# Pattern Recognition Classification of Early Voting Ballot (EVB) Return Envelope Images for Signature Presence Detection

*An Engineering Systems Approach to Identify Anomalies to Advance the Integrity of U.S. Election Processes*

**AUTHOR**
Dr. Shiva Ayyadurai, MIT PhD
SMVS, SMME, SBEE
701 Concord Avenue
Cambridge, MA 02138

**FINAL REPORT**
SEPTEMBER 24, 2021

**PREPARED FOR**

Honorable Senator Karen Fann
President of the Senate
Arizona State Senate
1700 West Washington Street
Phoenix, AZ 85007

EchoMail, Inc.
701 Concord Avenue
Cambridge, MA 02138 U.S.A.
Phone: 617-631-6874
Email: vashiva@echomail.com

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**ECHOMAIL AZ092021-1**

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# DEDICATION

*To the American People*
*Beyond Left & Right*
*Who Seek Truth Freedom Health*

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# AUTHOR'S BIO

Dr. Shiva Ayyadurai, MIT PHD, SMME, SMVS, SBEE, the inventor of email and polymath, holds four degrees from MIT, is a world-renowned engineer, systems scientist, inventor and entrepreneur. He is a Fulbright Scholar, Lemelson-MIT Awards Finalist, India's First Outstanding Scientist and Technologist of Indian Origin, Westinghouse Science Talent Honors Award recipient, and a nominee for the U.S. National Medal of Technology and Innovation. He holds multiple patents, is the author of twenty books, and has published original research, in leading peer-reviewed high-impact scientific journals including *IEEE, IJPRAI, Nature Neuroscience, CELL Biophysical Journal,* that have received thousands of citations. He has started seven successful high-tech companies, received numerous industry awards, consults for Global 2000 organizations and government, and has been invited to present Keynote and Distinguished lectures at leading institutions such as NSF, NIH, FDA, Harvard, and at MIT, where he delivered the Presidential Fellows Lecture.[1]

In 1978, as a 14-year-old, he was recruited as a Research Fellow by the University of Medicine and Dentistry of New Jersey (UMDNJ), in Newark, NJ after graduating with Honors from a special program in Computer Science at the Courant Institute of Mathematical Science at NYU. At UMDNJ, he invented email – ***the system*** as we know it today – when he was the first to convert the old-fashioned *interoffice paper-based mail system* consisting of the Inbox, Outbox, Memo (To:, From:, Date:, Subject:, Cc:, Bcc:), Attachments, Folders, etc. into its electronic equivalent by writing 50,000 lines of code to create a software system, which he named "Email," – a term never used before in the English language – and went on to be awarded the first U.S. Copyright *TXu 111-775* for "EMAIL, COMPUTER PROGRAM FOR ELECTRONIC MAIL SYSTEM" recognizing him as the inventor of email at a time when Copyright was the only legal mechanism to protect software inventions. Only in 1994 did the Federal Circuit recognize software as a "digital machine" allowing for software patents. Email is not the simple exchange of text messages. Dr. Shiva has never claimed to be the inventor of electronic messaging, which predates email - the system that he created in 1978.[2,3]

Recognizing his talents in software programming, UMDNJ gave him the opportunity to conduct medical research focused on developing pattern recognition classification methods for categorization of sleep signature patterns from babies with Sudden Infant Death Syndrome (SIDS). His research was published in IEEE and presented at the IEEE-EMBS conference in Espoo, Finland. Since that time and for more than forty years, his research and development efforts in academia and industry have been focused in the field of pattern recognition classification systems, systems science, and development of large-scale computational systems for analysis of diverse signals and signatures across a range of industries: biology and

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[1] Dr. Shiva Ayyadurai, Biography and Curriculum Vitae, https://vashiva.com/about-va-shiva-ayyadurai/

[2] Facts on the invention of email, https://www.inventorofemail.com/thefacts/

[3] The Man Who Invented Email, TIME, https://techland.time.com/2011/11/15/the-man-who-invented-email/

medicine, engineering (e.g. aeronautical, civil, mechanical, electrical), banking, finance, and, government, as well as across a diversity of applications including handwriting recognition of courtesy amounts on bank checks, automatic analysis and classification of electronic documents e.g. email, ultrasonic and radar wave signature classification for non-destructive evaluation (NDE), signals analysis of Tadoma feature identification, biomarker analysis for determining signatures of efficacy for multi-combination therapies, image analysis for cardiology, and signal detection of fluid flow anomalies in fluidized bed reactors.

He earned a Bachelors in Electrical Engineering and Computer Science, a Masters in Mechanical Engineering, and another Masters in Visual Studies from the MIT Media Laboratory. In the midst of his PhD research in 1993, where he aimed to create a generalized platform – *Information Cybernetics* – for pattern recognition, he won an industry-wide competition sponsored by the White House, Executive Office of the President, to automatically analyze and classify President Clinton's email, resulting in his developing EchoMail® - a platform for automatic classification of electronic documents –, and subsequently launching EchoMail, Inc., a company that grew to nearly $200 million in market valuation. EchoMail today applies its technologies across a diversity of applications.

In 2003, he returned to MIT complete his doctoral work in systems biology in the department of Biological Engineering where he developed CytoSolve®, a scalable computational systems biology platform for mathematically modeling the whole cell. Following his PhD, Dr. Shiva was selected for a Fulbright Fellowship returning him to India where he discovered the systems theoretic basis of eastern systems of medicine resulting in Systems Health®, a new educational program that provides a scientific foundation for integrative medicine. In 2012, Dr. Shiva launched CytoSolve, Inc. with the aim of modeling complex diseases and biomolecular processes to discover multi-combination medicines. His efforts led to CytoSolve earning an FDA allowance for a multi-combination therapy for pancreatic cancer in a record eleven months, developing innovative nutraceutical products, and garnering numerous industry and academic partnerships.

As an educator dedicated to the field of systems science and systems thinking, Dr. Shiva pioneered *Systems Visualization*, a course he taught at MIT to graduate and undergraduate students, which integrated systems theory, narrative story telling, metaphors, and data science to provide a pedagogy for visualization of complex systems. He founded the International Center for Integrative Systems, a research and educational institution and home to Innovation Corps and R.A.W./C.L.E.A.N. Food Certified, for broader applications of systems science.

Dr. Shiva has appeared in *The MIT Technology Review*, *TIME, The Wall Street Journal*, *New York Times*, *NBC News*, *USA Today* and other major media. Dr. Shiva was named Top 40 Under 40 in the *Improper Bostonian*. He continues his passion for entrepreneurialism as Managing Director of General Interactive to incubate, mentor and fund new startups in various areas including healthcare, media, biotechnology, information technology, to name a few.

