iVote Issues
Assessment of potential impacts on the 2021 NSW local government elections

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1 Introduction

In early December 2021, the Australian state of New South Wales (NSW) conducted one of the largest-ever Internet voting runs in the world,[3] receiving more than 650,000 votes over the Internet via a system called iVote, representing approximately 10% of votes in NSW local government elections. Like prior runs of iVote, the system suffered significant downtime during the election period and an analysis of its source code raised serious questions about its security.

On December 23, the NSW Electoral Commission (NSWEC) released a report which attempts to quantify how these problems affected election outcomes. They focused on voter exclusion resulting from downtime. They also published extensive and detailed data about the election. They concluded that six local government elections were potentially affected by iVote's problems, but that the remainder of results should be trusted.

The NSWEC successfully applied to the NSW Supreme Court to have three outcomes voided on the basis that the system downtime had unfairly prevented people from voting. [4] These three elections were re-run in July 2022. As far as we know, this is the first time in the world that an Internet voting failure led to election results being annulled.

However, the court was not asked to consider whether any other results should also be voided. In this report we conduct an alternative analysis based on NSWEC data, examining which NSW local government election results could have been altered by either voter exclusion due to downtime, or small changes in votes. Our main findings are as follows.

- In 25 contests, the election outcome based only on paper ballots is different from the outcome that incorporates iVote ballots. This does not mean that the official results are wrong, but it does mean that iVotes affected outcomes.
- In most contests, including both mayoral and councillor contests, the number of vote-changes sufficient to alter the election outcome is less than the number of votes received from iVote.
- In 39 contests, the election outcome can be changed by adding fewer votes than the number that NSWEC acknowledges were excluded by iVote's known performance issue. This includes the 6 contests that the NSWEC acknowledges were affected, plus 33 others.

New South Wales local government elections are conducted by a combination of attendance paper voting, postal voting and Internet voting. Seats are allocated via the Single Transferable Vote algorithm, for which general margin computation is infeasible. Our analysis therefore gives lower bounds but may not find the exact smallest change or addition necessary to alter the election result.

All our code is available at https://github.com/AndrewConway/ConcreteSTV.

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[3] Estonia runs a larger *fraction* of their votes over the Internet, but fewer by absolute number; Moscow runs a larger number of votes by Internet.

[4] https://www.caselaw.nsw.gov.au/decision/17f913a39e2ade551b821020

1.1 Brief overview of the Single Transferable Vote count and its use in NSW local government elections

The Single Transferable Vote (STV) is a complex social choice function incorporating both proportional and preferential aspects. Voters rank candidates in order, from their first preference downwards. The following is a high-level overview of the general algorithm—for NSW-specific details, see The NSW Local Government (General) Regulation (2005).[5]

Initially, a *quota Q* is computed as

$$Q = \lfloor \frac{v}{s+1} \rfloor + 1,$$

where v is the total number of valid votes and s is the number of seats to be filled.

Any candidate who has at least Q votes from first preferences is immediately elected.

The rest of the algorithm consists of repeating the following steps until all the seats are filled.

1. For any candidate who received a tally $T \geq Q$ (and hence won a seat) in the last step, redistribute their excess votes (that is, $T - Q$ votes) to the next preference specified on the ballot.[6]
2. If any candidate now has a tally $T \geq Q$, declare them elected and go to Step 1.
3. If no candidate has a tally $T \geq Q$, find the candidate with the lowest tally T and *exclude* them: remove them from consideration and distribute each of their ballots to the next-preferred candidate on that ballot.
4. If the number of remaining (i.e. neither seated nor excluded) candidates is equal to the number of unfilled seats, declare the remaining candidates to be winners and stop.

The state of NSW has more than 100 local councils, each with 5–15 councillors elected by STV. Some elect the mayor from within the council, others have a separate mayoral election using instant-runoff voting (IRV), which is the single-seat version of STV.

