yes <input type="radio"/> No <input type="radio"/></p>

(c) Warner, Precinct 1BF

Figure 1: Three ballot design were corrected between the initial election package (left column) and the revised package (center column). The differences are highlighted in red (right column). These changes initiated a sequence of events that led to the publication of erroneous results.

were present on the memory cards to those in each of the two election package versions. The results are summarized in Table 2. Every card matched either the initial or the revised election package, indicating that the election definitions on the cards were not otherwise altered. Only four cards matched the revised election package: Central Lake, because its card was reinitialized after the election in order to rescan the ballots; Banks, because its election definitions from both packages are identical, for reasons that will become clear; and the two cards from Mancelona, consistent with Antrim’s assertion that these were the only cards updated before the election.

3.2 Events on Election Night

On election night, November 3, county staff began loading results into the EMS as memory cards arrived from around the county. I reconstructed events that night from the EMS log.

The first card loaded successfully at 9:49 p.m. The earliest sign of trouble occurred when loading the next card, from Warner Township, at 10:31 p.m.: despite multiple attempts, the EMS refused to accept the data. After successfully loading two further cards, at 11:03 p.m. a staffer began manually entering the Warner results from the poll tape. At 12:28 a.m., the EMS was unable to load any votes from the card from Elk Rapids Precinct 1, although there was no problem with the Elk Rapids AV Board card. At 12:39 a.m., the EMS similarly was unable to load votes from the card from Milton Precinct 1 even though the Milton Township AV Board card had loaded normally. The EMS operator manually entered the results from these scanners. In all, 15 of the 18 cards loaded successfully, and three failed to load and were entered manually (see Table 2). The last card was loaded at 3:44 a.m., and the EMS generated the initial results report at 4:09 a.m. This report was printed, scanned, and uploaded to the county website [3].

Antrim received the first reports of errors in the results early the next morning, around 8:15 a.m. on November 4 [2]. The county confirmed that the totals were widely inconsistent with the poll tapes, took down the results, and began manually entering results from the poll tapes for affected scanners.

3.3 Representation of Ballots and Votes

Antrim County and the State Bureau of Elections have explained that the major discrepancies in the initial results were caused by the use of mismatched election definitions on the EMS and on some of the scanners [34]. To verify this, I first reverse engineered how Democracy Suite internally represents ballot designs, voted ballots, and election results.

Election workers use the EMS to define contests and associated choices (e.g., candidates), then assign each contest to one or more polling districts. Some precincts consist of only one district, but others are split into multiple polling districts with different local contests, e.g., if portions of the precinct fall within different school districts. Based on this data, the EMS automatically generates the election definition and ballot design for each polling district [17].

Internally, the EMS represents the structure of the ballots using several database tables. Each row in the `BallotManifestation` table corresponds to the ballot design used in a particular polling district, each row in the `ContestManifestation` table represents *an instance* of a contest appearing on a particular ballot design, and each row in the `ChoiceManifestation` table represents *an instance* of a choice appearing on a particular ballot design. Every row in these tables is associated with a numeric ID. When the EMS generates election definitions, it assigns sequential IDs to every ballot design, every contest instance, and every choice instance, across all polling districts. These ID sequences continue from one polling district to the next, in alphabetical order.

Each memory card is loaded with election definition data corresponding to the ballot designs used in that polling place. For each ballot design, the data specifies the coordinates of every voting target and the IDs of the corresponding contest instance and choice instance. It also includes the names of the contests and choices and other data necessary for the scanner to tally the votes and produce a poll tape.

The memory cards record results in two ways. First, each card contains a file with a name ending in `_TOTALS.DVD` that stores the scanner’s tallies. A second file, with a name ending in `_DETAIL.DVD`, stores the scanner’s interpretation of each ballot, which is known as a cast-vote record or CVR. It records whether or not the scanner detected a mark for each voting target on each contest on each ballot. These files do not contain the names of the contests and candidates. Instead, each result or selection is associated with the IDs of the corresponding ballot design, contest instance, and choice instance from the scanner’s copy of the election definition.

When loading results from the memory card, the EMS interprets them using its copy of the election definition. As long as the memory card and the EMS use identical election definitions, the results should be read correctly—as will normally be the case when scanners are properly configured. However, the Dominion EMS does not verify that they are identical. When they are different, as was the case with most of Antrim’s scanners, this can lead to inaccurate results.

3.4 Effects of the Ballot Design Changes

To perform the last-minute ballot design corrections, ElectionSource modified the election project and regenerated the ballot layouts and election definitions. I followed the same steps, and the only indication given by the EMS software that the changes might cause problems was a notice that, “All previously created and deployed election files will be unusable.” The software did not warn that use of the old files could potentially lead to inaccurate results. Antrim *did* use the previously deployed election definition files in 16 of the 18 scanners.

The way that the election definitions were regenerated had the side effect of assigning different choice instance IDs to most voting targets throughout the county, while leaving the ballot design IDs and most of the contest instance IDs the

same. This rendered the revised election definitions subtly incompatible with those that had already been deployed.

Correcting the school board contest on the Central Lake 1V ballot required adding a write-in blank. This caused the choice instance IDs to increase by one in later contests on that ballot and in all contests for alphabetically later townships.¹ These changes, coupled with the county’s failure to update the memory cards in most scanners, caused the major errors.

Figure 2 illustrates what went wrong. Scanners using the initial definition recorded votes to the memory cards using the initial choice instance IDs. The EMS interpreted the data using the revised choice instance IDs. Where these differed, the EMS assigned the votes to the wrong candidates. If the voter marked the first choice in an affected contest, the choice instance ID was no longer associated with the same contest instance ID under the revised election definition, and the EMS silently ignored the selection. A mark for any other choice was interpreted by the EMS as a mark for the choice above it.

The changes to the other two ballot designs were less significant. The correction in Mancelona Township left the number of choices the same, so it did not change the ID sequence. The added contest in Warner Township incremented later choice instance and contest instance IDs, but since Warner was the last township alphabetically and its results were entered manually on election night, there was no effect on reporting.

3.5 Why Cards Failed to Load

To understand what the EMS operator saw on election night, I loaded the memory card data using a copy of the software. The Warner card caused a generic error, “Failed to load [filename].” The Elk Rapids 1 and Milton 1 cards caused a warning, “Result file [filename] has not been closed. Result file will be loaded,” although no votes were loaded from either card. For all other cards, the EMS reported, “Result file [filename] was loaded successfully.” This appeared even for cards which were loaded incorrectly due to the mismatched election definitions.

I investigated why the three cards failed to load. Warner was uniquely affected by the change to fix the missing contest, which resulted in the card containing some votes recorded under old contest instance IDs that were no longer associated with the same ballot ID under the revised election definition. The EMS detected this anomaly and refused to load the card.

The Elk Rapids 1 and Milton 1 memory cards failed to load for a different reason: they did not contain any election results! To determine why, I examined the scanner logs on those cards (see Figure 6 in the appendix). The logs show that on election night, after closing the polls and printing poll tapes, workers in both townships commanded the scanners to “rezero” their memory cards, discarding the results and resetting the cards to a pre-election state. Rezeroing the cards is a significant deviation from normal procedures. Although the poll tape contains a record of the scanner’s totals, manually entering the

¹This explains why the election definition for Banks Township did not change: “Banks” comes before “Central Lake” in alphabetical sequence.

Central Lake, Precinct 1V Initial Ballot Definition		Central Lake, Precinct 1V Revised Ballot Definition	
Local School District		Local School District	
Board Member Ellsworth Schools Vote for not more than 2		Board Member Central Lake Schools Vote for not more than 3	
952	Mark Edward Groenink	952	Melanie Eckhardt
953	Christopher Wallace	953	Keith Shafer
954		954	
955		955	
Proposal Section		Proposal Section	
State		State	
Proposal 20-1 A proposed constitutional amendment to allow...		Proposal 20-1 An amendment is being...	
956	Yes	957	Yes
957	No	958	No

(1) The Central Lake, Precinct 1V ballot was modified to reflect the correct school board contest. This necessitated inserting an additional write-in blank.

(2) The insertion incremented the ID number of every subsequent voting target.

(3) In alphabetically later townships, the change in Central Lake incremented the ID for every choice.

(4) A scanner using the initial definition records this Trump vote as ID 970. The EMS, using the revised definition, reports ID 970 as a vote for Biden.