Dr. Shiva is a member of Sigma-Xi, Eta Kappa Nu, and Tau Beta Pi.

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***An Engineering Systems Approach to Identify Anomalies to Advance the Integrity of U.S. Election Processes***

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Email: vashiva@echomail.com | Tel: 617-631-6874

## ABSTRACT

The processing of Early Voting Ballots (EVBs), and, more broadly, election voting systems are complex *engineering systems* – sociotechnical systems – involving parallel and sequenced processes across multiple systems of systems, interconnecting diverse stakeholders.[4] Such engineering systems advance through constant observation and feedback, and particularly in response to anomalous behavior. The integrity of such engineering systems relies on a culture fostering the encouragement of stakeholders' to provide feedback and a commitment by leadership to investigate anomalies – small or large, insignificant or monumental. Engineers welcome signals of anomalous behavior for they provide a gateway to identify and resolve root cause issues towards greater systems integrity. In Maricopa County, Arizona, election officials processed 91.67% of all ballots cast in the November 2020 general election through EVB systems, as reported in the November General Election CANVASS report.[5] Constituent concerns about the 2020 U.S. general election in Maricopa County ("Maricopa") were one of the motivations for the Arizona State Senate to conduct a comprehensive audit.

[4] Early Voting Ballots (EVBs) are a method of voting prior to ("early" to) Election Day.
[5] https://recorder.maricopa.gov/pdf/11-03-2020-0 Canvass BOS SUMMARY NOV2020-two-sided print.pdf, accessed September 15,2021.

This audit sought to review the count of signatures on EVB return envelopes as reported in the *CANVASS* report. The Arizona State Senate commissioned this author – Dr. Shiva Ayyadurai – based on their review of his engineering experience and his more than forty years of contributions to the field of pattern recognition classification methods and engineering systems science, to provide his expertise and EchoMail, Inc.'s capabilities to audit Maricopa's EVB return envelope images from the 2020 general election. An example of an EVB return envelope image, ***and the explicit area in which the voter must SIGN WITHIN THE BOX, ("Signature Region")***, is illustrated in Figure 1, below.

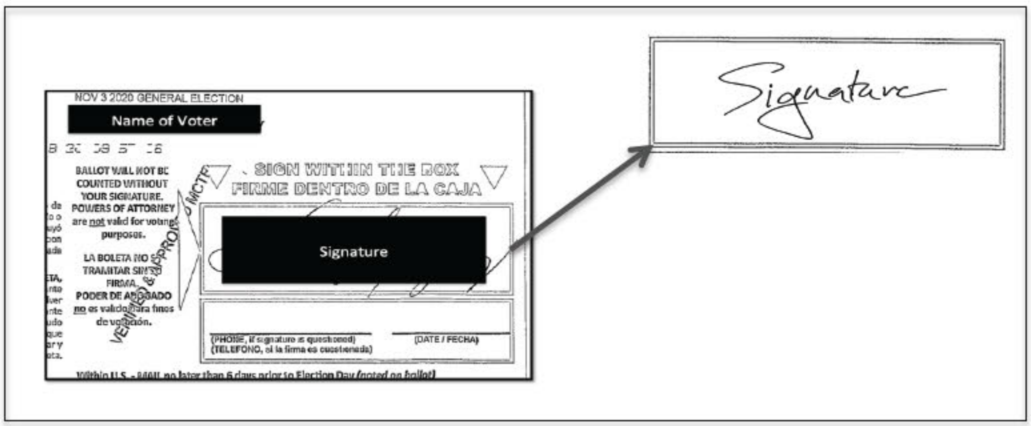



**Figure 1**: Example of an image of an Early Voting Ballot (EVB) return envelope, and the Signature Region, in which the voter must provide their signature.

In this audit, EchoMail was tasked with executing pattern recognition classification methods to identify the Signature Region on the EVB return envelope image, as shown in Figure 1, and then to classify that specific Signature Region as "Blank," "Likely Blank," "Scribble," or "Signature."[6] EchoMail received 1,929,240 EVB return envelope images from the Arizona State Senate that were represented to EchoMail as all EVB return

[6] A Signature Region is classified based on non-white pixel densities in the Signature Region as follows: if 0% then Blank; if 0%+ to 0.1% then Likely Blank; if 0.1%+ to 1% then Scribble; and, if greater than 1%, then as Signature. EchoMail's scope was ***not*** to identify a signature if it appeared elsewhere on the EVB return envelope image.

envelopes received by Maricopa for the November 2020 Election. EchoMail executed an array of pattern recognition classification algorithms to extract the specific Signature Region from the EVB return envelope image. The count of Signature Regions classified as Signature, was compared with the count, as reported by Maricopa election officials in the *CANVASS* report.

The analysis revealed various anomalies such as: 34,448 EVB return envelope images that were 2-Copy, 3-Copy and 4-Copy duplicates ("Duplicates") originating from 17,126 unique voters while no Duplicates were reported in Maricopa's *CANVASS* report; 6,545 ***more*** unique EVB return envelopes reported by Maricopa than that by EchoMail; 9,589 ***more*** EVB return envelopes with signatures in Maricopa's count; and, Maricopa's count of 587 "Bad Signatures" – equaling 0.031% of all EVB return envelopes received by Maricopa – appear to be surprisingly low, given that EchoMail itself, though not commissioned to audit or perform Signature Verification, detected 2,580 non-signature Scribbles, in the Signature Region, which would exceed Maricopa's "Bad Signatures" percentage of 0.031%, by over four times.

The anomalies identified in this audit raise questions on the integrity of Maricopa's EVB systems processes and support the need for further investigation including a review of Maricopa's Standard Operating Procedure (SOP) for EVB processing, Chain of Custody, and Signature Verification methods, including the methodologies for curing questionable signatures. Moreover, an independent scientific analysis of Maricopa's Signature Verification process that involves comparing *all* signatures on EVB return envelopes with the voter registration signatures is warranted. Such an effort will provide a quantitative metric to assess the confidence level of Maricopa's Signature Verification process; and, more importantly, serve as a valuable case study towards building objective metrics to assess the entire EVB systems process. This audit, based on an engineering systems approach, and the anomalies discovered herein provide the *systems feedback* necessary for all stakeholders to advance the systems integrity of U.S. elections processes.