Because the STV counting algorithm is so complex, it is computationally intractable to answer simple questions that are obvious for many other social choice functions, such as, "What is the minimum number of vote changes sufficient to change the outcome?" and, "If x voters were excluded, is it possible that that was sufficient to alter the outcome?" For many social choice functions, these questions can be answered with (very) basic arithmetic; for STV, much more difficult analysis is necessary.

1.2 The NSWEC's analysis and why it is not convincing

The NSWEC analysis[7] attempts to assess which of the 2021 Local Government contests were affected by iVote's downtime. Their methodology consists of simulating missing iVotes by randomly resampling them from existing iVotes. This is repeated 1000 times, and if no alternative outcomes appear, the results are accepted. This makes three significant assumptions, which are not supported by evidence.

1. It assumes all iVote results are accurate, hence disregarding possible security issues or bugs. The report does not provide any statistics about voter-verification attempts, nor any account of whether any other attempt to verify the iVote votes was made. Since the iVote protocol does not provide end-to-end verifiability, it does not seem possible at this stage to derive evidence supporting the apparent iVotes.
2. Its count of the number of potential additional iVotes includes only those who successfully registered but were not sent a voting credential, thus omitting

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[5] https://legislation.nsw.gov.au/view/whole/html/2020-10-27/sl-2005-0487#sch.5

[6] This step is complicated, but the main idea is to distribute the votes to their next preferences, but with a reduced weight so that the total value of transferred votes is equal to $T - Q$, because Q votes have been "used up" to elect a candidate. The exact details vary across jurisdictions.

[7] https://elections.nsw.gov.au/NSWEC/media/NSWEC/LGE21/iVote-Assessment-Methodology.pdf

- people who were unable to register,
- people who received a voting credential but were unable to vote, and
- people who heard about the technical problems and did not try to vote.

3. It assumes missing iVotes are distributed the same as existing iVotes, thus assuming no difference introduced by demographic differences between early and later voters, differences of opinion caused by recent news, or biases introduced by the downtime itself.[8]

In combination, these assumptions may cause a significant underestimate of the impact of iVote's performance and security issues.

iVote has a long history of issues affecting performance,[9] security [HT15], and cryptographic verification [HLPT20]. A report commissioned by NSWEC for the 2021 local government elections found that the codebase was so complex that the auditors could not tell whether the hardcoded passwords they found were in executable parts of the code [HS21]. They also noted that the NSWEC does not compile their own code, instead trusting the vendor to supply an executable version that matches the audited code. iVote does not provide any meaningful way for scrutineers or others to verify that its outputs accurately reflect voters' intentions, so complete trust in the accuracy of iVotes is not justified by evidence. This history is slowly influencing decisions: iVote will not be used for the NSW State General Election in 2023.[10]

There are also some evident calculation errors in the NSWEC analysis. For example, in Round 9 of the Albury council count,[11] C STAR was eliminated with 6 votes, but Esther HEATHER also had 6 votes and was not eliminated. Albury is listed in the NSWEC report as having a "Min vote difference during count" of 1 (p.18, Row 7, Col 5). It should be zero. We are not certain how much these calculation errors affected the analysis. If the source code for the NSWEC analysis is made openly available, we would be happy to help correct it.

We have, however, replicated the simulations described in the NSWEC report, adding the same number of votes that NSWEC acknowledges to be missing, and obtained broadly similar results. Hence the analysis is probably mostly correct *if* its assumptions are accepted. We ran one million simulations for each contest and discovered some low-frequency alternative outcomes that were not detected in NSWEC's thousand samples.

Example 1. In Blue Mountains Ward 3, an alternate outcome appeared 903 times out of one million samples, despite having occurred 0 times in the NSWEC's thousand samples: Kingsley LIU replaced Daniel MYLES (the official winner). The other elected councillors were unchanged.

The complete list of alternate outcomes with non-zero occurrences per million is listed in Appendix A of the full paper [CT22].

