Test Report - VxScan Bulk Scan & Warm Operational Conditions

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Purpose & Background

This test generally stressed the VxScan v4.0 system (Build 0 MCM and LP2 ballot box). The results help evaluate its resilience to high use. There were many specific purposes to this testing, listed below:

1. Give confidence that VxScan v4.0 can meet VVSG requirement **2.7-C: Continuous operation – varied environmental conditions** and support related requirements 1.2-C, 1.2-D, 1.2-G, 2.7-A, 2.7-B, 2.7-C, 1.1.6-F, TA2.7C 1 through 9, TA2.7-B 1.
    a. VVSG 2.7-C is a 104-hour continuous test, where the system scans for 15 minutes each hour. The ambient environment is tightly controlled to be 50-95°F and 25-55% relative humidity (RH), cycling between extremes every 12 hours for 72 hours out of the 104 total hours. This translates to 26 hours of scanning broken up into 15-minute intervals. It also means that the system is at warmer temperatures between 70-95°F for about 36 hours, and has a total *scanning time at temperatures between 70-95°F for just 9 hours*.
    b. The current test was designed to stress the system in a reasonably similar way to VVSG 2.7-C while not requiring 24-hour observation, due to limited staff and resources. Although the test described in the present report is a less rigorous test than VVSG 2.7-C in some ways (e.g. not continuous over 24-hours, only controlled from 70-95°F instead of 50-95°F), it is more rigorous than VVSG 2.7-C in other ways (e.g. constant scanning for full workdays instead of just 15 minutes per hour, total *scanning time near 95°F for at least 26 hours*).
    c. The test documented here is based on internal VotingWorks test “F3-a” previously defined in the Testing Plans document.
2. Give confidence that VxScan v4.0 can meet **VVSG 1.2-G: Misfeed rate benchmark**.
    a. The target misfeed rate is 1/500 or less, under operational conditions. The previous VxScan model had met this benchmark, but anecdotally VxScan v4.0 seemed to have less of a chance for misfeed, but we needed to quantify this.
    b. Previous preliminary testing (on Jul 15, 2024) of different paper weights (28#-46# bond) in warm conditions showed no difference in misfeed rates or behavior among the paper types. Therefore any paper weight could be chosen for “worst case” conditions for these tests.
3. Give confidence that VxScan v4.0 can meet **VVSG 1.2-E: Respond gracefully to stress of system limits**.

    a. This test could show the system response to extended scanning over time, being plugged in over many hours, over the hottest operational conditions, and scanning many ballots.
4. **Find the maximum capacity of the LP2 ballot box.**
    a. Ballot box capacity was to be investigated for the LP2 prototype. A maximum number of ballots that could fit in other ballot boxes was previously estimated as anywhere between 3000 to 8000 ballots. In this test, this number could be counted directly.
5. **Find failure modes for the system at higher use,** whether in hardware or software. These may only appear over long periods of use, for example related to scanner cleaning, wear of moving scanner parts, or software anomalies.
6. **Analyze the temperature of the system during high use.** It was previously noted that the MCM became warmer during use. This test would monitor this further during continuous scanning.

Materials

- MCM Build 0 (test unit 2)
- Ballot box LP2 (test unit 1)
- USB stick with election definition
- Smart cards configured for election
- Approximately 7000 test ballots (see Methods below for details)
- Climate-control tent
    - Plastic Greenhouse Tent (8’ x 6’ x 7.5’, Crown Shades)
    - Smart space heater (Govee 1500W)
    - Smart thermometer-hygrometer (Govee H5075)
    - Smart humidifier (Govee 3L)
    - Govee control app
- Auto-paper-feeder system, VxAustin
    - CueFeed paper feeder mechanism, Barnhart Engineering
    - Raspberry Pi 4-based control system, VotingWorks
    - Hydraulic table cart, at least 27in height, 500lb capacity
    - Spacer blocks (wood) and C-clamps
    - Extension cords
    - Cardstock paper sheet and plastic sheet, scissors, and painters tape
- Camera monitoring system, Simplisafe
- Thermal camera (Klein TI250)