Figure 2: Explaining the Major Reporting Discrepancy. The EMS assigns sequential IDs to voting targets across every ballot style. Correcting the ballot design for Central Lake Village added a write-in blank, which incremented the ID of every target on later contests and ballot styles. Most of Antrim’s scanners were not updated, so they used the old IDs to record votes. When the EMS interpreted these votes using the new IDs, it assigned them to the wrong candidates.

results is a laborious (and error-prone) process. Moreover, the data on the memory card is the primary electronic record of the votes and an important source of evidence if the integrity of the physical ballots is called into question.

It is noteworthy that workers in separate polling places rezeroed the memory cards almost simultaneously. Furthermore, it was not the first time that Antrim poll workers made this mistake. I found that during the previous election, in August 2020, the Elk Rapids AV card was rezeroed and entered manually. This pattern of lapses suggests that there may be a serious deficiency in poll worker training or documentation.

These procedural errors may have contributed to the publication of incorrect results in November 2020. Had the cards loaded, the county-wide discrepancies would have been even more stark, making it more likely that county staff would have noticed before posting the report. Moreover, the error message when loading the Warner card might have alerted staff that there was a potentially serious problem, had not a superficially similar issue occurred in August for which the solution was simply to enter results manually. This appears to be an instance of normalization of deviance—aberrant practices coming to be considered harmless if they do not immediately cause a catastrophe—a phenomenon that has contributed to major disasters in aerospace and industry [46].

	Final Results				Reproduced Error			Δ	
	Biden	Trump	Jorgensen		Biden	Trump		B	T
Banks	349	756	11	(a)	349	756		0	0
Central Lake	549	906	16	(a)	549	906		0	2
Chestonia	93	197	3	←	197	3		0	0
Custer	240	521	11	←	521	11		2	0
Echo	198	392	8	←	392	8		0	0
Elk Rapids 1	784	611	5	(b)	784	611		0	0
Elk Rapids AV	202	414	12	←	414	12		0	2
Forest Home	610	753	19	←	753	19		2	0
Helena	306	431	4	←	431	4		1	0
Jordan	183	371	13	←	371	13		1	0
Kearney	471	743	16	←	743	16		1	0
Mancelona 1	276	835	20	(c)	276	835		0	0
Mancelona 2	247	646	13	(c)	247	646		0	0
Milton 1	143	478	12	(b)	143	478		0	0
Milton AV	626	543	6	←	543	6		0	0
Star	161	462	10	←	462	10		0	0
Torch Lake	462	526	7	←	526	7		1	1
Warner	60	163	3	(b)	60	163		0	0
Total	5960	9748	189		7761	4504		8	5

Precinct notes: (a) IDs not shifted; (b) Entered manually; (c) Used updated card

Table 3: Approximating the Presidential Errors. A simple rule closely reproduces the erroneous initial results. Working backwards from the final results (*left*), shift Trump’s votes into Biden’s column and Jorgensen’s into Trump’s column (*right*), except for in precincts that were unaffected for the reasons noted. This yields totals that differ from the initial results by only 13 votes, or 0.1% (Δ). The erroneous initial results can be reproduced exactly by accounting for the more complex effects of overvotes and the straight-party option and for the Central Lake rescan.

3.6 Effects on the Presidential Contest

The presidential candidates appeared in the same order on all ballots, beginning with Biden, Trump, and Libertarian Party candidate Jo Jorgensen. The ballots also contained a “Straight Party Ticket” option, for which the first three choices were the Democratic, Republican, and Libertarian parties. If the voter selected a party, that party’s presidential candidate would receive a vote unless the voter selected a presidential candidate from a different party or a write-in.

The initial results from several scanners were unaffected by the election definition mismatch. In Banks, the election definition simply did not change. In Central Lake, although the altered school board race affected choice instance IDs for all subsequent contests, it occurred after every instance of the presidential contest within the township. Both Mancelona cards were provisioned with the revised election definition before the election. Finally, the Elk Rapids 1, Milton 1, and Warner cards could not be loaded into the EMS, so the initial results were entered manually and unaffected.

The initial results from all other scanners were impacted in a consistent way. The EMS ignored selections for Biden, treated selections for Trump as selections for Biden, and treated selections for Jorgensen as selections for Trump. Other third-party candidates and write-ins were similarly shifted. The same pattern occurred with the straight-party option. Considering the effects on the straight-party and presidential selec-

tions together, the EMS ignored *most* votes intended for Biden, reported all votes intended for Trump as votes for Biden, and reported all votes intended for Jorgensen as votes for Trump.

This pattern lets us almost exactly reproduce the erroneous initial results from the final presidential results by simply shifting the totals for each candidate in the affected precincts, as shown in Table 3. Biden and Trump’s totals in this reconstruction differ from the initial results by only 13 votes (0.1%).

This small difference is due to unusual cases not covered by the simple rule above. Ballots with both the Republican straight-party option and Biden selected were *correctly* reported as votes for Biden, because the EMS misinterpreted the candidate selection as blank but also misinterpreted the party selection as Democratic. Similarly, ballots marked for the Libertarian straight-party option and for Biden were reported as votes for Trump, since the EMS misinterpreted them as having the Republican Party selected with no selection in the presidential contest. Table 4 lists all cases in which the EMS attributed correctly marked ballots to Biden and to Trump.

Finally, if the voter made *two* selections in the straight-party option or for president, this creates an overvote condition and should lead to both being ignored. However, if one of the marks was for the Democratic Party or Biden, the EMS ignored that mark but accepted the second mark as if it had been shifted one place up the ballot, leading to a complicated set of potential errors. Such overvotes were extremely rare.

Voter's Selections		EMS Interpretation		Correct Vote		EMS Reported
Party	President	Party	President			
<i>No selection</i>	Trump	<i>No selection</i>	Biden	Trump	≠	Biden
<i>X</i>	Trump	<i>X - 1</i>	Biden	Trump	≠	Biden
Republican	<i>No selection</i>	Democratic	<i>No selection</i>	Trump	≠	Biden
Republican	Biden	Democratic	<i>No selection</i>	Biden	=	Biden
<i>No selection</i>	Jorgensen	<i>No selection</i>	Trump	Jorgensen	≠	Trump
<i>X</i>	Jorgensen	<i>X - 1</i>	Trump	Jorgensen	≠	Trump
Libertarian	<i>No selection</i>	Republican	<i>No selection</i>	Jorgensen	≠	Trump
Libertarian	Biden	Republican	<i>No selection</i>	Biden	≠	Trump

Table 4: Votes Reported for Trump and Biden. As a result of the mismatched election definitions, when the EMS interpreted memory cards from most scanners that used the initial election definition, Biden received the votes intended for Trump plus those of voters who selected the Republican straight-party option but split the ticket for Biden. Trump received the votes intended for Libertarian candidate Jo Jorgensen plus those of voters who selected the Libertarian straight-party option but split the ticket for Biden. *X* represents any choice, and *X - 1* the choice above it.

3.7 Data Entry Errors

To correct the errors caused by the mismatched election definitions, county workers manually entered results for all affected tabulators and published a second, partial set of unofficial results on November 5 [4]. However, due to an operator error, totals for three precincts included *both* the manually entered results and the incorrect results loaded from the memory cards.

While entering results, county staff discovered that the poll tape for Central Lake Village contained the wrong school board race, because the memory card had used the initial election definition from before the race was corrected. To fix this, county staff reinitialized the Central Lake memory card using the revised election definition, and the township scanned the ballots again on November 6 [2].

The County Board of Canvassers certified the official results late on November 6, including the results from rescanning Central Lake. However, some results did not match the poll tapes as a result of data entry errors. The most common kind of error was contests or candidates that were omitted, but there were also some typographical errors. In all, these errors affected about 2.6% of votes county-wide.

Michigan canvassing procedures call for county canvassers to compare the reported results to the poll tapes from individual machines [29], so these errors should have been caught on November 6, but they were not. Checking the poll tapes is important not only for catching data entry errors but also as a security mechanism: it ensures that results are not manipulated during transmission from the polling places, or by accessing the EMS after the election. That this comparison was not correctly completed by the canvassers in Antrim is a significant procedural breakdown that warrants further investigation.

Antrim amended its certified results on November 16 to fix data entry errors in one township and again on November 21 to fix data entry errors in five more townships. These second amended certified results remain the official results of the election [7]. The Board of State Canvassers certified Michigan's state and federal results on November 23 [26].

3.8 Confirming That Errors Have Been Corrected

I conducted a series of experiments to confirm that the explanations discussed above fully account for the discrepancies between the county-level results and the poll tapes and to verify that these discrepancies have been corrected.