1.3   This report: Data-only analysis of election differences

In this report, we do not attempt to guess anything about the missing votes or the size of any iVote security or accuracy issues. We simply analyse the existing data and ask how many dropped or altered votes could have changed the election results.

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[8] The authors are aware of at least one family that was intending to use iVote, but decided to go to a polling place when the performance issue made iVote inaccessible. This behaviour change might have been much easier for some voters than others. For example, those who were genuinely very distant from the nearest polling place, or genuinely living with a physical disability, might not have been as easily able to vote in person. Such a difference might have meant that the omitted iVotes were quite different from the iVotes that would have been received if it had not gone down.

[9] https://www.smh.com.au/nsw-election-2019/this-is-ridiculous-nsw-voters-struggle-to-lodge-early-vote-after. html

[10] https://www.elections.nsw.gov.au/About-us/Media-centre/News-media-releases/ Electoral-Commissioner-iVote-determination

[11] https://vtr.elections.nsw.gov.au/LG2101/albury/councillor/report/dop-cnt-009

We thank the NSWEC for the detailed election data and distribution-of-preferences transcripts that are freely available online. This gives us, and other interested members of the public, the opportunity to examine and check the results. Some other electoral commissions fail to make any useful election data available, and most do not share informal votes. We appreciate the opportunity to use real election data to make our own examination and share the results with others.

Section 2 examines the differences between the paper votes and the iVote votes, identifying those contests in which the paper-only outcomes differ from those that include iVotes. Section 3 computes the exact margins for each mayoral contest. Section 4 finds examples in which a small number of vote changes can change the overall election outcome—this quantifies the size of iVote security issues or software errors that could make a difference to the outcome. In almost all contests, this is fewer than the number of votes received over iVote. Section 5 does a similar analysis, but only for adding votes—this quantifies the number of excluded votes that could have altered the outcome. In 39 contests, the number of required additions is less than the number NSWEC acknowledges that they excluded. In many other contests, the number is only slightly more.

2   Comparing paper-only and paper-plus-iVote results

In prior runs of iVote, which all occured during state elections, it was argued that iVote's security was not important because "on the current scale of internet voting it is unlikely that people will want to intervene to try to alter the election result," and "it is highly likely that intervention that changed results would be detected. Psephologists, political parties, pollsters and other experts would most likely query and question outcomes that are inconsistent with expectations." [Wil18] Whether this was true previously,[12] it is certainly not true for the 2021 local government elections—the iVote results were sufficiently numerous, and in many cases sufficiently different from the paper-only returns, to alter election outcomes. We are not aware of any psephologists who have been able to compare these outcomes to any detailed predictions about the outcome of each mayoral race or precise composition of each multi-member council.

Example 2. In the City of Sydney, more than 33% of votes were received via iVote. If we count only the paper votes (including both postal and attendance), the elected councillors are Jess SCULLY, Shauna JARRETT, Linda SCOTT, Sylvie ELLSMORE, Robert KOK, Emelda DAVIS, William CHAN, Yvonne WELDON and Damien MINTON. Including the iVotes alters the outcome, substituting Lyndon GANNON for Damien MINTON. The Mayor of Sydney and the other councillors are unchanged.

Example 3. In the city of Maitland, the Mayor elected when we count only paper ballots is Loretta BAKER. Including the iVotes changes the outcome, electing Philip PENFOLD instead.

Table 1 lists all contests for which the paper-only results were different from the official results, which included both paper and iVote votes.

These differences do not prove that there were software bugs or security problems that affected the iVote results, because there are possible legitimate reasons for the differences. For example, iVote voters may have voted earlier, or may have come from different demographics, than those who voted on paper. It does, however, mean that any possible iVote security and verification issues do matter, because iVote votes changed election outcomes.