Methods

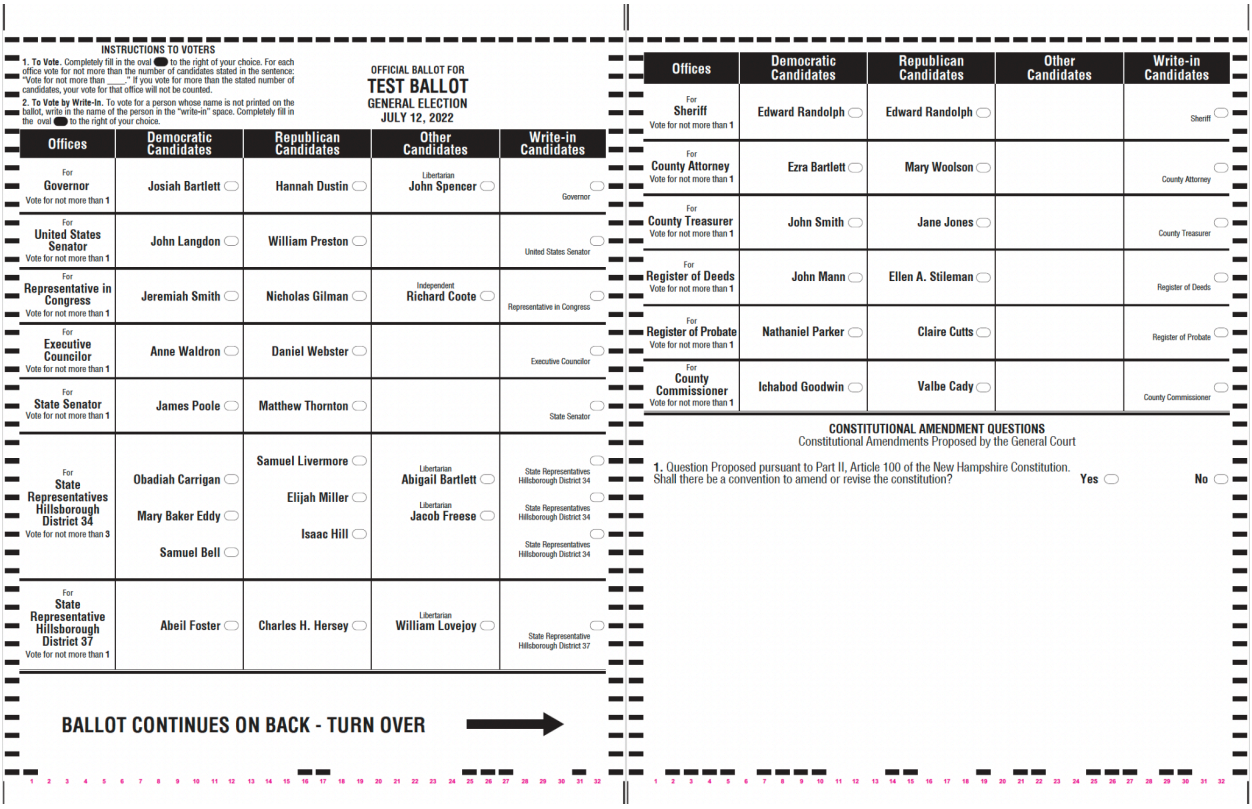
1. The MCM was configured with the appropriate image and election corresponding to the desired test ballot.

   For these tests, the image used was *2024-06-24-austin-testing-vxscan-rc2.img.lz4* and the election definition used was the UAT election definition.

2. Appropriate ballots were printed for scanning.

   These tests used lighter weight, smaller ballots, to attempt to see worst-case behavior when flexible ballots are fed. Flexible ballots theoretically might curl, fold, move, and get caught in the paper path more easily than heavier ballots.

   a. 8.5” x 11”
   b. 28# (majority), also 32# and 60# when limited with 28#
   c. Black & white
   d. Different finishes, edges. These were printed from three different vendors in Austin, Texas. Three vendors were used because of availability to do large batch printing in the desired time frame:
      i. PostNet, 28# (4500 sheets)
      ii. Global Printing Solutions, 28# (2000 sheets)
      iii. FedEx - 32# (300 sheets), 60# (200 sheets)
   e. Some unfilled (blank) ballots, some filled (by computer and printed), from the NH Test Election ballot, file pictured below:



INSTRUCTIONS TO VOTERS

1. To Vote. Completely fill in the oval ⬬ to the right of your choice. For each office vote for not more than the number of candidates stated in the sentence: "Vote for not more than ____." If you vote for more than the stated number of candidates, your vote for that office will not be counted.

2. To Vote by Write-In. To vote for a person whose name is not printed on the ballot, write in the name of the person in the "write-in" space. Completely fill in the oval ⬬ to the right of your choice.

OFFICIAL BALLOT FOR
TEST BALLOT
GENERAL ELECTION
JULY 12, 2022

Offices	Democratic Candidates	Republican Candidates	Other Candidates	Write-in Candidates
For Governor (Vote for not more than 1)	Josiah Bartlett	Hannah Dustin	Libertarian John Spencer	Governor
For United States Senator (Vote for not more than 1)	John Langdon	William Preston		United States Senator
For Representative in Congress (Vote for not more than 1)	Jeremiah Smith	Nicholas Gilman	Independent Richard Coote	Representative in Congress
For Executive Councilor (Vote for not more than 1)	Anne Waldron	Daniel Webster		Executive Councilor
For State Senator (Vote for not more than 1)	James Poole	Matthew Thornton		State Senator
For State Representatives Hillsborough District 34 (Vote for not more than 3)	Obadiah Carrigan Mary Baker Eddy Samuel Bell	Samuel Livermore Elijah Miller Isaac Hill	Libertarian Abigail Bartlett Libertarian Jacob Freese	State Representatives Hillsborough District 34 State Representatives Hillsborough District 34 State Representatives Hillsborough District 34
For State Representative Hillsborough District 37 (Vote for not more than 1)	Abeil Foster	Charles H. Hersey	Libertarian William Lovejoy	State Representative Hillsborough District 37

BALLOT CONTINUES ON BACK - TURN OVER

Offices	Democratic Candidates	Republican Candidates	Other Candidates	Write-in Candidates
For Sheriff (Vote for not more than 1)	Edward Randolph	Edward Randolph		Sheriff
For County Attorney (Vote for not more than 1)	Ezra Bartlett	Mary Woolson		County Attorney
For County Treasurer (Vote for not more than 1)	John Smith	Jane Jones		County Treasurer
For Register of Deeds (Vote for not more than 1)	John Mann	Ellen A. Stileman		Register of Deeds
For Register of Probate (Vote for not more than 1)	Nathaniel Parker	Claire Cutts		Register of Probate
For County Commissioner (Vote for not more than 1)	Ichabod Goodwin	Valbe Cady		County Commissioner

CONSTITUTIONAL AMENDMENT QUESTIONS
Constitutional Amendments Proposed by the General Court

1. Question Proposed pursuant to Part II, Article 100 of the New Hampshire Constitution. Shall there be a convention to amend or revise the constitution? Yes ⬭ No ⬭

A total of approximately 7000 ballots were printed for potential scanning.