Remedying the Election Definition Mismatch I used the EMS software to test whether loading the memory cards using a matching election definition would produce the reported results. First, I loaded the initial election project and attempted to load the memory cards from all scanners that used the initial election definition for which electronic results were available.² These 13 cards loaded successfully, including Warner's, which had failed to load on election night. Using a series of SQL queries, I confirmed that the results obtained in this way matched the final certified results from the EMS database.³ Next, I restored the revised election project and loaded the Central Lake and Mancelona 1 and 2 memory cards under the revised election definition. The loaded results again matched the final results in the EMS database. This demonstrates that using matching election definitions would have prevented the reporting anomalies. It also confirms that the manually entered results from the 16 scanners for which memory card data is available do not contain further data entry errors and match the results that would have been obtained from the cards.

Electronically Counting Votes Without the EMS In a second experiment, I counted the presidential results from the cards without relying on the EMS software. This provides an independent check of the accuracy of the results aggregation.

Each memory card stores cast vote records (CVRs) in a proprietary binary file format. The files are encrypted using AES in CBC mode, but the encryption key and initialization vector

²That is, all but Central Lake and Mancelona 1 and 2, which scanned using the revised definition, and Elk Rapids 1 and Milton 1, where the cards were rezeroed at the polling places.

³The only discrepancy was that the Boyne Falls Public Schools Millage appears in the reported results for Warner (with zero recorded votes) but is not present on the Warner memory card. I explain why in Section 4.

can be retrieved from the EMS database. I decrypted the files and reverse engineered the data format. Each voting target is represented by the associated ballot ID, contest instance ID, and choice instance ID, and by a boolean value indicating whether the scanner detected that the target was marked.

I created a Python script to extract the set of marked targets from each memory card and to count them using election definition data from either the initial or the revised election project database. Producing correct counts required several considerations. The program first verifies that each marked choice instance ID is in fact associated with the contest instance ID given in the CVR, and otherwise it ignores the mark. Next, it discards any overvotes and then applies Michigan's straight-party voting rules to partisan contests.

I used the program to count the CVRs from each card with the matching version of the election definition. As expected, every card that contains results data (i.e., all but Elk Rapids 1 and Milton 1) exactly matched the final presidential results.

I then used this program to count all cards under the revised election definition, mimicking the behavior of the EMS on election night. As expected, the presidential results were an exact match for the initial results, except for those that were entered manually and Central Lake, which matched the results of the rescan. This provides additional confirmation that the mismatched election definitions caused the major errors.

Manually Comparison to the Poll Tapes For additional confirmation, I manually compared the final election results [7] to copies of the poll tapes provided by the county.⁴ The results on the poll tapes for all contests in all precincts are correctly reflected in the final results. This confirms that the county-level reporting anomalies have been fully corrected.

4 Discrepancies in the Scanner Poll Tapes

The analysis above firmly establishes that the major reporting anomalies resulted from Antrim's failure to ensure that all scanners used the same election definition as the EMS. It also shows that the errors introduced during county-wide reporting have been corrected, and the final results match the poll tapes.

However, the poll tapes from certain precincts themselves contain errors that affect smaller numbers of votes, mainly in specific down-ballot contests. These errors have a different pattern than the major reporting anomalies. In most precincts, the design of the printed ballots was not changed, and so the individual scanners counted normally whether they were using the initial or the revised election definition. But ballot designs *were* changed in parts of three townships—Central Lake, Mancelona, and Warner—and I show that the changes led to a small number of errors on poll tapes within these localities. I investigate what caused the poll tape errors, determine the effects, and show that certain errors affecting a small number of votes remain uncorrected in the final results.

⁴The final certified results published on Antrim's website [7] are missing pages 47–48, containing parts of two contests, likely due to human or mechanical error during scanning. Antrim provided the missing pages at my request.

4.1 Outdated Ballots and Election Definitions

Two factors led to inaccuracies in these townships. First, scanners using the initial election definitions omitted contests and choices that were added when the ballot designs were revised, and they miscounted choices for which voting targets changed position. Second, some of the paper ballots themselves used the outdated designs, and these were analogously miscounted when scanned using the revised election definitions.

The last-minute ballot design changes occurred after absentee voting had begun. For instance, according to Antrim County, 224 absentee ballots for Central Lake Village had been sent to voters before the change. Although these voters were later sent corrected ballots, some of them voted using the initial ballot designs. There was apparently no special process for handling the initial ballots that were received—they were scanned mixed together with the revised ballots. Because ElectionSource had regenerated the ballot designs in such a way that the initial and revised designs used the same ballot design IDs, there was no way for the scanners to distinguish between the two versions. They acted as if all used either the initial design or the revised design, depending on which election definition was on the memory card.

Effects in Warner Township The ballot for Warner Township Precinct 1BF was altered to add a missing contest, the Boyne Falls Public Schools Sinking Fund Proposal, as shown in Figure 1c. It was added to the end of the last column of the ballot, so no other contests or voting targets were affected. However, as the Warner scanner was never updated to read the revised ballot design, votes in this contest were not read by the scanner at all, and it does not appear on the poll tape.

There were only three registered voters in Warner 1BF. The EMS shows three ballots were cast, but no votes were recorded for the Sinking Fund contest. Some voters may have left it blank, and any who voted ballots using the initial design would have lacked the contest entirely. Therefore, we can conclude only that 0–3 votes in the Sinking Fund contest were never counted. This is too few votes to affect the outcome.

Effects in Mancelona The Mancelona Precinct 1V (Mancelona Village) ballot was revised to add a missing candidate for Village Trustee, Eugene K. Kerr. The contest also changed from vote-for-three to vote-for-two, so the effect was that Kerr replaced a write-in blank, and no other contests or choices changed position, as shown in Figure 1b.

Mancelona's scanners used the revised election definition, but some absentee voters may have used the initial ballot design. Since the scanners were not configured to read it, if any of these voters selected the first write-in blank, the scanners would have misinterpreted this as a vote for Kerr. Likewise, if any of these voters selected three candidates, the votes would have been unexpectedly ignored as overvotes. The data is insufficient to determine how many votes, if any, were affected. However, the contest was decided by a large margin, so the outcome was likely unaffected by these unusual cases.

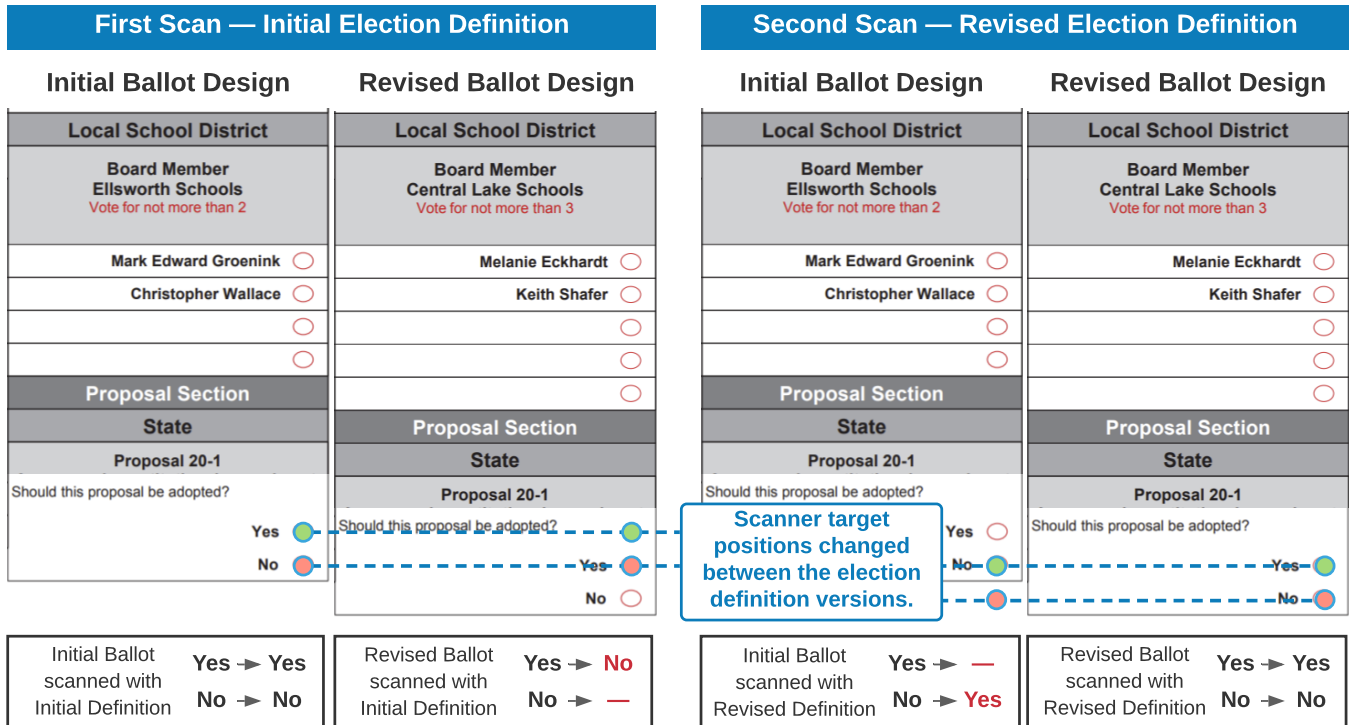


Figure 3: Central Lake scanned ballots twice, first with the initial election definition (*left*) and then with the revised election definition (*right*). Some ballots used the initial design and others used the revised design, in which targets for State Proposal 20-1 shifted down by one row. In both scans, Proposal 20-1 selections on ballots that did not match the election definition in use were miscounted, as shown in boxes at bottom.