These differences are probably the main reason that the NSWEC's simulations produced a result different from the official result substantially more than half the time in Kempsey, out of only two possible results. It would otherwise be surprising to sample from

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[12] This claim deserves skepticism even for prior iVote runs, because 5% of votes is enough to alter a close Legislative Assembly contest or a crossbench Legislative Council seat, which are hard to predict.

the same distribution and get the other result 61% of the time—it happens because the iVote returns are distributed differently from the paper ones.

The fraction of votes accepted through iVote varied by location, from less than 5% in some rural electorates to more than 33% in Sydney. On average, it was much higher than in the 2019 state election. Complete statistics, including iVote rates and overall turnout, are given in Appendix B of the full paper [CT22].

Contest	Official winner (iVotes included)	Paper-only winner
City of Blue Mountains - Ward 2	HOARE Brent	VAN DER KLEY Chris
Burwood	HULL David	YANG Alex
Byron	HUNTER Alan	CLARKE Bruce
Coonamble	DEANS Barbara	SMITH Steven (Jay Jay)
Dubbo Regional - Wellington Ward	GOUGH Jess	JONES Anne
Hilltops	FITZGERALD Patrick	HORTON John
Inner West - Marrickville - Midjuburi (Lillypilly) Ward	TSARDOULIAS Zoi	MACRI Victor
Kempsey	FREEMAN Joshua	SAUL Dean
Kiama	LARKINS Stuart	GEORGE Tanya
Lane Cove - East Ward	ROENFELDT David	VISSEL Frances
City of Maitland Mayoral	PENFOLD Philip	BAKER Loretta
Moree Plains	COCHRANE Mekayla	RITCHIE Stephen
Muswellbrook	BOWDITCH Mark	OGG Malcolm
Nambucca Valley	WILSON John	HALL David
Narrabri	BOEHM Rohan	STAINES Cameron
North Sydney - Cammeraygal Ward	LAMB Georgia	BAUER Hugo
Parkes	WEBER Daniel	SNYMAN Erik
City of Parramatta - Rosehill Ward	NOACK Paul	STRANO Franceska
City of Randwick - West Ward	VEITCH Philipa	STAVRINOS Harry
City of Shellharbour - Ward A	EDWARDS Maree	BITSCHKAT Shane
Singleton	McNAMARA Tony	JOHNSTONE Sarah
Snowy Valleys	IVILL Michael	DALE Kenneth
City of Sydney	GANNON Lyndon	MINTON Damien
Walgett	KEIR Jane	TAYLOR Michael
Yass Valley	REID Mike	GINN Bill

Table 1. Contests in which the paper-only outcome differs from the outcome when iVotes are included. In multi-winner contests, the other winners stay the same and are omitted from the table.

3 Calculating the exact margin for single-winner contests

In NSW, many Mayors are elected directly using a single-winner preferential (Instant Runoff) electoral system similar to that used in Australian lower-house parliamentary seats.

This section reports on the exact margins of all single-winner contests—this is the number of votes that would need to change in order to alter the outcome. To put it another way, this is the number of (iVote or other) votes that would need to have been altered by a software bug or security problem to divert the result from the correct one.

The calculations were conducted by Michelle Blom using her code at https://github.com/michelleblom/margin-irv, which implements the algorithms described in [BTST16].

In most cases, the true margin is the last-round margin, i.e. half the difference between the winner and the runner-up in the last stage of the count, when all but two candidates have been excluded. For example, if Alice and Bob are the only two candidates remaining after all others have been eliminated, and Alice wins with A votes while Bob loses with B votes, then we could make Bob win (or tie) by taking $\lceil (A - B)/2 \rceil$ of Alice's votes and changing them into votes for Bob.[13] To put it the other way, if a software bug or security

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[13] $\lceil \cdot \rceil$ represents rounding up to the nearest whole number.

problem had inappropriately changed $\lceil (A - B)/2 \rceil$ of Bob's votes into votes for Alice, this election outcome would be wrong.