3. The MCM was set up on the ballot box so it could be fed ballots from an auto-paper-feeder system.

The MCM was placed in a low-fidelity climate-control tent with a smart space heater, smart humidifier, and thermometer-hygrometer. It can heat up the internal environment to 95°F and hold it there within 5°F. A close-up image of the setup is shown here, and more images are provided in Appendix A. Key environmental targets during testing were:

a. Scan during the day at 95°F, targeting 55%RH when at 95°F as closely as possible.

b. Let the system go back to room temperature and humidity outside work hours, but keep the MCM on and running.

4. The MCM scanned ballots consistently, during typical daytime work hours.

Paper feed data was recorded in the overall Build 0 paper tracker.

Scanning was planned to continue through 5 business days in order to reach at least 104 hours of the machine being on, with a plan to stop or pause if any major errors occurred.

The MCM and ballot box were regularly observed for problems or anomalies. These could potentially include paper misfeeds, software errors, user-friendliness issues, temperatures of the system at different parts, and behavior of any key functions. Reports were also printed at the beginning and end of test days in order to test printer function.

5. When testing was completed, functionality was confirmed.

The stop conditions for this particular test could be any of the following:

a. The MCM scanned while experiencing 36 hours of hot temperatures, if the system was on for at least 104 test hours.
b. Major errors were found that have to be investigated before continuing.
c. Full ballot box prevents more testing.

The 36-hour requirement comes from reinterpreting the VVSG 2.7-C test to allow for regular 8-hour workdays, as described in Purpose & Background.

The full ballot box was a stop condition because VotingWorks at the time wanted to investigate further different ways of addressing the full ballot box in software. Therefore we would not empty the ballot box to continue scanning. We predicted a full ballot box would not be reached in less than 36 hours of continuous scanning.

At the end of testing, the CVRs were checked to confirm there are no anomalies with the saved files.

Results

Scanning started on Tuesday, Aug 6, 2024, and continued through Saturday, Aug 10, 2024.

Main results were as follows:

1. Tests stopped from a full ballot box.

Testing stopped at 5882 ballots in the ballot box. These included 5873 scanned properly, and 9 unscanned “ghost ballots” that were not scanned but still in the ballot box due to a known bug in dealing with ballots stuck on the pile of ballots in a full ballot box. (see image below) The ghost ballot error started occurring at scan 5825, and was fairly consistent by scan 5872. The pile of ballots in the ballot box was about 19 inches high from the internal bottom floor of the ballot box.

Full ballot box. New ballots scanned after this point start to have the possibility of getting stuck at the top of the pile without poll worker intervention, opening or shaking the ballot box to get the ballot unstuck.

Full ballot box showing bulging at the sides. The ballot box was not weighed but was very heavy and would not be recommended to move without emptying it.

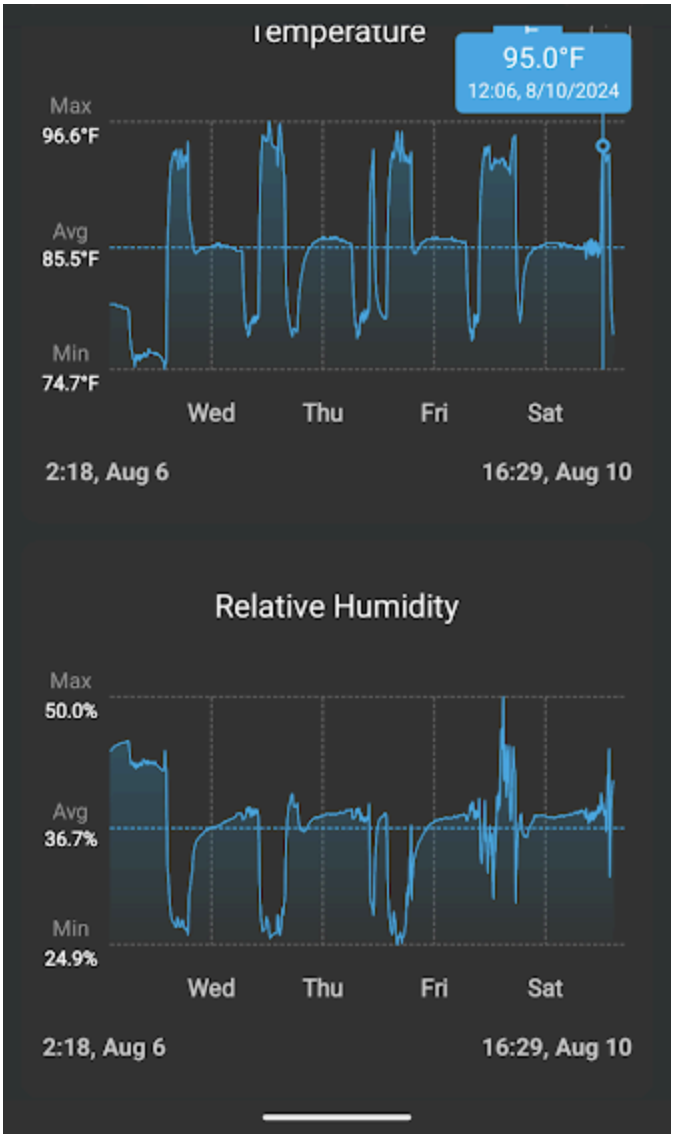
2. The MCM was powered on for about 96 hours.