## SUMMARY RESULTS

| | EchoMail Analysis | Maricopa Reported | Variance |
|---|---|---|---|
| **EVB Return Envelopes Received** | **1,929,240*** | ***Unknown*** | **NA** |
| | | | |
| **Duplicate Analysis** | | | |
| **Duplicates**[7] | (17,322) | *Un-reported* | NA |
| **Unique EVB Return Envelopes** | **1,911,918** | **1,918,463****| **(6,545)** |
| | | | |
| **Signature Presence Detection** | | | |
| **No Signature Ballots**[8] | (1,919) | (1,455) | (464) |
| **Scribbles**[9] | (2,580) | NA | (2580) |
| **EVBs Ready for Signature Verification** | **1,907,419** | **1,917,008** | **(9,589)** |
| | | | |
| **Signature Verification** | | | |
| **"Bad Signatures"** | NA | (587) | NA |
| **"Late Returns"** | NA | (934) | NA |
| **Total EVBs Verified and Counted** | **NA** | **1,915,487** | **NA** |

**Table 1:** Summary report of EchoMail Analysis of EVB return envelope images compared with Maricopa's results reported in November General Election *CANVASS* report.

*This count is the total count of all the EVB return envelope images received by EchoMail from Arizona State Senate.

**This count is all EVB return envelopes verified and counted by Maricopa (1,915,487) plus those classified by Maricopa as "No Signatures" (1455), "Bad Signatures" (587), and "Late Returns" (934), as documented in Maricopa County's November 2020 *CANVASS* report.

[7] In the EchoMail Analysis, those EVB return envelope images with same image file name were deemed "Duplicates." The EVB return envelope image file names are voter specific. 17,126 unique voters submitted 34,448 2-Copy, 3-Copy, 4-Copy Duplicates. The *CANVASS* report filed by Maricopa election officials did not report Duplicates.

[8] "No Signature Ballots" in EchoMail Analysis are those Signature Regions on EVB return envelope images classified to be "Blanks" based on a non-white pixel density of 0%, and "Likely Blanks" based on a non-white pixel density between 0%+ to 0.1%.

[9] "Scribbles" in EchoMail Analysis are those EVB return envelope images containing likely illegible signatures in the Signature Region, wherein a scribble is defined as a Signature Region containing a non-white pixel density between 0.1%+ to 1%.

## KEY FINDINGS

- **It is unknown, per the *CANVASS* report, how many EVB return envelopes were *originally* received by Maricopa election officials.** EchoMail received a data set of 1,929,240 EVB return envelope images that were represented to EchoMail as being the set of *all* EVB return envelopes originally received by Maricopa. However, the *CANVASS* report does not document how many EVB return envelopes were originally received Maricopa election officials.[10]

- **EchoMail identified 34,448 EVB return envelope images being 2-copy, 3-copy and 4-copy Duplicates** originating from 17,126 unique voters, while no Duplicates were reported in Maricopa's *CANVASS* report.[11]

- 6,545 ***more*** unique EVB return envelopes were processed by Maricopa than identified by EchoMail.

- 464 ***more*** "No Signature" EVB return envelopes were reported by EchoMail. EchoMail identified 1,919 EVB return envelope images with Blank or Likely Blank in the Signature Region i.e. "No Signature." Maricopa reported 1,455 "No Signature" EVB return envelopes.

- 2,580 Scribbles identified by EchoMail in the Signature Region of EVB return envelope images. A "Scribble" is when a Signature Region on an EVB return

[10] All EVBs reported that were received by Maricopa are assumed to have been accompanied by return envelopes or affidavits with signatures.
[11] The 2020 November General Election *CANVASS* report does not mention Duplicates. A search of the keyword "duplicate" reveals no instances in the *CANVASS* report.

envelope image contains a non-white pixel density between 0.1%+ to 1%, and may indicate a potential "Bad Signature." EchoMail was not commissioned with the task of performing Signature Verification.

- Maricopa reported 587 "Bad Signatures," which is 0.031% of the total EVB return envelopes received by Maricopa. Though EchoMail was not commissioned to perform Signature Verification, if EchoMail's identification of 2,580 Scribbles were all designated as "Bad Signatures," that would be 0.134% of Maricopa's total EVB return envelopes received. This percentage is at least four times more than the "Bad Signatures" percentage reported by Maricopa.

- While the number of EVB returns envelopes in Maricopa for the 2016 general election ***increased*** from 1,257,179 to 1,918,463 EVB return envelopes for the 2020 general election, representing a 52.6% ***increase*** (or by 661,284 EVB return envelopes), the number of rejections from Signature Mismatches of EVB return envelopes, from 2016 to 2020, ***decreased*** by 59.7%. This inverse relationship requires explanation.

- 9,589 ***more*** EVB return envelopes were submitted for Signature Verification by Maricopa than the EVB return envelope images identified by EchoMail as having signatures.

- A full audit of Maricopa's Signature Verification process is necessary, and can be accomplished by comparing each signature on EVB return envelope images with an image of the voter's signature from voter registration files. This will provide a quantitative metric to assess confidence level of Signature Verification.

- Disclosure of Maricopa's Standard Operating Procedure (SOP) for EVB processing, Chain of Custody, and Signature Verification methods, including the SOP and methodology for curing questionable signatures, is necessary.

# INTRODUCTION

The 21st century is the era of complex *engineering systems*.

The processing of Early Voting Ballots (EVBs), and, more broadly, election voting systems are complex engineering systems – sociotechnical systems – involving parallel and sequenced processes across multiple systems of systems, interconnecting diverse stakeholders.[12] Early Voting Ballots (EVBs) are a method of voting prior to i.e. "early" to, Election Day. In Maricopa County, Arizona, election officials processed 91.67% of all ballots cast in the November 2020 general election through EVB systems as reported in the November General Election CANVASS report.[13]

Over the past two decades, the nascent discipline of engineering systems has evolved towards developing a systems theoretic framework, including new pedagogies and *lingua franca*, to comprehend the complexity of large-scale systems involving multiple stakeholders. These developments are essential to build and deliver systems that meet stakeholders' implicit and explicit needs. Engineering systems recognize that the needs of stakeholders – voters, in this case – can best be addressed through a sociotechnical systems approach in defining the properties of such systems.

[12] Early Voting Ballots (EVBs) are a method of voting prior to ("early" to) Election Day.
[13] https://recorder maricopa.gov/pdf/11-03-2020-0 Canvass BOS SUMMARY NOV2020-two-sided print.pdf, accessed September 15,2021.