However, the true margin is not always the last-round margin, and the candidate who remains in the count second-longest is not always the alternative candidate closest to winning. Sometimes a small change earlier in the count can alter the elimination order and result in a different outcome.

Example 4. In Hunter's Hill, Richard QUINN was excluded at Count 3, with 2,153 votes.[14] If 109 votes are removed from Ross WILLIAMS and added to QUINN, WILLIAMS is excluded in Count 3 instead, then QUINN defeats Zac MILES (the official winner) in the last step.[15]

In NSW Local Government Elections 2021, the Mayoral contests in Broken Hill, Coffs Harbour and Lismore also had a true margin smaller than the last-round margin, because early elimination steps affected the final result. For all the rest, the true margin was the last-round margin. The smallest margins were:

Hunter's Hill	109
Kempsey	194
Orange	244
Port Stephens	284

For 2/3 of mayoral contests, the margin was smaller than the number of votes accepted from iVote. The full results are given in Appendix C of the full paper [CT22].

This is a much more useful value than the least-difference used in the NSWEC report, because it is both a *working example* and a *lower bound*: when we say that the margin for Kempsey Mayor 194 is votes, this means that altering 194 votes suffices for changing the outcome, and also that there is no change of less than 194 votes that changes the outcome.

4   Altering votes to change outcomes in multi-winner contests

Ideally we would also calculate exact margins for the multi-winner council elections. This would answer the question, "What is the smallest alteration or misrecording of votes that could have altered the outcome?" Unfortunately, however, there is no known efficient algorithm for answering this question—the problem is probably intractable in practice.

We have therefore implemented some simple heuristics that look for small alterations that change the outcome. These are exact working examples—if a solution is found, it definitely produces a different set of winners. However, unlike the IRV margins calculated in Section 3, the search is not exhaustive and does not produce a lower bound: there might be even smaller vote changes that alter the outcome, which our algorithm did not find. This paper has been updated slightly since the first version, as algorithmic improvements found better results in some contests.

Code for the heuristics in this section and the next are available at https://github.com/AndrewConway/ConcreteSTV. The main idea is to change which candidate is excluded or seated at each count, then check whether that change induces a different election outcome. The main steps are:

1. at each count where a candidate E is excluded, for each continuing candidate C,
   (a) calculate n, the number of votes that must be moved from C to E so that C's tally will be smaller than E's and hence E will not be excluded,
   (b) try to find n appropriate votes from among existing iVotes,
   (c) change them from votes that count for C to votes that count for E,
   (d) check whether this changes the election outcome,

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[14] https://vtr.elections.nsw.gov.au/LG2101/hunters-hill/mayoral/report/mayoral-dop
[15] This assumes that the tie is broken in QUINN's favour—otherwise, one more vote would be required.

(e) if so, check whether changing a smaller number of them also changes the outcome;
2. do the same for each count at which some candidate C is seated, moving votes from the candidate who got a seat to the highest candidate who did not.

We found many contests in which small vote changes could alter the election outcome. In most contests, the number of votes received through iVote was much more than the number of changes sufficient to change the winners.

Example 5. In the council election for Walgett, altering two votes can change the election outcome. Changing two (below-the-line) votes that mention Jane KEIR to list Anna WITT instead causes Jo COLEMAN, rather than KEIR, to be elected. The rest of the elected council remains the same. The specific changes are:

	1st preference	2nd	3rd
Vote Change 1: from	TRINDALL Garry	KEIR Jane	TURNBULL Robbie ...
to	TRINDALL Garry	WITT Anna	TURNBULL Robbie ...
Vote Change 2: from	TRINDALL Garry	KEIR Jane	COLEMAN Jo ...
to	TRINDALL Garry	WITT Anna	COLEMAN Jo ...

This can also be expressed in reverse: it means that if two iVotes were misrecorded or altered in the opposite way, the election outcome would be wrong. There are probably many other related ways to produce the same effect.