This is less than the desired 104 hour test defined in VVSG warm operational tests (92% of the target VVSG test time). But no problems were found during this time.

3. The MCM scanned ballots for 27 hours, spread out across 5 days, at the warmest operational conditions.

This current test scanned ballots for 27 hours, during daytime work hours. The vast majority of scans happened at 90-97°F, and at 25-45%RH.

The image below shows the environmental data read by the thermometer-hygrometer above the MCM over the test period. The temperature highs around 95°F occurred when the heater and humidifier were on, and also when scanning took place. The other temperatures at about 85°F and lower occurred when the heater and humidifier were off, allowing the climate tent to cool down to the ambient temperature of the lab during those dates outside of work hours.



As shown above, humidity was more difficult to control. RH% readings during testing fluctuated between 25-50%RH on different days, with the later days having better control due to getting more experience with the humidifier and filling it more fully with water.

4. The system misfeed rate was 0.06% or less.

The “ghost ballot” error from a full ballot box only started to be seen at the 5825th ballot scan. To ignore those errors, the misfeed rate can be measured from the 1st to 5000th ballots. In this range, 3 misfeeds occurred. This is an observed misfeed rate of 0.06%.

The three misfeeds occurred at these times, with these circumstances:

- Sheet #1012: rejected at the infeed, not reproducible, unknown cause
- Sheet #2387: vertical lines appeared on the timing marks, resolved by cleaning

- Sheet #4500: leading edge of sheet possibly got caught at the side of the scanner infeed when inserted at an angle

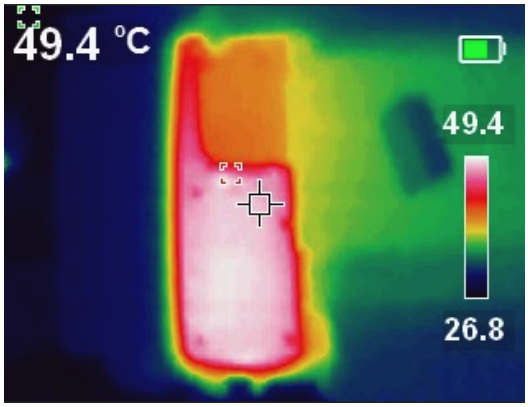
None of these misfeeds appeared to be caused by inherent design issues or to internal paper path features. Instead they were caused by residue getting stuck on the scanner, which could be cleaned, or paper insertion issues where the paper feeder placed a ballot sheet such that an edge or corner got stuck right at the start of the infeed.

5. The MCM printed reports without problems.

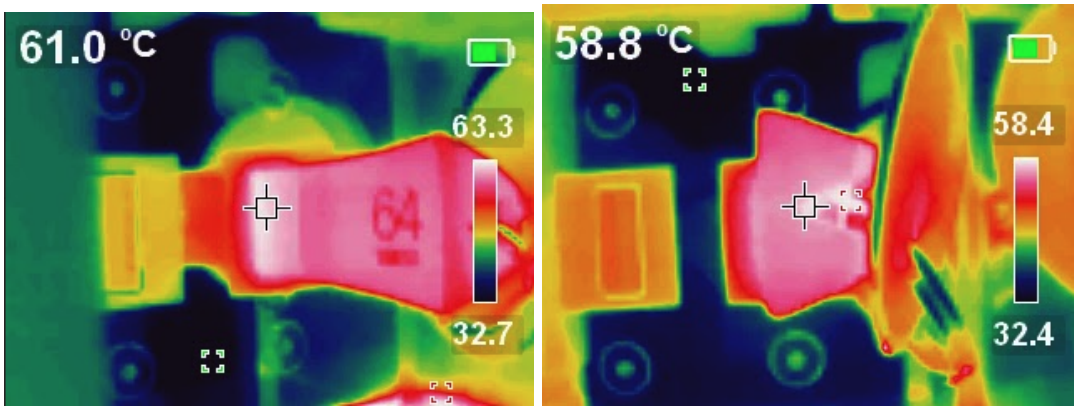
Before and after scanning on each test day, the MCM printed reports. No problems were seen throughout the test. The following were analyzed for each report: print quality and contrast, printer paper jams, tearing quality, and print accuracy. The newer thermal paper roll used for August 2024 UAT was used here.

6. The MCM was hot on the left side of the system.

This unit did not have any fans or active cooling. Temperatures in the system rose mostly on the left side. The surface temperature of the metal panel above the SBC on the left side reached about 121°F (50°C), or an increase from warm ambient temperatures of about +25°F (+15°C):



The Samsung metal bar USB stick reached about 140°F (60°C) along its length, or an increase from warm ambient temperatures of about +45°F (+25°C):



Conclusions

1. An absolute maximum hardware limit to the ballot box capacity could be defined as 5000, for 8.5” x 11” paper with 28# bond weight.