4.2 Effects in Central Lake

The effects of the ballot design changes in Central Lake were considerably more complicated. Figure 3 shows how the ballot design in Central Lake Precinct 1V (Central Lake Village) was altered to correct the school board contest from Ellsworth Schools to Central Lake Schools. This changed the name of the contest and candidates and also the allowed number of selections, which increased from two to three. The increase necessitated an additional write-in blank, which shifted the the contest below, State Proposal 20-1, down by one row.

Central Lake used the initial election definition on election day, and results loaded from the memory card were included in the first unofficial results. The township then rescanned using the revised election definition on Nov. 6, producing a second poll tape, which was manually entered as part of the certified results. Results in the three contests affected by the ballot changes differed dramatically between the two scans. Neither set of results is correct, since ballots that used the revised design were read incorrectly during the first scan and vice versa.

Effects on the School Board Contest During the second scan, the scanner interpreted ballots that used the initial design, showing the Ellsworth Schools contest, as if they had votes for the Central Lake Schools contest, and awarded votes to candidates in the equivalent positions. On these ballots, the darkly shaded “Proposal Section” header occupies the

position of the voting target for the third write-in blank on the revised design. This caused the scanner (which only senses the shading) to act as if there was a vote for the third write-in. The memory card records 10 write-ins cast using the first blank, 4 using the second, and 74 using the third. Since voters usually use earlier write-in blanks before later ones, this strongly suggests that at least 70 ballots used the outdated ballot design. Given the reported margins, these ballots are unlikely to have affected the outcome of the Central Lake Schools contest.

Effects on State Proposal 20-1 The poll tapes also contain incorrect results for State Proposal 20-1, as depicted towards the bottom of Figure 3. In the revised ballot design, the voting target for “Yes” is in the same position as the target for “No” was in the old design, and the target for “No” is in a position that was unused in the old design. In the first scan, revised ballots were misread such that the poll tape reported “Yes” votes as “No” and failed to record “No” votes at all. During the second scan, ballots that used the initial design had “Yes” votes ignored and “No” votes counted for “Yes”. Since the final reported results match the poll tapes, these errors have not been corrected. In Appendix B, I use data from the two scans to estimate that approximately 61 votes were not incorporated into the final results. Since State Proposal 20-1 was decided by more than 3 million votes statewide, the error in Central Lake Village could not have affected the outcome.

A Proposed Initiated Ordinance to Authorize One (1) Marihuana Retailer Establishment Within the Village of Central Lake (1)	
Yes:	262
No:	262
Total Votes:	524

A Proposed Initiated Ordinance to Authorize One (1) Marihuana Retailer Establishment Within the Village of Central Lake (1)	
Yes:	262
No:	261
Total Votes:	523

Election Day Scan (Nov. 3)

Second Scan (Nov. 6)

Figure 4: Central Lake Village Marihuana Initiative. Central Lake scanned its ballots twice. In one local contest, the poll tapes differ by one vote—enough to change the outcome. The data suggests that three ballots that were scanned on Nov. 3 were omitted when ballots were rescanned on Nov. 6, either correctly or due to human error.

4.3 Three Potentially Missing Ballots

Beyond the discrepancies noted above, the two Central Lake scans show a large number of small differences. Many contests have one or two fewer votes in the second scan. One of these differences potentially affected the outcome of a local contest held in part of the township, the Central Lake Village Marihuana Retailer Initiative (Figure 4). In the first scan, the initiative was tied (and thus defeated), but in the second scan, which became the final result, it passed by a single vote.

The scanner log from election day, as recorded in the EMS, shows that 1494 ballots were scanned in all of Central Lake. Yet the log from the memory card shows that only 1491 ballots were scanned on November 6. Antrim has not offered an explanation for this difference, but the data suggests that three ballots that were included in the first scan were omitted when the ballots were rescanned, whether correctly or erroneously.

The memory card from the first scan was overwritten to prepare it for the second scan, so the original digital records of the ballots are not available. However, the EMS database contains CVRs derived from the original memory card. Using this data, I was able to reconstruct the scanner’s interpretation of the three ballots, shown in Figure 7 in the appendix.

The CVRs in the EMS record the EMS’s interpretation of each ballot, which was sometimes affected by the election definition mismatch. Within Central Lake, only ballots from Central Lake Village are affected, and then only particular contests. Selections for the third write-in blank in the school board contest were never recorded. In subsequent contests, selections for the first choice were never recorded, and those for any later choice were assigned to the preceding choice. I extracted the CVRs for the first scan from the EMS database and the CVRs for the second scan from the memory card.

After accounting for the election definition mismatch, all but three ballots from the first scan also appear in the second scan.

The first ballot is from Central Lake Precinct 1CENT; the reconstruction is complete, since this precinct was not affected by the election definition mismatch. The second ballot is from Central Lake Village and so would have been affected by the mismatch, but it was recorded by the EMS as blank. The third ballot is also from Central Lake Village. After correcting for the election definition mismatch, the data indicate that the scanner detected a mark for “No” in the Marihuana Initiative.

There are multiple possibilities for why these three ballots were not included in the second scan. For instance, it is possible that they were deemed invalid due to some defect and properly excluded (as may be suggested by the fact that one was blank). It is also possible that the election workers simply did not scan them the second time, due to human error. If these ballots are valid, it is likely that the final outcome of the Central Lake Village Marihuana Retailer Initiative is incorrect and that the true result is a tie, as shown on the election day poll tape. As no one requested a recount during the statutory period for challenging the result, the final outcome stands.

4.4 Results of the Presidential Hand Count

On December 17, the state conducted a county-wide hand-count of the presidential contest [32]. It provides strong empirical evidence that there are no significant errors in Antrim’s final presidential results, including due to any scanning mishap. The recount [31] showed a loss of 1 vote for Biden, a gain of 12 votes for Trump, and gains of 1 vote for three other candidates. Although Trump’s total changed by more than any other candidate’s, it differed from the county’s final result by only about 0.1%. (Trump lost state-wide by 2.8%.)

The precinct-level totals closely matched the scanner results. Within individual precincts, Trump and Biden’s results changed by at most three votes, except in Star Township, where Biden gained 5 votes and Trump gained 6. Eight precincts showed no change for either Trump or Biden, and six (including Central Lake and Warner) showed no changes.

Small differences are common when ballots are counted by hand [21]. Sometimes people counting ballots make mistakes. Humans also interpret some votes differently than do optical scanners, which can misread votes when voters incompletely fill-in voting targets or otherwise deviate from ballot instructions. Such “marginal marks” can cause scanners to fail to count a valid vote, count an invalid vote, or assign a vote to the wrong candidate [8].

Notably, the hand-count results from Central Lake agree with the results of the township’s second scan, which found 906 votes for Trump, and not the first scan, which found 908 votes for Trump. This may indicate that the three ballots discussed above (two of which my reconstruction shows were marked for Trump) were not present during the hand count. It is also possible that this is a coincidence, and Trump lost two votes in the Central Lake hand count for unrelated reasons.

5 Critique of the ASOG Report

This section reviews the ASOG report in light of the preceding analysis. The “Antrim Michigan Forensics Report—Revised Preliminary Summary, v2”, dated December 13, 2020, was prepared by Russell James Ramsland, Jr., of Allied Security Operations Group (ASOG) based on his analysis of the same forensic data I examined. A redacted version is available online [24]. The report contains an extraordinary number of false, inaccurate, or unsubstantiated statements and conclusions, many of the most serious of which I refute below.