In addition to 6 contests acknowledged by NSWEC to have been problematic, many others were very close, including 17 for which the election outcome could be changed by altering 10 or fewer votes. These are listed in Table 2.

Contest	Total votes	Added votes to change outcome	Vote changes to change outcome
City of Blue Mountains - Ward 3	12567	19	10
Bogan	1467	17	7
Byron	17735	16	8
Carrathool - Ward A	694	7	4
Coolamon	2576	8	5
Coonamble	2096	5	3
Forbes	5628	27	6
Gilgandra	2492	20	10
Hay	1747	4	2
⋆ Kempsey	16204	1	1
Kiama	15016	10	5
Lockhart - B Ward	615	20	9
Muswellbrook	8756	16	9
Nambucca Valley	12043	12	6
Parkes	8027	12	6
⋆ City of Shellharbour - Ward A	13138	6	2
⋆ Singleton	12745	3	2
Snowy Valleys	8310	27	8
Walgett	2507	11	2
Warren - D Ward	335	6	3
Weddin	2380	15	7
City of Willoughby - Naremburn Ward	8633	19	9

Table 2. Contests with the closest margins found by our algorithm. The last column is the number of iVote changes that can alter the outcome. The second-last column is the number of added votes that can alter the outcome, which is usually (but not always) close to double. The three contests selected by NSWEC as having the highest simulated frequency of alternate outcomes are marked with ⋆.

The contests with very small margins tend to have small populations, but some larger cities require a very small number of changes as a fraction of the overall votes. The smallest margins as a fraction of the total number of votes are in Table 3—there were 13 contests

that could be altered by changing fewer than 0.2% (but more than 10) of the votes, of which only one (Paramatta - Rosehill Ward) was already acknowledged as problematic.

Contest	Total votes	Added votes to change outcome	Vote changes to change outcome	Vote changes as % of total
City of Albury	28378	34	17	0.06%
Armidale Regional	15223	46	25	0.16%
Bathurst Regional	24704	85	45	0.18%
City of Blue Mountains - Ward 2	12493	25	13	0.10%
City of Campbelltown	89337	240	120	0.13%
Goulburn Mulwaree	17394	89	28	0.15%
Hilltops	11021	21	11	0.10%
Inner West - Marrickville - Midjuburi (Lillypilly) Ward	20347	48	32	0.16%
City of Orange	23740	70	35	0.15%
City of Parramatta - Rosehill Ward	22283	20	13	0.06%
City of Shoalhaven - Ward 1	21724	99	39	0.18%
Snowy Monaro Regional	11746	40	20	0.17%
Tamworth Regional	35318	70	34	0.10%

Table 3. Councils with closest margins as a fraction of the total votes, excluding those with vote changes less than 11, which are in Table 2.

Another 9 council outcomes can be altered by 11–20 vote changes: Dubbo Regional - Wellington Ward, Junee, Oberon, Temora, Uralla - Ward B, Walcha - B & D Wards, Warren - A & B Wards.

Appendix D of the full paper [CT22] contains the complete list of the smallest vote changes we found that could alter the election outcome. In almost every case, there were sufficiently many iVotes that a carefully-chosen change could alter the outcome. Our companion website at https://andrewconway.github.io/ConcreteSTV/NSWLGE2021/ gives further details on each case, including the alternate winners. Note that we will continue to improve the heuristics after this paper is produced, so the numbers may improve.

5 Adding votes to change outcomes in multi-winner contests

It is extremely difficult to quantify the number of iVote votes that might have been mis-recorded or altered—the system generally does not provide any evidence either way. However, it is broadly agreed that in the 2021 NSW LGE at least some voters were unable to vote due to iVote's performance issue. In this section we therefore consider only missing votes. We repeat the analysis of Section 4, but generate different election outcomes only by *adding* votes, without changing any. The heuristic is otherwise the same as that of Section 4 and is implemented as an option in the same code.