   5000 sheets is 85% of the observed maximum ballot box capacity of 5825 sheets, at which ballots began to get stuck in the ballot box. A safer or more conservative recommended maximum capacity could be 4000 of these types of paper sheets. VotingWorks should recommend that poll workers empty the ballot box at or before reaching this recommended maximum.

2. The MCM functioned properly throughout warm operational conditions comparable to VVSG requirements.

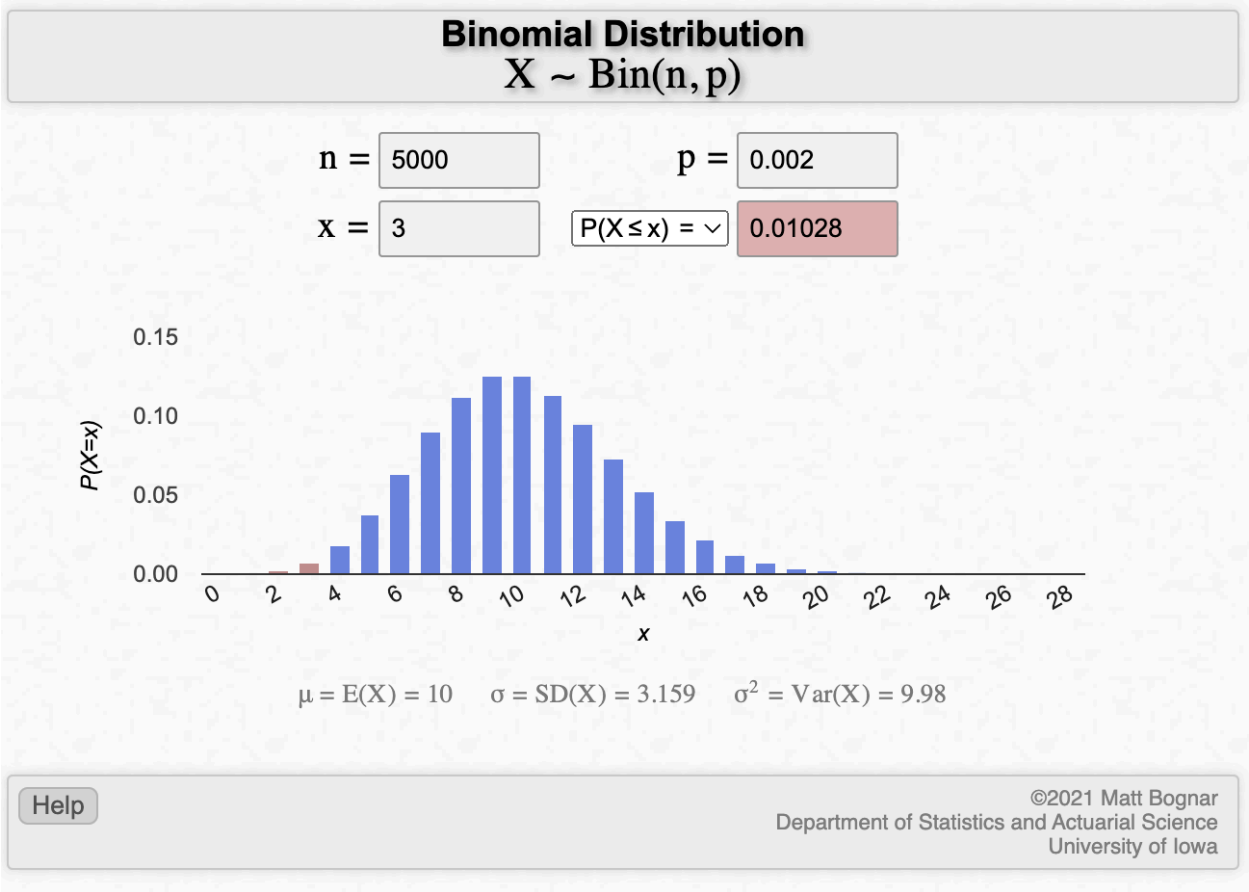
   No functional problems in the MCM were observed throughout the 96 hours of testing that had similar conditions to VVSG 2.7-C. The VVSG test requires scanning only for 15 minutes in each hour, or 26 hours of scanning spread out across the days of the test; 9 of those hours is scanning between 70-95°F and 25-55%RH. In comparison, this current test scanned ballots for 27 hours, in 3- to 8-hour periods spread out across the days of the test; scanning happened between 90-97°F and at 25-45%RH for all 26 hours. Furthermore, the VxScan system was allowed to cyclically cool each night into the next morning before the next test. There were no signs that any failures would occur if extending the test to 104 hours of remaining powered on.

It is not expected to see problems operating the MCM down to 50°F, the lower limit of VVSG 2.7-C. The specifications of all internal MCM components are rated for operation well below 50°F.

3. The misfeed rate was significantly lower than the VVSG threshold.

The observed VxScan misfeed rate was approximately 0.06%, which is favorable to meeting VVSG requirements. The 0.2% (1/500) misfeed threshold listed in VVSG 1.2-G is 3.3x greater than our observed misfeed rate.