## ENGINEERING SYSTEMS APPROACH

The modern world has moved from the world of creating simple isolated components to a world of tightly coupled systems of systems. The engineering systems approach offers a framework to study such systems. While the goals of this audit are well defined, this manuscript also aims is to motivate an engineering systems perspective in election voting systems with the hope of moving beyond partisanship, vitriol, and controversy, to appreciate that modern election voting systems are indeed complex engineering systems.

In the fields of global manufacturing and supply chains, transportation systems, space travel and aeronautical systems, electrical power generation and distribution networks, self-driving autonomous vehicle management systems, and modern health care systems, that appreciation has emerged. Stakeholders of election voting systems: election officials, voters, suppliers, and policy makers may greatly benefit from such a concomitant appreciation to advance the integrity of a foundational system that aims to enable a democracy for a wide range of stakeholders, beyond left and right.

Such engineering systems advance through constant observation and feedback, and particularly in response to anomalous behavior. The integrity of such engineering systems relies on a culture fostering stakeholders' encouragement to provide feedback and a commitment to investigate observed anomalous behavior – small or large, insignificant or monumental. Engineers welcome signals of anomalous behavior for they provide a gateway to identify and resolve root cause issues towards greater systems integrity. Constituent concerns about the 2020 U.S. general election in Maricopa County was one of the motivations for the Arizona State Senate to conduct a comprehensive audit.

One element of this audit sought to review the count of signatures on EVB return envelopes as reported in the *CANVASS* report. The Arizona State Senate commissioned this author – Dr. Shiva Ayyadurai – based on their review of his engineering experience and his more than forty years of expertise in the field of pattern recognition classification methods and engineering systems science, to provide his and EchoMail, Inc.'s capabilities to audit Maricopa's EVB return envelope images from the 2020 general election.

Identifying and addressing root causes of such anomalies can only lead to one outcome: a more robust election system exhibiting the properties of precision, reliability, auditability, and reproducibility, among others. Over the past two decades, engineering systems theory and pedagogies have developed the *lingua franca* of such properties or "ilities," in order to define requirements of a system that can have overall impact on system behavior; for example, the top twenty "ilities" are identified in the graph in Figure 2 below.[14] The "ilities" in this graph are based on an analysis of journal articles and google hits of many well-known and common engineering systems. The top four "ilities" are quality, reliability, safety, and flexibility.

[14] p.67, http://strategic.mit.edu/docs/es_book_004_proof.pdf accessed on September 15, 2021.

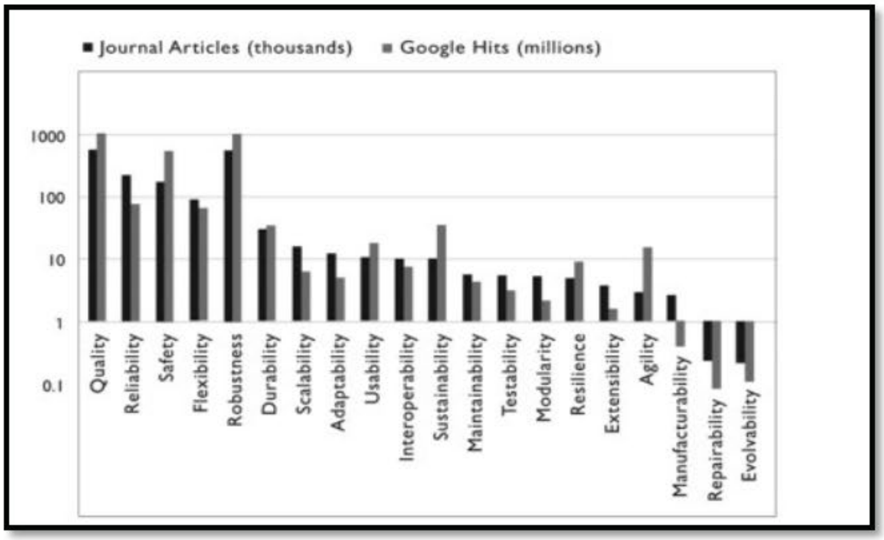



**Figure 2:** The Top 20 "Ilities"[8]

When considering election voting systems, given the interconnectivity of such systems with the most important stakeholders – voters –, while reliability emerges as an obvious desirable systems property, other "ilities" such as, precision (does not have to end in "ility"), auditability, and reproducibility of election results, for example, though not identified in the above graph, are likely to be some of the most relevant and necessary properties for ensuring integrity in election voting systems. The non-existence of these key "ilities" in the above graph reflects the likely reality that engineering systems approaches to election voting systems are a relatively new application area. The efforts herein, therefore, provide a unique and historic opportunity for an engineering systems approach to election voting systems.

# THE EVB SYSTEMS PROCESS

The processing of Early Vote Ballots (EVBs) is a multi-step engineering systems process requiring many "ilities" (properties that have yet to be perhaps consciously decided by all stakeholders) such as precision, reliability, auditability, and reproducibility.

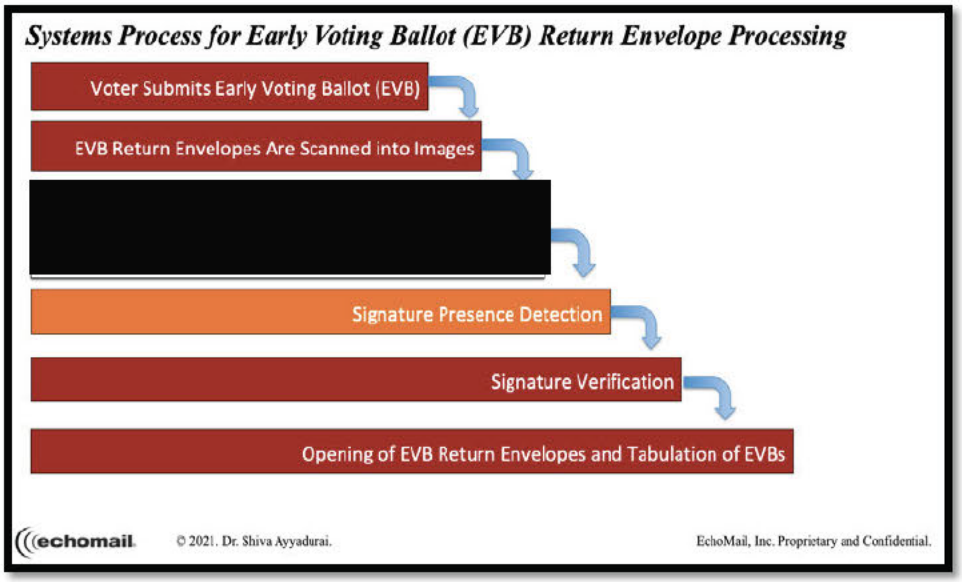



**Figure 3:** The systems process for Early Voting Ballot (EVB) return envelope processing.

Figure 3 provides the key steps in the multi-step systems process of EVBs. After a voter submits their EVB in a return envelope, the EVB return envelopes are scanned into digital images. EVB return envelopes come in an assortment of formats depending on location, and voter needs. There are EVB return envelopes for U.S. citizens residing in the United States, for those residing outside of the United States, and as well for military personnel. In addition, formats vary for those with poor eyesight e.g. large print format, and the blind e.g. Braille format. The images are stored in file types such TIFF and PDF.