5.1 Claims Regarding Adjudication

Ramsland’s central conclusion is that “the Dominion Voting System is intentionally and purposefully designed with inherent errors to create systemic fraud and influence election results.” His reasoning is that the system generates many errors while scanning ballots in order to cause the images of the ballots to be reviewed by an EMS operator, a process known as electronic adjudication in which the votes can be manually edited. This provides an opportunity, Ramsland believes, for a malicious operator to change votes without being detected. Citing his forensic examination, Ramsland claims that a “staggering number of votes [in Antrim] required adjudication,” and that “all adjudication log entries for the 2020 election cycle are missing” and must “have been manually removed.”

There are several problems with this theory. First, adjudication occurs after ballots are scanned and poll tapes are printed. In Antrim, the final results match the poll tapes in essentially all cases and thus could not have been altered in adjudication.

Second, Ramsland mischaracterizes the adjudication process. Dominion’s adjudication system produces detailed logs, which are recorded in the EMS together with the ballot scan and the scanner’s original interpretation, as illustrated in Figure 5. Far from being an ideal way to cheat without possibility of detection, adjudication creates abundant digital evidence.

Third, and fatally, electronic adjudication functionality was not enabled in Antrim during the November 2020 election. It is an optional component of Democracy Suite. Antrim did not purchase it, and my examination of the EMS shows that it was not installed. There are no adjudication logs for the simple reason that adjudication was not used. Moreover, the tabulators were not configured to store ballot images—a necessary pre-

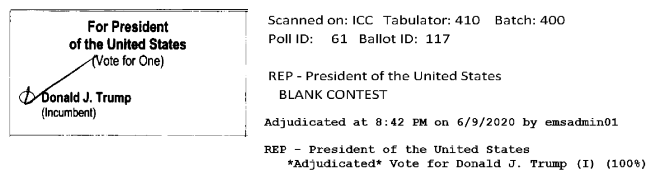


Figure 5: An Adjudicated Vote. Dominion’s adjudication system stores the ballot image, the scanner’s interpretation of the votes, and a log of any changes made by the system operator. Electronic adjudication is an optional feature and was not used in Antrim County.

condition for electronic adjudication—and my inspection of the memory cards confirms that no ballot images are present. Far from a “staggering number” of ballots being adjudicated, the actual number was zero, and therefore Ramsland’s theories are completely inapplicable to the incident in Antrim.

5.2 Claims Regarding Errors and Error Rates

Ramsland claims that Antrim’s scanners exhibited a high rate of errors during ballot processing as a means of enabling systemic fraud. Some scanning errors did occur, as I explained in Section 4, but they affected only specific contests in a small number of precincts, and there is no reason to believe they were intentional. However, Ramsland is largely referring to others kinds of errors that he believes occurred on the basis of mistaken interpretations of the forensic evidence.

For instance, the report repeatedly refers to an error rate of 68.05%. Ramsland calculates this from the Central Lake scanner log, which contains 15,676 lines, 10,667 of which he classes as errors. These “resulted in overall tabulation errors or ballots being sent to adjudication,” he says, concluding that “[t]his high error rate proves the Dominion Voting System is flawed and does not meet state or federal election laws.” In actuality, the 68% figure is meaningless. Scanning a ballot produces a variable number of log lines (from two to dozens), often including many benign warnings or errors. The fraction of lines does not represent a fraction of ballots or votes.

Moreover, the errors in the log file do not mean what Ramsland purports them to. He claims that “there were 1,222 ballots reversed out of 1,491 total ballots cast, resulting in an 81.96% rejection rate. All reversed ballots are sent to adjudication.” This is referring to log entries that say, “Ballot has been reversed.” These entries have nothing to do with adjudication. They mean that the ballot has been returned to the voter; i.e., the *paper feeding mechanism* has been reversed, as when a vending machine returns a misfed bill. This is a benign and common occurrence. It often takes multiple tries to feed a ballot into a scanner, particularly when using a ballot privacy sleeve like those provided in Michigan.

Ramsland goes on to claim that on “November 21, 2020, an unauthorized user unsuccessfully attempted to zero out election results.” His evidence is an EMS log entry, “EmsLogger - There is no permission to {0},” which he claims “is direct proof of an attempt to tamper with evidence.” Programmers will recognize that {0} is merely a format-string placeholder [37]. It has nothing to do with “zeroing” election results.

Citing another EMS log entry, “XmlException: The ’ ’ character, hexadecimal value 0x20, cannot be included in a name”, Ramsland concludes, “Bottom line is that this is a calibration that rejects the vote.” This is baseless. The error refers to an XML attribute or entity name, which are not allowed to contain whitespace [13]. It has no relation to candidate names, and there is nothing to suggest it resulted in a rejected vote.

Ramsland further claims that the scanner log shows that “RCV or Ranked Choice Voting Algorithm was enabled”

which “allows the user to apply a weighted numerical value to candidates and change the overall result.” However, although some log entries reference the voting system’s RCV feature, they do not indicate that it was enabled. The EMS and memory card data show that RCV was not in use, as do the results of the hand recount of the presidential contest.

5.3 Claims Regarding “Software Updates”

Ramsland repeatedly mischaracterizes the updates to the scanner election definitions as “software updates.” Although sometimes referred to as “ballot programming,” election definitions in the Dominion system are not software but rather data files that specify the layout of the ballots. Ramsland is wrong when he describes Central Lake as scanning twice with “different software versions of the operating program to calculate, not tabulate votes.” The scanner used the same software both times but was configured using different election definitions. Ramsland seems to confuse ballot definition changes with firmware updates. Ballot definitions are necessarily changed for every election, but there is no evidence that any firmware updates occurred during the 2020 election cycle in Antrim.

5.4 Claims Regarding Security Problems

Some of the ASOG report’s claims about security problems in Antrim’s election equipment are correct or based in fact, but Ramsland draws several incorrect conclusions.

Software Updates The report is correct that the EMS is missing important Windows security patches, potentially leaving it vulnerable to various methods of attack. It runs Windows 10 version 1607, which was released in 2016, and it appears not to have had any updates installed for at least two years. The antivirus definitions are similarly out of date.

This is a serious security problem, but Ramsland is wrong that “[t]here is no way this election management system could have passed tests or have been legally certified.” In fact, missing software updates are frequently an unfortunate consequence of the federal certification process, under which voting system vendors must obtain EAC approval for any changes to election software, including Windows updates [45]. If there are any security updates that have been approved for the Dominion system, Antrim should promptly install them. However, installing unapproved updates, even for critical vulnerabilities, would potentially violate the system’s certification.

Network Connectivity The report is correct that Dominion scanners have the ability to be connected to external networks, which some Michigan jurisdictions use to transmit preliminary results to their EMSes via wireless modems. The Michigan Secretary of State’s Election Security Advisory Commission has recommended that jurisdictions discontinue wireless result transmission, warning that the practice creates risks that “unofficial results could be intercepted or manipulated, that the locality’s election management system server could be attacked remotely over the network, or that optical scanners could themselves be remotely attacked” [36]. However,

Antrim did not purchase and does not use the Dominion wireless functionality. Instead, results are returned by physically transporting memory cards. Based on the EMS logs, it does not appear that the EMS has ever been connected to a network.

Security Event Log The report is correct that the Windows security event log in the EMS image only contains entries extending back to November 4, 2020, the day after the election. However, the timing appears to be a coincidence: the system is configured so that the maximum log size is 192 MB, and when it grows beyond this size, the oldest entries are automatically removed. Nevertheless, since security logs are important sources for forensic investigation, they should be retained for as long as they are potentially relevant. The fixed size used in Antrim was clearly too small.

Authentication and Access Control The report is correct that the authentication and access control mechanisms on the EMS have serious weaknesses. Antrim workers almost exclusively used a single Windows user account that had full administrative privileges, including to alter log files and bypass other security controls. For instance, anyone logged into this account can make arbitrary changes to the election databases using SQL Server Management Studio (which is already installed), and this database access can be used to circumvent account passwords within the EMS software applications.

The report also states that the EMS hard disk was not encrypted. This would make it possible for an attacker with physical access to the computer to bypass the Windows account passwords, install malicious software, and read or change arbitrary data. Whether or not Antrim maintains strong physical security for the EMS, disk encryption should be enabled going forward to provide an added layer of defense.

These genuine security problems should be mitigated promptly. However, there is no evidence that any security problem was ever exploited against Antrim’s election system. As my analysis shows, the anomalies that occurred in the November 2020 results are fully explained by human error.