The observed low misfeed rate is significantly less than the VVSG threshold and unlikely due to chance. If the probability of seeing a misfeed is represented as a binomial distribution, where the chance of one misfeed p = 0.002 (0.2%), the number of scans n = 5000, and the number of observed misfeeds x = 3, then the probability of seeing exactly 3 or fewer misfeeds is $P(X \leq x) = 0.01$, according to the online binomial distribution model by Dr. Matt Bognar of the University of Iowa (see figure below):



This means that if our VxScan test unit really had a true misfeed rate of 0.2%, the random chance of seeing only 3 misfeeds is very small, just 1%. The true misfeed rate is probably much less than 0.2%.

4. The MCM needs cooling solutions for the components in the left compartments.

EN 62368-1:214 Table 38 and IEC 62368-1:20xx Table 38 lists maximum safe touch temperatures for metal surfaces held by ordinary users for 1-10 seconds as 140°F (60°C). For informed users, this temperature is 158°F (70°C). The USB stick approaches the edge of safe touch temperatures. The Samsung bar USB stick also hovered around its own operating temperature maximum of (140°F) 60°C . A cooling solution should be implemented to reduce risks from hot temperatures on the left side.

5. Future warm operational tests should use stronger or more robust humidity control.

The Govee humidifier used in this test helped the climate tent hit the desired humidity better when it was more filled up with water at least 30% full. Future tests should make

sure to do the same, instead of only filling up less than that. Alternatively, a stronger humidifier system could be used.

A dehumidifier was not needed in these tests in the summer, but it might be needed in other seasonal conditions.