One of the critical steps in the processing of EVBs is to ensure the *presence* of a signature. Voters are expected to sign their names in a specific Signature Region on the envelopes or affidavit accompanying the EVB. ***The instructions indicate that the voter must sign inside the box. Per the Scope of Audit, EchoMail is to analyze, solely this Signature Region.***

## Signature Presence Detection

This process of verifying a signature's existence in the Signature Region of the EVB return envelope image, is denoted as "Signature Presence Detection." Figure 4 below illustrates the key aspects of Signature Presence Detection.

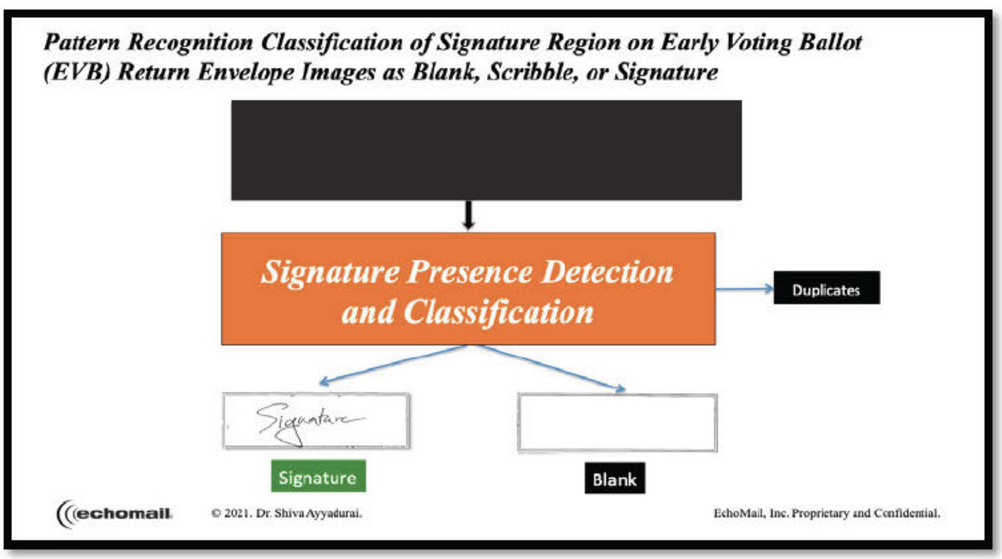



**Figure 4:** The key aspects of Signature Presence Detection.

The first step in this process is to receive and organize all of EVB return envelope images for classification. Another step is to tag and resolve Duplicates, so only one EVB return envelope is associated with one unique voter i.e. "One Person, One Vote." Classification involves looking at the Signature Region and determining if it is has a Signature or a Blank i.e. "No Signature." A blank in the Signature Region is officially tagged as "No Signature." In this audit, EchoMail was tasked with further refining the classification of the Signature Region into: Signature, Blank, Likely Blank, and Scribble, which are discussed in detail in the *Scope of Audit* and *Methodology* sections.

## *Signature Verification*

One of the other critical steps in the processing of EVB return envelopes is to verify that the signature in the Signature Region matches with signature that the election officials have on file for the voter. This process denoted as "Signature Verification" appears to vary from state to state, and even from county to county. During Signature Verification, the reviewer may also look for a signature elsewhere, beyond the Signature Region, on the EVB return envelope. Information from the Recorder's office in Maricopa along with information provided by an independent organization's interview with Maricopa election officials reveals the key elements of Signature Verification.[15,16]

Based on these information sources, and in the absence of access to a formal Standard

[15] FAQ 11 of https://recorder maricopa.gov/site/faq.aspx, accessed on September 15, 2021.
[16] pp. 13-14 of https://healthyelections.org/sites/default/files/2020-11/arizona-110220.pdf, accessed on September 15, 2021.

Operating Procedure (SOP) for Signature Verification, the process of Signature Verification appears to consist of the following elements:

- Each EVB return envelope, containing a code unique to the voter, is made available to reviewers
- The signature on EVB return envelope is reviewed by a County employee.
- During the review, the reviewers "…are trained to look at 27 different points of comparison on a signature to complete verification, including slopes, pen drops, and other identifiable components of a person's handwriting" with a signature on file that is associated with their voter registration signature, accessible using the code unique to the voter.
- Two watchers customarily observe review of signatures on EVB return envelopes – one selected from Democratic Party, and the other selected from the Republican Party.
- If the signature matches the records, the EVB return envelope is marked as "Good Signature" and the EVB is sent for vote tabulation.
- If the signature does not match, as confirmed by a second and third round of review, election officials make reasonable efforts to contact the voter and "cure" the questionable signature where "…the county recorder or other officer in charge of elections shall make reasonable efforts to contact the voter, advise the voter of

the inconsistent signature and allow the voter to correct or the county to confirm the inconsistent signature."[17]

- If unable to contact the voter and verify e.g. cure the questionable signature, the signature is not counted and the EVB is deemed to be a "Bad Signature."
- If the Signature Region of the EVB return envelope is blank, then the reviewers may look for signatures elsewhere on the EVB return envelope e.g. in the phone area, and may attempt to verify and cure. If the signature does not exist anywhere, the EVB is deemed a "No Signature."
- Any EVBs that are submitted after the deadline are classified as "Late Returns."

Table 1 displays the signature-matching practices and requirements for mail-in ballots in the battleground states.

*Table 1: Legal Framework for Signature Verification in Battleground States*

| Battleground State | Requires Signature Verificatio n Process? | Signature Verification Practices Codified? | Witness Requirements? | Allows Cure of Missing Voter Signature? | Allows Cure of Mismatched Signature? | Allows Cure of Witness Signature Error? | Voters have a chance to cure signature issues *after* Election Day? |
|---|---|---|---|---|---|---|---|
| **AZ** | YES | YES | NO | YES | YES | N/A | YES |
| **FL** | YES | YES | NO | YES | YES | N/A | YES |
| **MI** | YES | NO | NO | YES | YES* | N/A | NO |
| **NC**** | NO | N/A | YES | YES | N/A | YES | YES |
| **PA** | NO | N/A | NO | YES | N/A | N/A | NO |
| **WI** | NO | N/A | YES | YES | N/A | YES | NO |

Table 1 is color-coded based on whether or not the practice in question makes it easier (green) or harder (red) for voters to cast their ballots.