6 Conclusions and Recommendations

My investigation shows that the Antrim incident was initiated by unusual circumstances. After making last-minute revisions to certain ballot designs, workers made two key errors that directly led to inaccurate results: (i) County staff failed to ensure that all scanners used the revised election definition; this caused the EMS to misinterpret some scanner results, leading to major election-night reporting errors (now fully corrected). (ii) Township staff failed to ensure that all ballots used the revised ballot designs; those that did not match the scanner configurations were misread, leading to smaller errors in specific down-ballot contests (that remain uncorrected).

Antrim could have discovered these problems before incorrect results were published or deemed official, but several opportunities to do so were missed: (i) Townships failed to notice poll tape errors during pre-election testing; (ii) Poll

workers erased memory cards, making the reporting errors harder to spot; (iii) County staff did not adequately investigate EMS errors on election night; (iv) County staff failed to “sanity-check” the initial results before posting them.

To their credit, the county and state quickly understood the technical cause of the major anomalies. However, during the process of correcting the original problems, further human errors occurred that led to additional inaccurate results: (i) County staff neglected to remove bad data before publishing updated results on November 5, again causing widespread reporting errors (later corrected); (ii) County staff made data entry errors when manually inputting results, affecting more than 2% of reported votes across the county (now fully corrected); (iii) County canvassers failed to ensure that all results matched the poll tapes, allowing data entry errors to affect some of the certified results (now corrected); (iv) Three ballots may have been omitted when Central Lake rescanned on November 6, which possibly changed the outcome of the Central Lake Village Marihuana Retailer Initiative.

The events in Antrim serve to remind us that elections are complex human processes that depend on the careful operation of technology and the faithful execution of procedures by people who, like everyone, occasionally make mistakes. That *so many* mistakes happened in Antrim speaks in part to the extreme pressures that election workers faced in 2020, amidst a pandemic and a bitterly contested presidential race. While some of these human errors would have been harmless individually, several of the procedures that broke down were also important security protections, and the combined effect of the mistakes undermined safeguards that should have ensured accuracy. Fortunately, my analysis was able to precisely account for all known anomalies in Antrim’s November 2020 results, and none was the product of a security breach.

6.1 Recommendations

Antrim’s experience suggests several lessons for improving the administration of future elections within the county, across the state, and throughout the country.

Strengthening Procedural Failsafes Jurisdictions should require *end-to-end* pre-election testing, in which memory cards from scanning test ballots are loaded into the EMS and the results are checked for accuracy. Such testing would have detected the mismatched election definitions in Antrim.

All states should also require a post-election comparison between reported results and the original poll tapes (and Michigan, which already requires such checks, should ensure they are properly performed). This provides an additional safeguard against errors introduced during reporting.

Finally, Michigan and other states should expand the use of risk-limiting audits (RLAs) so that they occur in all major contests. RLAs ensure that if the reported outcome is wrong, the audit has a high probability of proceeding to a full hand count [25]. This provides a last line of defense against error and fraud and additional basis for voter confidence.

Improving Usability for Election Workers Much research has addressed the usability of election technology for *voters* (e.g., [1, 9, 11, 39]), but there has been little attention to usability problems confronting election workers [15]. While there is no credible evidence that the Dominion system was deliberately designed to induce errors, the events in Antrim show that there were missed opportunities for the software to do more to help election staff avoid making mistakes. When modifying the ballot designs, the software stated that old ballots and election definitions would be “unusable,” but it failed to warn that using them anyway could lead to erroneous results. The EMS and scanners were also not programmed to detect or prevent the use of such incompatible ballots and election definitions. Dominion should revise its software to address these, and other voting system vendors should review their equipment to determine whether reporting errors could potentially occur under similar circumstances. Vendors, states, and researchers should devote more attention to usability in election management software, documentation, and training.

Safeguarding Election Management Systems The Antrim EMS lacked important security updates, had weak authentication and access control mechanisms, and was vulnerable to compromise if an attacker had physical access to the computer. These are serious issues, and vendors and jurisdictions should work to mitigate them on a priority basis, even though there is no indication that any of them was ever exploited in Antrim. Jurisdictions should pay particular attention to the physical security of EMS components. Although Antrim did not transmit scanner results over the Internet or use wireless modems, localities that do should discontinue these risky practices [36].

Facilitating Post-Election Forensics Jurisdictions should consider enabling the capability of their scanners to save ballot images. Although ballot scans cannot substitute for an RLA of the physical ballots [10], they may help resolve questions about the accuracy of results in future incidents, especially if the integrity of the paper trail is in doubt. Jurisdictions should also retain digital election records, such as memory cards and EMS data, for as long as physical records are kept. (Memory cards are commonly reused for the next election.) The events in Antrim demonstrate that such digital records can provide important evidence for investigating—or disproving—problems that are later discovered or alleged.

Learning from Election Incidents When future election incidents occur, even if they receive less public attention than the events in Antrim County, responsible states should consider performing investigations like this one to ensure that the problems are well understood and that lessons are disseminated to help other jurisdictions avoid similar issues. Post-incident technical investigations occur rarely in the elections world [47], but they are widely practiced in industries that prioritize safety and reliability, including transportation [20] and engineering [41]. Normalizing them within election administration would help uphold and enhance public trust.

Acknowledgements

This paper is derived from a report produced by the author as an expert witness under contract to the Michigan Department of Attorney General [22]. Subsequent work was supported in part by the National Science Foundation under Grant No. CNS-1518888 and by the Andrew Carnegie Fellows Program.