Appendix A: Photos of Test Setup

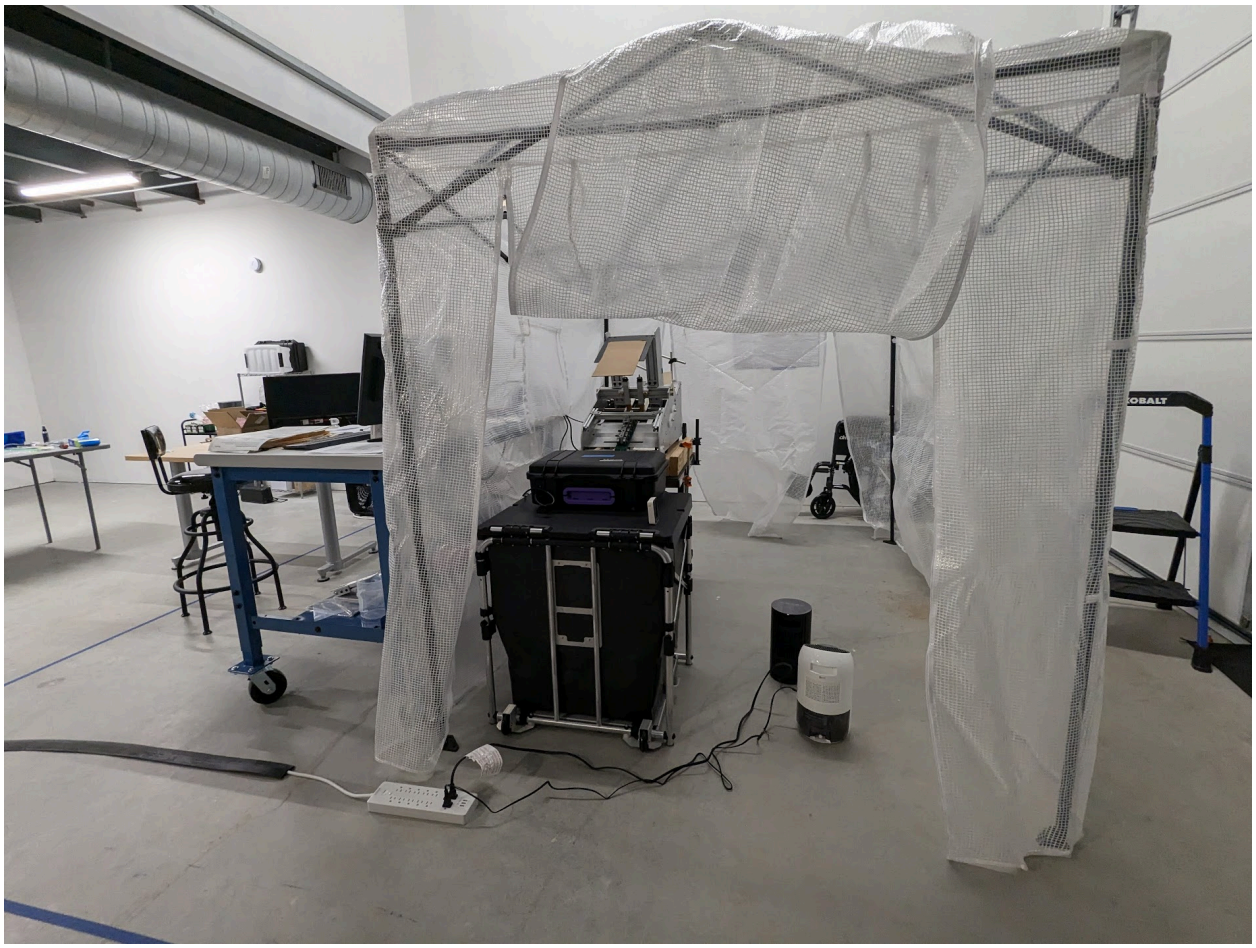


Figure A.1. Arrangement of test setup, before testing. The climate-control tent contains the ballot box, MCM locked onto it, automatic paper-feeder behind the MCM and ballot box, and the low-power smart heater and smart humidifier on the floor. The smart heater and humidifier were placed away from any objects and tent walls to avoid hazards. Outside and adjacent to the tent on the left is another workbench with the auto-paper-feeder control system and computer monitor. The auto-paper-feeder control system is connected to the auto-paper-feeder with wires running through the tent window on the left side. Not shown are the monitoring camera (Simplisafe) and emergency fire extinguisher on hand to prevent any hazards while running without someone directly monitoring it. This system never ran overnight or when people could not easily check its status.

Figure A.2. General test setup internal to the climate tent, while the tent is zipped closed to retain heat and humidity. The automatic paper feeder can be seen resting on spacer blocks on a hydraulic cart, in order to get to an appropriate height to easily feed ballot paper directly into the MCM. A cardboard shield was fixed to the top of the auto-paper-feeder in order to ensure more reliable paper detection from the IR sensor at the front of the paper feeder. The thermometer-hygrometer rests on top of the MCM bottom tub while the pollworker doors are closed, in order to better capture environmental temperature and humidity at the MCM. The smart space heater (black) was configured to heat the environment to a target setpoint of 95°F (35°C), which took about 30 minutes while the tent was closed.

Figure A.3. Close-up photo of the test setup of the MCM. A guide made of cardstock paper and plastic was temporarily fixed with painters' tape over the MCM infeed to help guide and funnel ballot paper sheets from the auto-paper-feeder directly into the MCM infeed. This was necessary to allow more constant feeding without the paper missing the infeed or getting stuck outside the infeed. The cardstock guides did not interfere with the normal paper path of ballots through the MCM or ballot box, and they only mimicked a person positioning a ballot directly into the infeed.