*Voters must spoil the ballot with the mismatched signature and request a new ballot. Some jurisdictions may allow voters to cure their original ballot, but there is no state law to that effect.

**Under new NCSBE Guidance issued on October 4, 2020, North Carolina's notice and cure process for missing signatures and witness defects is temporarily suspended until several pending lawsuits are resolved, likely in the near future.

**Figure 5:** Legal framework assessment of Signature Verification in six 2020 battleground states.[18]

In Figure 5, is a screenshot of a table from a report aggregating metrics defining the legal

17 https://www.azleg.gov/ars/16/00550.htm, accessed September 15, 2021.

18 p.8, http://healthyelections.org/sites/default/files/2020-10/Signature%20Verification%20Report%20(Oct%207%2C%202020).pdf, accessed September 15, 2021.

framework for Signature Verification in six battleground states in the 2020 election. This table indicates that Arizona and Florida may have the most comprehensive support for Signature Verification, as denoted by achieving five "YES" qualifications out of the seven criteria.[19] In that same report, the results of the Election Administration and Voting Survey (EAVS) of Mail-In ballot rejections for Signature Mismatch, following Signature Verification, are provided for the 2016 and 2018 general elections and midterms, respectively. In Figure 6, an extract of a table from that report, highlighting the Signature Mismatch data for the **State of Arizona**, is shown.

*Table 4: Historic Ballot Rejections for Signature Mismatch (2016 & 2018 EAVS data) & Which States Are Required to Compare Signatures in the 2020 General Election*

| General Election: November 8, 2016 | | | | | Midterm Election: November 6, 2018 | | | | | 2020 General |
|---|---|---|---|---|---|---|---|---|---|---|
| State | Rejected for Signature Mismatch | Mail-in Ballots Received | % of Votes that are Mail-in | Signature Mismatch Rejection Rate* | State | Rejected for Signature Mismatch | Mail-in Ballots Received | % of Votes that are Mail-in | Signature Mismatch Rejection Rate* | State Signature Matching Requirement? |
| AK | N/A | 27,626 | 8.55% | N/A | AK | N/A | 24,425 | 8.50% | N/A | No |
| AL | N/A | 88,601 | 4.15% | N/A | AL | N/A | 57,832 | 3.36% | N/A | No |
| AR | 94 | 27,525 | 2.63% | 0.34% | AR | 21 | 15,208 | 1.92% | 0.14% | Yes |
| AZ | 2,657 | 2,017,722 | 74.11% | 0.13% | AZ | 1,516 | 1,899,240 | 78.81% | 0.08% | Yes |
| CA | 25,965 | 8,511,992 | 58.26% | 0.31% | CA | 16,116 | 8,286,228 | 59.92% | 0.19% | Yes |
| CO | 16,149 | 2,654,993 | 92.05% | 0.61% | CO | 13,027 | 2,449,409 | 94.70% | 0.53% | Yes |
| CT | N/A | 132,012 | 7.88% | N/A | CT | N/A | 91,602 | 6.44% | N/A | No |
| DC | Data not available | 16,625 | 5.33% | N/A | DC | 44 | 9,351 | 4.04% | 0.47% | Yes |

**Figure 6:** Highlighting the Signature Mismatch metrics for the **State of Arizona** 2016 and 2018 general election and midterm election, respectively.

On the left side of Figure 6, for the State of Arizona for the 2016 general election, the number of Mail-In ballots received is 2,017,722; 2,657 Mail-In ballots were rejected for

19 p.8, https://healthyelections.org/sites/default/files/2020-10/Signature%20Verification%20Report%20(Oct%207%2C%202020).pdf, accessed September 15, 2021.

Signature Mismatch, representing a Signature Mismatch Rejection Rate of 0.132%. The Signature Mismatch Rejection Rate is calculated by dividing the Mail-In ballots rejected for Signature Mismatch by the total number of Mail-In ballots received. On the right side of Figure 6, for the State of Arizona for the 2018 midterm election, the number of Mail-In ballots received is 1,899,240; 1,516 Mail-In ballots were rejected for Signature Mismatch, representing a Signature Mismatch Rejection Rate of 0.079%. These results are consolidated in Table 2.

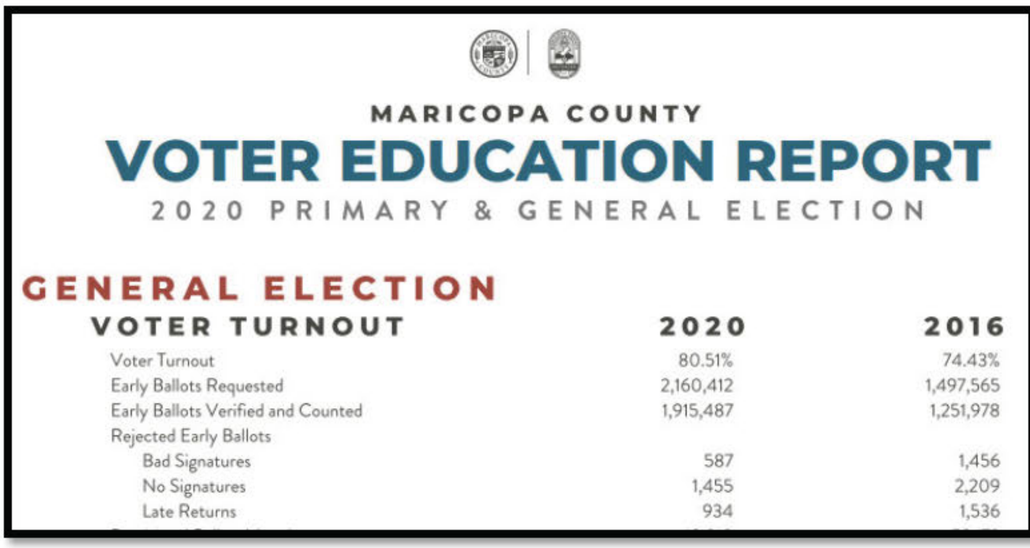
| | **State of Arizona 2016 General Election** | **State of Arizona 2018 Midterm Election** |
|---|---|---|
| Mail-In Ballots | 2,017,722 | 1,899,240 |
| Rejection from Signature Mismatch | 2,657 | 1,516 |
| Signature Mismatch Rejection Rate | 0.131% | 0.079% |

**Table 2**: Comparison of Signature Mismatch Rejection Rates in the **State of Arizona** for 2016 general election with 2018 midterm election.