References

- [1] Claudia Ziegler Acemyan and Philip Kortum. “Assessing the usability of the Hart InterCivic eSlate during the 2016 Presidential Election.” In: *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 61.1 (2017), pp. 1404–1408.
- [2] Antrim Cnty. *Election Timeline*. Prepared by Antrim County Clerk Sheryl Guy. Nov. 2020. URL: <https://committees.senate.michigan.gov/testimony/2019-2020/Testimony,%20Antrim%20County%20Clerk%20Sheryl%20Guy.pdf>.
- [3] Antrim Cnty. *Unofficial Election Results*. Nov. 4, 2020. URL: http://www.antrimcounty.org/downloads/unofficial_election_results_november_3_2020.pdf.
- [4] Antrim Cnty. *Partial Unofficial Election Results*. Nov. 5, 2020.
- [5] Antrim Cnty. *Partial Unofficial Election Results*. Nov. 6, 2020.
- [6] Antrim Cnty. *Official Election Results, 1st Amended*. Nov. 16, 2020.
- [7] Antrim Cnty. *Official Election Results, 2nd Amended*. Nov. 21, 2020. URL: http://www.antrimcounty.org/downloads/official_results_2nd_amended.pdf.
- [8] Andrea Bajcsy, Ya-Shian Li-Baboud, Mary Brady, et al. *Systematic measurement of marginal mark types on voting ballots*. Technical report, National Institute for Standards and Technology, 2015.
- [9] Benjamin B. Bederson, Bongshin Lee, Robert M. Sherman, Paul S. Herrmson, and Richard G. Niemi. “Electronic voting system usability issues.” In: *Proc. ACM Conference on Human Factors in Computing Systems (CHI)*. 2003.
- [10] Matthew Bernhard, Kartikeya Kandula, Jeremy Wink, and J. Alex Halderman. “UnclearBallot: Automated ballot image manipulation.” In: *4th Conf. on Electronic Voting and Identity (E-Vote-ID)*. 2019.
- [11] Matthew Bernhard, Allison McDonald, Henry Meng, Jensen Hwa, Nakul Bajaj, Kevin Chang, and J. Alex Halderman. “Can voters detect malicious manipulation of ballot marking devices?” In: *41st IEEE Symposium on Security and Privacy*. May 2020.
- [12] M. Bowden and M. Teague. *The Steal: The Attempt to Overturn the 2020 Election and the People Who Stopped It*. Grove Atlantic, 2022.
- [13] Tim Bray, Jean Paoli, C. M. Sperberg-McQueen, Eve Maler, and François Yergeau. *Extensible Markup Language (XML) 1.0: Names and tokens*. W3C. <https://www.w3.org/TR/xml/#NT-Name>. 2008.
- [14] Emma Brown, Aaron C. Davis, Jon Swaine, and Josh Dawsey. *The making of a myth*. The Washington Post. May 9, 2021. URL: <https://www.washingtonpost.com/investigations/interactive/2021/trump-election-fraud-texas-businessman-ramsland-asog/>.
- [15] Dana Chisnell, Karen Bachmann, Sharon Laskowski, and Svetlana Lowry. “Usability for poll workers: A voting system usability test protocol.” In: *International Conference on Human-Computer Interaction*. Springer, 2009, pp. 458–467.
- [16] Samuel Dodge. *Judge allows forensic investigation of voting equipment in Antrim County*. MLive. Dec. 6, 2020. URL: <https://www.mlive.com/public-interest/2020/12/judge-allows-forensic-investigation-of-voting-equipment-in-antrim-county.html>.
- [17] Dominion Voting Systems. *Democracy Suite EMS Election Event Designer user guide, version 5.5::212*. Oct. 10, 2017.
- [18] Dominion Voting Systems. *Democracy Suite EMS Results Tally & Reporting user guide, version 5.5::16*. Oct. 10, 2017.
- [19] Ariel J. Feldman, J. Alex Halderman, and Edward W. Felten. “Security analysis of the Diebold AccuVote-TS voting machine.” In: *Proc. USENIX Electronic Voting Technology Workshop (EVT)*. 2007.
- [20] Eric Fielding, Andrew W Lo, and Jian Helen Yang. “The National Transportation Safety Board: A model for systemic risk management.” In: *Journal Of Investment Management* 9.1 (2011).
- [21] Stephen N Goggin, Michael D Byrne, and Juan E Gilbert. “Post-election auditing: Effects of procedure and ballot type on manual counting accuracy, efficiency, and auditor satisfaction and confidence.” In: *Election Law Journal* 11.1 (2012), pp. 36–51.
- [22] J. Alex Halderman. *Analysis of the Antrim County, Michigan November 2020 election incident*. Mar. 2021. URL: https://www.michigan.gov/documents/sos/Antrim_720623_7.pdf.
- [23] J. Alex Halderman. “Practical attacks on real-world e-voting.” In: *Real-World Electronic Voting: Design, Analysis and Deployment*. Ed. by Feng Hao and Peter Y. A. Ryan. 2016, pp. 145–171.
- [24] Russell J. Ramsland Jr. and Allied Security Operations Group. *Antrim Michigan forensics report, revised preliminary summary, v2 (redacted version)*. Dec. 2020. URL: <http://www.13thcircuitcourt.org/DocumentCenter/View/15743/Antrim-Michigan-Forensics-Report-12-13-2020--v2-REDACTED>.
- [25] M. Lindeman and P.B. Stark. “A gentle introduction to risk-limiting audits.” In: *IEEE Security & Privacy* 10 (2012).
- [26] Michigan Board of State Canvassers. *Draft meeting minutes*. Nov. 23, 2020. URL: https://www.michigan.gov/documents/sos/112320_draft_minutes_708672_7.pdf.
- [27] Michigan Bureau of Elections. *Election Officials Manual, Chapter 10: Preparation of election equipment*. Feb. 2019. URL: https://www.michigan.gov/documents/sos/X_Preparation_of_Voting_Equipment_266000_7.pdf.
- [28] Michigan Bureau of Elections. *Election Officials Manual, Chapter 12: Precinct Canvass—Closing the polls*. Feb. 2019. URL: https://www.michigan.gov/documents/sos/XII_Precinct_Canvass_-_Closing_the_Polls_266013_7.pdf.
- [29] Michigan Bureau of Elections. *Manual for Boards of County Canvassers*. Oct. 2020. URL: https://www.michigan.gov/documents/sos/BCC_Manual_464331_7.pdf.
- [30] Michigan Bureau of Elections. *Test procedure for tabulators and voter assist terminals (VAT)*. Jan. 2019. URL: https://www.michigan.gov/documents/test_deck_manual05_131814_7.pdf.
- [31] Michigan Department of State. *Antrim hand count tally sheet, Dec. 17, 2020*. URL: https://www.michigan.gov/documents/sos/AntrimCounty_Presidential_Race_Full_Hand_Count_November2020_711027_7.pdf.
- [32] Michigan Department of State. *Final numbers from Antrim County audit continue to affirm accuracy of election results*. Dec. 18, 2020. URL: <https://www.michigan.gov/som/0,4669,7-192-47796-547970--,00.html>.
- [33] Michigan Department of State. *General election audit processes*. 2020. URL: https://www.michigan.gov/documents/sos/2020_Gen_Election_Audit_Processes_711978_7.pdf.
- [34] Michigan Department of State. *Isolated user error in Antrim County does not affect election results, has no impact on other counties or states*. Nov. 7, 2020. URL: https://www.michigan.gov/documents/sos/Antrim_Fact_Check_707197_7.pdf.
- [35] Michigan Department of State. *Statewide election audit process affirms presidential election outcome*. Feb. 2021. URL: <https://www.michigan.gov/sos/0,4670,7-127--552029--,00.html>.
- [36] Michigan Election Security Advisory Commission. *Report and recommendations*. Oct. 2020. URL: https://www.michigan.gov/documents/sos/ESAC_Report_Recommendations_706522_7.pdf.
- [37] Microsoft. *C# reference: String interpolation*. URL: <https://docs.microsoft.com/en-us/dotnet/csharp/language-reference/tokens/interpolated>.
- [38] National Academies of Sciences, Engineering, and Medicine. *Securing the Vote: Protecting American Democracy*. National Academies Press, 2018. URL: <https://www.nap.edu/catalog/25120/securing-the-vote-protecting-american-democracy>.

- [39] M. Maina Olembo and Melanie Volkamer. “E-Voting system usability: Lessons for interface design, user studies, and usability criteria.” In: *Human-Centered System Design for Electronic Governance*. IGI Global, 2013.
- [40] Nicole Perloth and Jack Nicas. *No, software glitches are not affecting vote counts*. The New York Times. Nov. 9, 2020. URL: <https://www.nytimes.com/2020/11/09/technology/no-software-glitches-are-not-affecting-vote-counts.html>.
- [41] John A Stoop. “Independent accident investigation: A modern safety tool.” In: *Journal of Hazardous Materials* 111.1-3 (2004), pp. 39–44.
- [42] Tara Subramaniam. *Fact-checking Trump’s claims of voting machine errors in Michigan*. CNN. Dec. 16, 2020. URL: <https://www.cnn.com/2020/12/16/politics/antrim-county-michigan-error-trump-tweets-fact-check/index.html>.
- [43] Betsy Woodruff Swan. *Read the never-issued Trump order that would have seized voting machines*. Politico. Jan. 21, 2022. URL: <https://www.politico.com/news/2022/01/21/read-the-never-issued-trump-order-that-would-have-seized-voting-machines-527572>.
- [44] U.S. Election Assistance Commission. *Democracy Suite 5.5–A (modification)*. Jan. 2019. URL: <https://www.eac.gov/voting-equipment/democracy-suite-55-modification>.
- [45] U.S. Election Assistance Commission. *Windows Update critical FAQ*. 2020. URL: <https://www.eac.gov/windows-critical-update-faq>.
- [46] Diane Vaughan. *The Challenger launch decision: Risky technology, culture, and deviance at NASA*. University of Chicago Press, 1996.
- [47] Alec Yasinsac, David Wagner, Matt Bishop, Ted Baker, Breno de Medeiros, Gary Tyson, Michael Shamos, and Mike Burmester. *Software review and security analysis of the ES&S iVotronic 8.0.1.2 voting machine firmware*. Report for Florida Dept. of State. 2007.

```

Nov 03/2020 06:46:02 *****
Nov 03/2020 06:46:02 * System Starting
Nov 03/2020 06:46:02 * Model Type PCOS-320C (Rev 1072)
Nov 03/2020 06:46:02 * Serial Number: AAFAJHX0109
Nov 03/2020 06:46:02 * Protective Counter: 5360
Nov 03/2020 06:46:02 * Software Version: 5.5.3-0002 #2
Nov 03/2020 06:46:02   Fri Jul 27 09:18:31 CDT 2018
Nov 03/2020 06:46:02 * Election Project: Antrim November 2020
Nov 03/2020 06:46:02 *****
      :
Nov 03/2020 20:15:28 Total number of ballots = 1423.
Nov 03/2020 20:16:14 Administrator key for 'Admin' detected.
Nov 03/2020 20:16:14 Administrative Key inserted
Nov 03/2020 20:16:18 Admin chose to Close the Poll
Nov 03/2020 20:16:38 Correct passcode entered for Close.
Nov 03/2020 20:16:38 Requesting confirmation to close poll.
Nov 03/2020 20:16:49 Starting election database close poll
Nov 03/2020 20:16:49   procedure.
Nov 03/2020 20:16:49 Saving Poll-Close time.
Nov 03/2020 20:17:38 Beginning to create Total Results file.
Nov 03/2020 20:18:45 - Successfully created Total Results file
Nov 03/2020 20:18:45   '/cflash/1120_6_6_0_TOTALS.DVD' .
Nov 03/2020 20:18:46 Printing 1 copy of RESULTS TAPE
      :
Nov 03/2020 20:32:59 Admin chose Utilities Options
Nov 03/2020 20:33:07 Admin chose to Rezero the Results.
Nov 03/2020 20:33:16 Correct passcode entered for Rezero.
Nov 03/2020 20:33:16 Start election database re-zero poll
Nov 03/2020 20:33:16   procedure.
Nov 03/2020 20:35:24 Total Results completed (rc=0)
Nov 03/2020 20:35:24 >> Shutting down AVS.