These results answer the question "Could the omission of a certain number of votes have altered the outcome?" This was the question most relevant in the 2013 West Australian Senate counting problem, in which a ballot box went missing—it sufficed to show that it had contained enough votes that its omission may have altered the outcome. This also seems to be the right question for analysing only the omissions caused by iVote's performance issue, assuming that the votes received from iVote were accurate.

Example 6. In the city of Albury council, NSWEC acknowledges missing at least **142** votes as a consequence of iVote's performance issue.

If **34** votes are added for Henk VAN DE VEN, the outcome changes: in Count 48 (where VAN DE VEN would be excluded[16]), David THURLEY is excluded instead.[17]

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[16] https://vtr.elections.nsw.gov.au/LG2101/albury/councillor/report/dop-cnt-048
[17] This assumes the tie is resolved in favour of VAN DE VEN. If it were not, one more vote would be needed.

Then in the next count, Ross HAMILTON wins a seat instead of David THURLEY. The other elected councillors are unchanged.

This means that if the omitted votes contained 34 more votes for VAN DE VEN than THURLEY, and otherwise did not alter the distribution of preferences, the announced outcome would be wrong.

There are at least 39 contests in which the outcome can be changed by adding fewer votes than the NSWEC acknowledges missing. These are shown in Table 4. Appendix D of the full paper [CT22] contains the complete list of the smallest number of added votes that can change each election outcome. Our companion website at https://andrewconway. github.io/ConcreteSTV/NSWLGE2021/ gives further details on each case, including the alternate winners.

As in Section 4, these results are working examples but not lower bounds: if we find a solution, it certainly suffices to change the outcome, but we may have missed smaller sets of added votes that also change the outcome. More sophisticated heuristics such as [BCST20] (https://github.com/michelleblom/STV-manipulator) would probably get better results.

These results are, therefore, probably an underestimate of the number of contests that could have been affected by iVote's performance issue. This is partly because our heuristic search may have missed some smaller solutions, and partly because NSWEC's estimate of the votes they missed may be conservative.

6 Discussion and Conclusion

The NSWEC has engaged with technology more extensively than any other electoral commission in Australia. Some of this is beneficial, such as their extensive publication of election data, allowing independent studies like this one. Some choices, however, put the foundations of democracy at risk. Use of iVote should be permanently discontinued because it does not securely convey votes, and leaves the state without a rigorous way of assessing how much its problems affected the integrity of the election. The same situation could easily recur if another election is run with the same unreliable, insecure and unverifiable technology.

Apart from the 6 contests identified as at risk by NSWEC, there are another 33 in which it is possible to change the outcome by adding fewer votes than the NSWEC acknowledges to be missing due to iVote's performance issue.

Many other outcomes are highly dependent on the integrity of the iVotes. In 25 contests (of which only 5 are acknowledged as problematic by NSWEC), the official outcome is different from the outcome when only paper ballots are tallied. This does not prove the iVotes are wrong, but it does prove that the integrity of the outcome is dependent on the accuracy of the iVote ballots, which cannot be verified. In most of the remaining contests, there are sufficient iVotes that a targeted manipulation or unlucky software error could have altered the outcome.

The tiny margins in Sections 4 and 5 indicate the importance of the assumptions behind the official NSWEC analysis of the impact of the iVote performance issue. The decision to retain the apparent outcome in all but three contests depends very strongly on their assumptions that the iVotes are accurate, and that the votes they are missing are distributed randomly according to the same distribution as the votes they already have. If those assumptions are not accepted, there is a possibility that many of the announced election outcomes do not accurately represent the choice of the people.