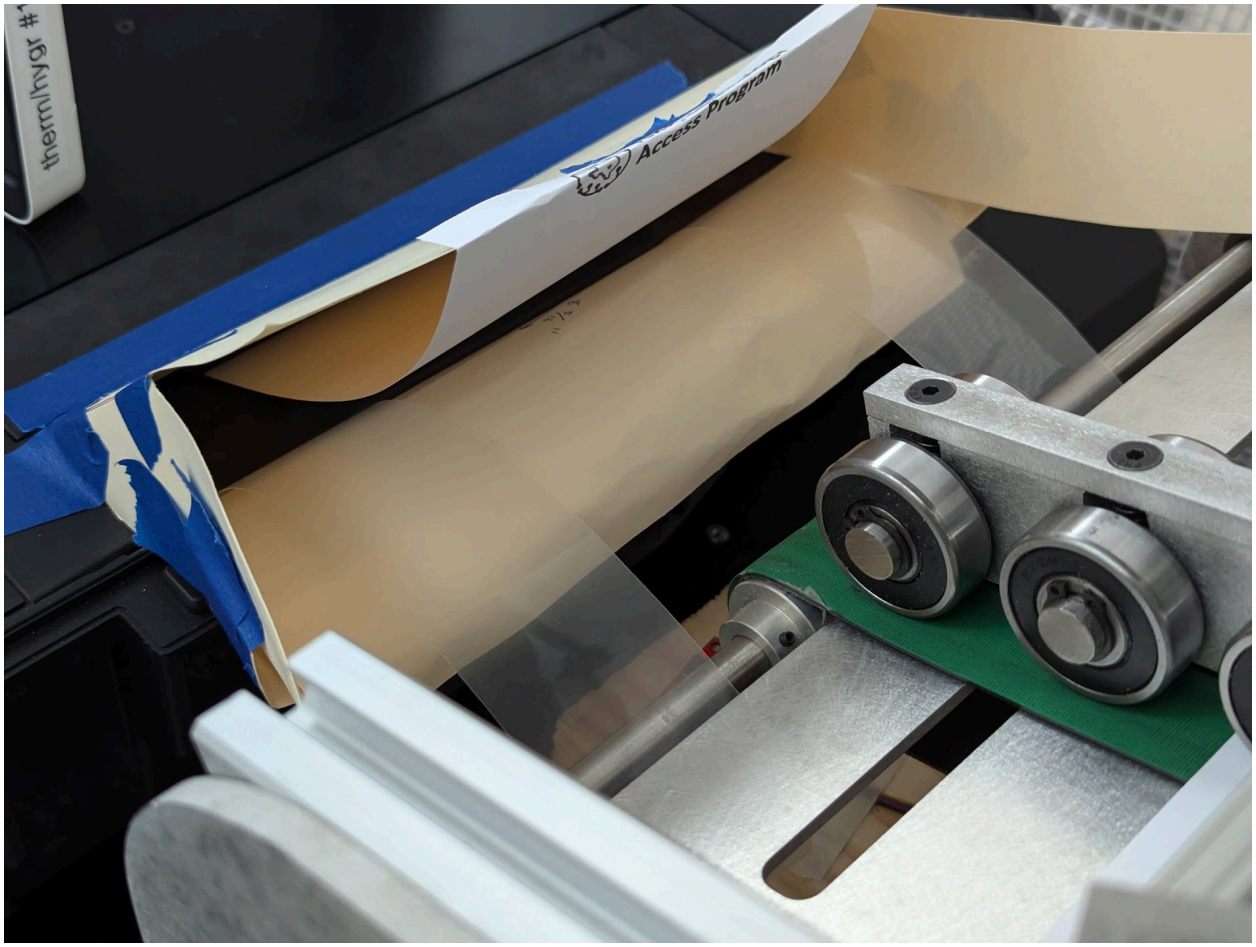


Figure A.4. A more close-up view of the rough guide between the auto-paper-feeder and MCM infeed. It was made of paper-and-plastic sheet, and curved surfaces help push paper sheet directly into the scanner infeed, similarly to how a person would.

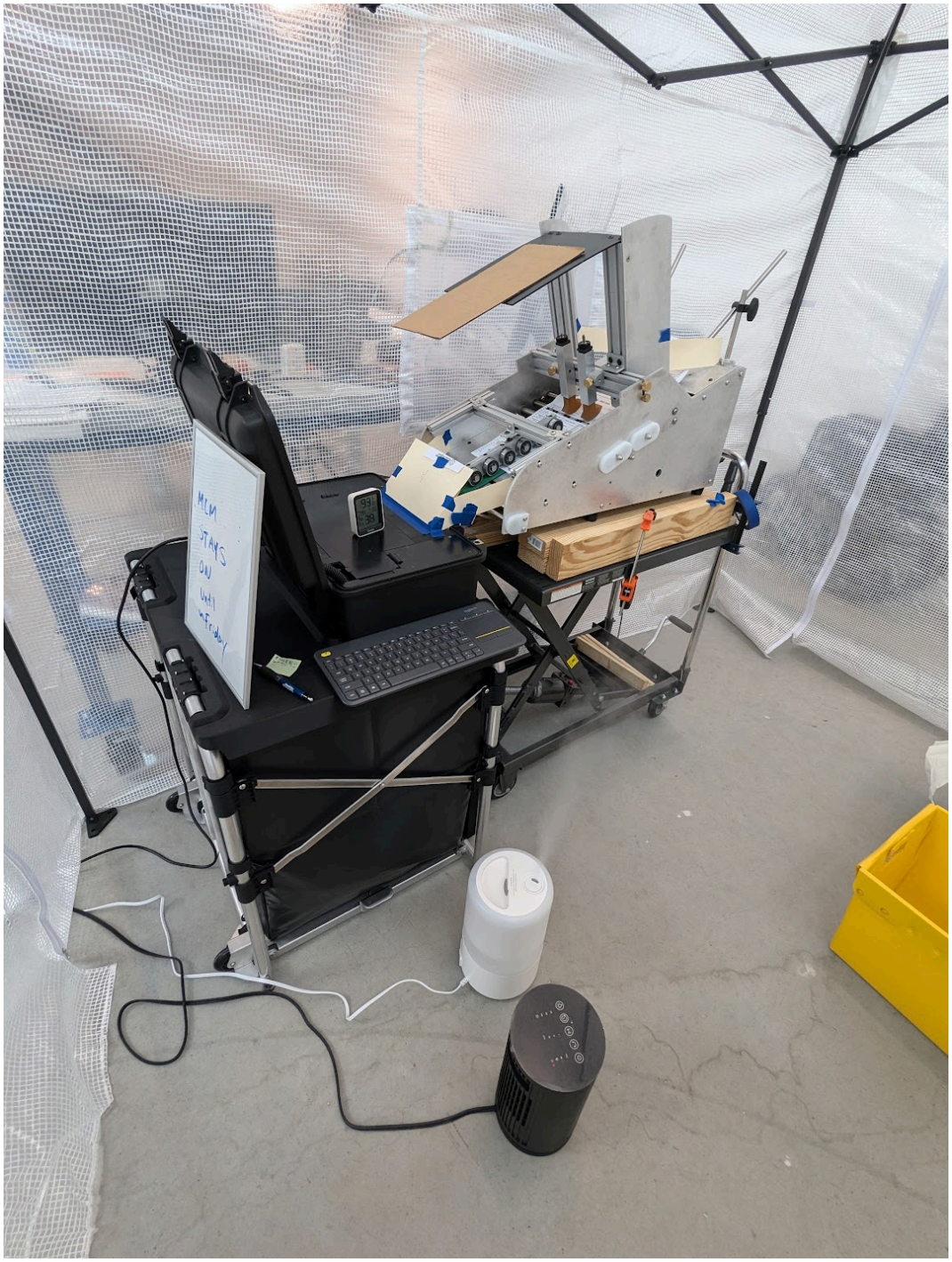


Figure A.5. Another photo of the test setup inside the climate tent, from an angle behind the MCM, showing more of the auto-paper-feeder. The yellow bin on the right held additional ballots inside the climate tent, for reloading the auto-paper-feeder as needed. For this test, the auto-paper-feeder could feed a sheet approximately once every 7-10 seconds, giving enough time for the MCM to scan and respond to the sheet. The auto-paper-feeder could only function well for stacks of approximately 200 sheets or less (or for about 30 minutes' worth of sheets), and so new stacks of ballot sheets had to be added periodically for this test.