```

Figure 6: Cards Mistakenly Rezeroed. Logs from Elk Rapids 1 (excerpt above) and Milton 1 show that workers at both locations “rezeroed” the memory cards after polls closed, discarding the digital results. The results had to be entered manually from the poll tapes.

Scanner	L&A Test Dates	Test Deck Sizes
Banks	October 22	50, 256
Central Lake *	October 23	128
Chestonia	October 19	262
Custer	October 24	256
Echo	October 14 and 21	192; 192
Elk Rapids 1	October 14 and 21	64, 64; 128
Elk Rapids AV	October 14, 21, and 29	64, 64; 128; 8
Forest Home	October 23	192
Helena	October 20	64
Jordan	October 28	192
Kearney	October 27	192
Mancelona 1	October 24	126
Mancelona 2	October 24	127
Milton 1	October 17	64, 64
Milton AV	October 17	64
Star	October 20	64
Torch Lake	October 21	64, 64, 64
Warner *	October 20	64, 192

Table 5: Logic and Accuracy Testing checks that scanners produce correct poll tapes when tallying sets of ballots with known selections (“test decks”). All Antrim memory cards used on election day were tested, but testers in two townships (*) failed to flag visible errors.

A Appendix: Logic and Accuracy Testing

Logic and accuracy testing (L&A testing) helps ensure that election definitions are properly prepared and match the ballot designs. Workers scan one or more “test decks”—sets of ballots marked in advance so that the correct results are known—and verify that the poll tapes show the expected output. Although L&A testing cannot protect against sophisticated attacks on voting equipment [19], it *can* detect some kinds of accidental or deliberate configuration problems.

Michigan requires L&A testing of all scanners [30]. To determine whether such testing took place in Antrim, I examined the logs from the memory cards. Every scanner was tested before the election, as shown in Table 5. Notably, both Mancelona scanners were tested after their cards were updated with the revised election definition. (The Central Lake scanner was not retested after its card was updated for the second scan on Nov. 6, but it was tested prior to the election.) Unfortunately, these tests failed to detect the impending problems.

The poll tapes produced during testing in Central Lake and Warner Township reflected the initial ballot designs, so they contained an incorrect contest and were missing a contest, respectively. By the time the testing occurred, the county was aware of the ballot design errors, and so, presumably, were the townships. The workers who performed the testing may have either ignored these discrepancies or failed to review the test decks and poll tapes carefully enough to spot them. Had the townships reacted to these errors by updating their election definitions, it would have prevented some (but not all) of the anomalies described in Section 4.

Michigan only requires L&A testing at the local level. The state recommends, but does not require, “end-to-end” pre-election testing to confirm that loading results from scanner memory cards into the EMS produces correct results. No such testing was conducted in Antrim. Had the county performed such testing, it likely would have detected the mismatched election definitions and averted the major anomalies.

B Appendix: Estimated Error in Prop. 20-1

The two scans from Central Lake provide enough information to estimate the number of ballots that used the initial ballot design and the size of the errors in the State Prop. 20-1 results.

The first poll tape, based on the initial election definition, showed 61 votes for “Yes” and 371 for “No” from Central Lake Village. Per Figure 3, the “Yes” votes would have been only those marked for “Yes” and using the initial design, while the “No” votes would have been those marked “Yes” using the initial ballot design plus those marked “No” using the revised ballot design. The second poll tape, based on the revised definition, shows 370 votes for “Yes” and 69 for “No.” Votes counted for “Yes” would have been those marked “Yes” using the revised ballot design plus those marked “No” using the initial ballot design. Those counted for “No” would have been only those marked “No” using the revised ballot design. (The values 371 and 370 should be equal; the difference is due to the ballots omitted in the second scan, shown in Figure 7.)

We can use these facts to estimate the correct results. Let a be the number of votes for “Yes” cast using the revised ballot design, and let b be the number of votes for “No” cast using the initial ballot design. Based on the facts above, $a + b \approx 370$. In the rest of Central Lake Township, which was unaffected by the error, “Yes” received 84% of the votes. Under the assumption that Central Lake Village voted for each option in the same proportion:

$$\frac{61 + a}{(61 + a) + (b + 69)} \approx 84\%$$

By simple algebra, $a \approx 359$ and $b \approx 11$.

As shown in Table 6, this implies that approximately $61 + 11 = 72$ votes were cast using the initial ballot design and that approximately $50 + 11 = 61$ votes are not incorporated in the final results for the contest.

Choice	Ballot Design		Total	Δ
	Initial	Revised		
Yes	61	$a \approx 359$	420	+50
No	$b \approx 11$	69	80	+11

Table 6: Remaining Errors in State Prop. 20-1. My estimates (blue) show that approximately 61 votes are missing from Central Lake’s results for Prop. 20-1, roughly 50 for “Yes” and 11 for “No.”

Ballot 1—Central Lake Township, Precinct 1CENT
President and Vice President : Donald J. Trump / Michael R. Pence
United States Senator for State : John James
Representative in Congress 1st District : Jack Bergman
Representative in State Legislature 105th District : Ken Borton
Member of the State Board of Education : Tami Carlone, Michelle A. Frederick
Regent of the University of Michigan : Sarah Hubbard, Carl Meyers
Trustee of Michigan State University : Pat O’Keefe, Tonya Schuitmaker
Governor of Wayne State University : Don Gates
County Prosecuting Attorney : Write-in
County Sheriff : Write-in
County Clerk : Sheryl Guy
County Treasurer : Sherry A. Comben
County Register of Deeds : Patty Niepoth
County Drain Commissioner : Mark Stone
County Surveyor : Scott Papineau
County Commissioner 2nd District : Joshua E. Watrous
Township Supervisor for Central Lake Township : Write-in
Township Clerk for Central Lake Township : Judy Kosloski
Township Treasurer for Central Lake Township : Andrew Smith
Township Trustee for Central Lake Township : Patrick Hanlon, Pat Marshall
Justice of Supreme Court : Katherine Mary Nepton, Brock Swartzle
Judge of Court of Appeals 4th District Incumbent Position : Michael J. Kelly, Amy Ronayne Krause
Judge of Court of Appeals 4th District Non-Incumbent Position : Michelle Rick
Judge of Circuit Court 13th Circuit Incumbent Position : Kevin A. Elsenheimer
Board Member for Charlevoix-Emmet Intermediate School District 6 Year Term : Thelma A. Chellis
State Proposal 20-1 : Yes
State Proposal 20-2 : Yes

Ballot 2—Central Lake Township, Precinct 1V
[*No selections.]

Ballot 3—Central Lake Township, Precinct 1V
Straight Party Ticket : Republican Party
President and Vice President : Donald J. Trump / Michael R. Pence
United States Senator for State : John James
Representative in Congress 1st District : Jack Bergman
Member of the State Board of Education : Tami Carlone, Michelle A. Frederick
Regent of the University of Michigan : Sarah Hubbard, Carl Meyers
Trustee of Michigan State University : Pat O’Keefe, Tonya Schuitmaker
County Prosecuting Attorney : James L. Rossiter
County Sheriff : Daniel S. Bean
County Clerk : Sheryl Guy
County Treasurer : Sherry A. Comben
County Register of Deeds : Patty Niepoth
County Commissioner 2nd District : Joshua E. Watrous
Township Supervisor for Central Lake Township : Stanley A. Bean
Village President for Village of Central Lake : Rob Tyler
Village Trustee for Village of Central Lake : Bill Chapman
* School Board Member for Central Lake Schools : Melanie Eckhardt, Keith Shafer
* State Proposal 20-1 : —
* State Proposal 20-2 : —
* A Proposed Initiated Ordinance to Authorize One (1) Marihuana Retailer Establishment Within the Village of Central Lake : No

* contest potentially incomplete due to limited data

Figure 7: Reconstructed Ballots. The scanner in Central Lake recorded three ballots on Nov. 3 that were not included when ballots were rescanned on Nov. 6. If Ballot 3 was omitted in error, it likely altered the outcome of the Central Lake Village Marihuana Initiative.