Table 2 shows that *as the number* of Mail-In ballots in the State of Arizona ***decreased*** from 2,017,722 in the 2016 general election by 118,482 Mail-In ballots to 1,899,240 in the 2018 midterm election, representing a 5.62% ***decrease***, the rejections from Signature Mismatch also ***decreased*** by 1,141 Mail-In ballots, a 42.9% ***decrease*** from 2016 to 2018. In addition, the Signature Mismatch Rejection Rate ***decreased*** from 0.131% in 2016, by 39.7%, to 0.079% in 2018. In summary, ***decreases*** in Mail-In ballots were followed by ***decreases*** in rejections from Signature Mismatch. This appears to be consistent i.e. less Mail-In ballots, less rejections from Signature Mismatch.

# MARICOPA EVB RESULTS SUMMARY

The *November General Election CANVASS* report filed by Maricopa County election officials, documents the various counts for EVB return envelopes, during the 2016 and 2020 general elections. These counts are shown in Figure 7.[20]


MARICOPA COUNTY

VOTER EDUCATION REPORT

2020 PRIMARY & GENERAL ELECTION

GENERAL ELECTION

| VOTER TURNOUT | 2020 | 2016 |
|---|---|---|
| Voter Turnout | 80.51% | 74.43% |
| Early Ballots Requested | 2,160,412 | 1,497,565 |
| Early Ballots Verified and Counted | 1,915,487 | 1,251,978 |
| Rejected Early Ballots | | |
| Bad Signatures | 587 | 1,456 |
| No Signatures | 1,455 | 2,209 |
| Late Returns | 934 | 1,536 |

**Figure 7:** EVB return envelope metrics for **Maricopa County,** including Verified and Counted, Bad Signatures, No Signatures and Late Returns, as reported in the *CANVASS* report.

Per the report for **Maricopa County** as shown in Figure 7, for 2020, 1,915,487 EVB return envelopes were Verified and Counted (after Signature Verification); 587 were classified as "Bad Signatures;" 1,455 were classified as "No Signatures;" and, 934 were classified as "Late Returns." Summing up these counts yields a total of 1,918,463 unique EVB return envelopes that were processed by Maricopa County election officials in 2020. Similarly,

[20]Voter Education Report, https://recorder maricopa.gov/pdf/11-03-2020-0%20Canvass%20BOS%20SUMMARY%20NOV2020-two-sided%20print.pdf, accessed September 15, 2021

for 2016, 1,251,978 EVB return envelopes were Verified and Counted; 1,456 were classified as "Bad Signatures;" 2,209 were classified as "No Signatures;" and, 1,536 were classified as "Late Returns." Summing up these counts yields a total of 1,257,179 unique EVB return envelopes that were processed by the Maricopa County election officials in 2016. Figure 8 summarizes these results.

***Summary of Results from Maricopa County***

| | Maricopa Reported in 2020 | Maricopa Reported in 2016 |
|---|---|---|
| **Unique EVB Return Envelopes** | 1,918,463 | 1,257,179 |
| **Duplicate Analysis** | | |
| **Duplicates** | NA | NA |
| **Total Unique EVB Return Envelopes** | 1,918,463 | 1,257,179 |
| **Signature Presence Detection** | | |
| **No Signature Ballots** | (1,455) | (2,209) |
| **Total Ready for Signature Verification** | **1,917,008** | **1,254,970** |
| **Signature Verification Process** | | |
| **"Bad Signatures"** | (587) | (1,456) |
| **"Late Returns"** | (934) | (1,536) |
| **Total EVBs Verified and Counted** | **1,915,487** | **1,251,978** |

**Figure 8:** Results for **Maricopa County**, for 2016 and 2020 general elections, with calculated total of unique EVB return envelopes processed.

Using the data from Figure 8, a comparison chart in Table 3 is created to compare Signature Mismatch Rejection Rates for **Maricopa County** for the 2016 and 2020 general elections. In 2016, the number of unique EVB return envelopes processed is 1,257,179. There are 1,456 EVB return envelopes rejected for "Bad Signatures" i.e. Signature Mismatches. The Signature Mismatch Rejection Rate for **Maricopa County in 2016** is therefore 0.116%. In 2020, the number of unique EVB return envelopes processed is 1,918,463. There were 587 EVB return envelopes rejected for "Bad Signatures" i.e. Signature Mismatches. The Signature Mismatch Rejection Rate for **Maricopa County in 2020** is 0.031%. These results are consolidated in Table 3.

| | Maricopa County, AZ 2020 General Election | Maricopa County 2016 General Election |
|---|---|---|
| EVB Return Envelopes | 1,918,463 | 1,257,179 |
| Rejection from Signature Mismatch | 587 | 1,456 |
| Signature Mismatch Rejection Rate | 0.031% | 0.116% |

**Table 3**: Comparison of Signature Mismatch Rejection Rates in **Maricopa County 2016** general election with **Maricopa County 2020** general election.

Table 3 reveals that *as the number* of EVB return envelopes in Maricopa County ***increased*** from 1,257,179 in the 2016 general election by 661,284 to 1,918,463 unique EVB return envelopes in the 2020 general election, representing a 52.6% ***increase***, the rejections from Signature Mismatches, however, ***decreased*** by 869 EVB return envelopes, a 59.7% ***decrease*** during the same period. In addition, the Signature Mismatch Rejection Rate ***decreased*** from 0.116% in 2016 by 73.3% to 0.031% in 2020. In summary, ***increases*** in EVB return envelopes from 2016 to 2020 were followed by ***decreases*** in Signature Mismatches. This appears to be *inverse* i.e. more EVB return envelopes, ***less*** Signature Mismatches. Maricopa election officials can best answer this inverse relationship.