7 Acknowledgements

Electorate	Votes	Added votes to change outcome	Votes NSWEC acknowledges excluding
City of Albury	28378	34	142
Armidale Regional	15223	46	71
Bathurst Regional	24704	85	137
Bayside - Ward 2	17168	109	245
City of Blue Mountains - Ward 2	12493	25	73
City of Blue Mountains - Ward 3	12567	19	94
City of Broken Hill	10395	26	38
Byron	17735	16	127
Cabonne	7836	42	57
City of Campbelltown	89337	240	764
Clarence Valley	30661	139	143
Coolamon	2576	8	19
Coonamble	2096	5	10
Forbes	5628	27	37
Goulburn Mulwaree	17394	89	93
City of Griffith	12556	60	73
Hay	1747	4	6
Hilltops	11021	21	45
Inner West - Marrickville - Midjuburi (Lillypilly) Ward	20347	48	242
⋆ Kempsey	16204	1	34
Kiama	15016	10	57
Muswellbrook	8756	16	69
Nambucca Valley	12043	12	35
North Sydney - Cammeraygal Ward	19088	182	251
Northern Beaches - Curl Curl Ward	29742	270	305
City of Orange	23740	70	172
Parkes	8027	12	41
City of Parramatta - Rosehill Ward	22283	20	119
City of Randwick - West Ward	13609	92	140
⋆ City of Shellharbour - Ward A	13138	6	54
City of Shellharbour - Ward B	10527	69	86
City of Shoalhaven - Ward 1	21724	99	145
⋆ Singleton	12745	3	55
Snowy Monaro Regional	11746	40	45
City of Sydney	117362	1044	2003
Tamworth Regional	35318	70	194
Walgett	2507	11	23
Weddin	2380	15	23
City of Willoughby - Naremburn Ward	8633	19	43

Table 4. Contests in which the added votes sufficient to change the outcome are fewer than the number NSWEC acknowledges missing due to iVote's performance issue. The last column is the number of missing votes acknowledged by NSWEC. The second-last is the number of votes that can alter the outcome if added. The three contests selected by NSWEC as in doubt are marked with ⋆.

References

BCST20. Michelle Blom, Andrew Conway, Peter J Stuckey, and Vanessa J Teague. Did that lost ballot box cost me a seat? Computing manipulations of STV elections. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 34, pages 13235–13240, 2020. https://researchmgt.monash.edu/ws/portalfiles/portal/337436562/337433276_oa.pdf.

BTST16. Michelle Blom, Vanessa Teague, Peter J Stuckey, and Ron Tidhar. Efficient computation of exact IRV margins. In *Proceedings of the Twenty-second European Conference on Artificial Intelligence*, pages 480–488, 2016. https://arxiv.org/abs/1508.04885.

CT22. Andrew Conway and Vanessa Teague. ivote issues: Assessment of potential impacts of the 2021 NSW local government elections (full version), January 2022. https://github.com/AndrewConway/ConcreteSTV/blob/main/reports/NSWLGE2021Report.pdf.

HLPT20. Thomas Haines, Sarah Jamie Lewis, Olivier Pereira, and Vanessa Teague. How not to prove your election outcome. In *2020 IEEE Symposium on Security and Privacy (SP)*, pages 644–660. IEEE, 2020. https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/2723423/main.pdf.

HS21.   David Hook and Carsten Schürmann.   Review of the revised iVote 2021 system,
        2021.   https://www.elections.nsw.gov.au/NSWEC/media/NSWEC/Reports/iVote%20reports/
        demtech-source-code-review-report.pdf.
HT15.   J Alex Halderman and Vanessa Teague. The new south wales iVote system: Security failures and
        verification flaws in a live online election. In *International conference on e-voting and identity*,
        pages 35–53. Springer, 2015. ArXiv: https://arxiv.org/abs/1504.05646.
Wil18. Roger Wilkins.   Report on the security of the iVote system, May 2018.
        https://www.elections.nsw.gov.au/NSWEC/media/NSWEC/Reports/iVote%20reports/
        Report-on-the-Security-of-the-iVote-System.PDF.