## SCOPE OF AUDIT

Arizona State Senate commissioned EchoMail to perform audit of Signature Presence Detection ***solely within the Signature Region of EVB return envelope images.*** On August 27, 2021, a Master Agreement and Statement of Work ("SOW") were executed by Dr. Shiva Ayyadurai, the President/CEO of EchoMail, Inc., and by Karen Fann, President of the Senate for the Arizona State Senate. Per the SOW, the Arizona State Senate was responsible for:

- Providing the EVB return envelope images that were received by Maricopa County to EchoMail
- Ensuring that the EVB envelope images were delivered to EchoMail via postal mail on a hard drive or uploaded to a secure repository for EchoMail to download

EchoMail was responsible for conducting the following pattern recognition classification processing activities:

- Pre-processing of the EVB return envelope images including auto-aligning, resizing, and calibrating the images to detect the Signature Region
- Detecting the presence of signatures in the Signature Region of the EVB return envelope images
- Detecting if the Signature Region contained a Scribble as recognized by the EchoMail algorithm

- Tabulating a breakdown of the number Signature Regions of the EVB return envelopes with Signatures, with Blanks, and with Scribbles (potentially invalid signatures requiring human review).

On or before September 20, 2021, EchoMail was expected to deliver the following:

- A breakdown of counts of the number of EVB return envelope images where the Signature Region had Signatures, Blanks, and Scribbles
- The images of those EVB return envelopes where the Signature Region was categorized as containing Blanks i.e. "No Signatures"
- The images of those EVB return envelopse where the Signature Region was categorized as containing Scribbles

As of the writing of this report, both parties have met their responsibilities on or before the deadlines established. EchoMail's scope of work, to be clear, was ***not*** to perform Signature Verification, that is to compare the signatures identified in the Signature Region of the EVB return envelope images with signatures stored in an official repository such as voter registration files. EchoMail's role was limited to identifying the presence of a signature in the Signature Region of the EVB return envelope images. ***If a signature appeared elsewhere on the EVB return envelope image, EchoMail was not responsible for detecting or classifying such instances.***

# METHODOLOGY

Pattern recognition classification methods are at the core of the methodology for Signature Presence Detection. Pattern recognition classification involves a systematic process of feature detection, clustering, and learning to distinguish "normal" states from "abnormal" states as illustrated in Figure 9.

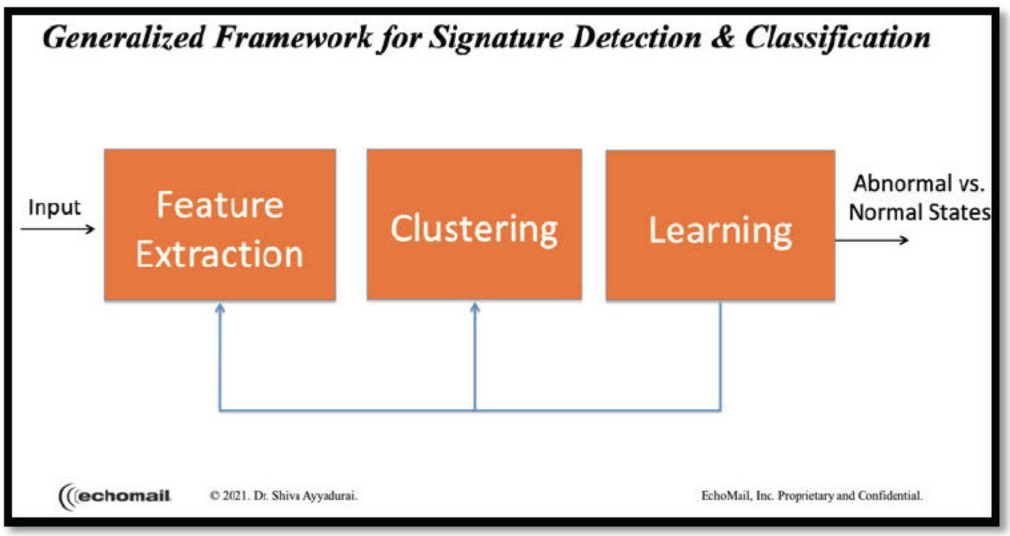



**Figure 9:** Generalized framework for signature detection and classification.

Given the likely diversity of backgrounds in the readers of this manuscript, fundamental concepts concerning pattern recognition along with a review of this author's – Dr. Shiva's – expertise, across a range of signals and signatures, are provided for the reader to gain a foundational understanding of the field along with an appreciation of the many diverse applications afforded by pattern recognition classification methods.

# FOUNDATIONS OF PATTERN RECOGNITION

Consider a basic system with an input and an output as shown in Figure 10. At any point in time, the system possesses a system *state.*

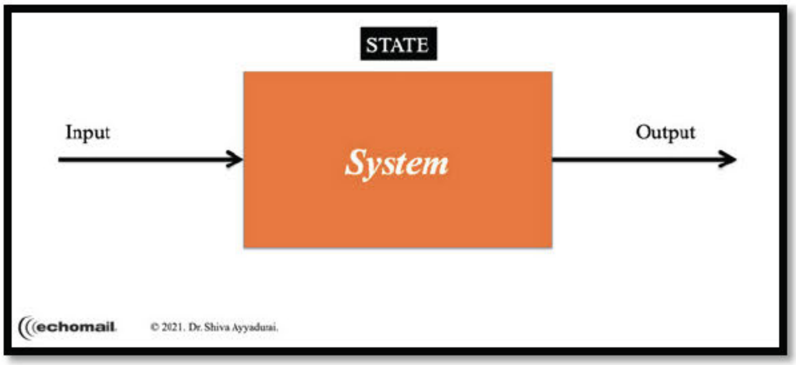



**Figure 10:** Basic system with input, output, and state.

One aim of pattern recognition classification methods is to identify system states, which may be the system's desired or "Normal State" as denoted in Figure 11, determined by the system's input and output behavior.

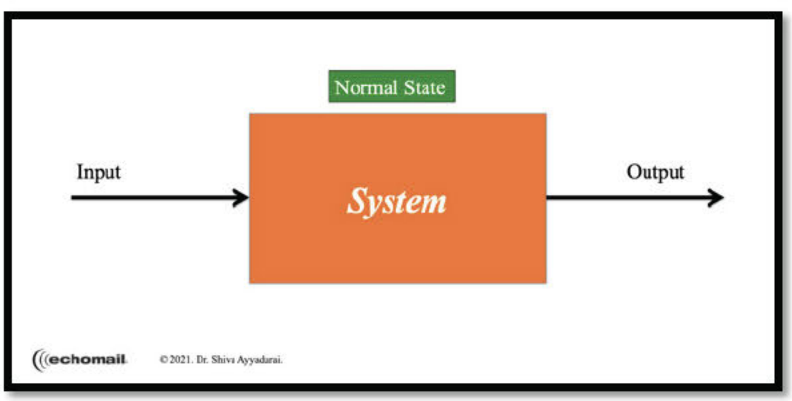



**Figure 11:** A system in a "Normal State" as a function of its input-output behavior.

Or, pattern recognition classification methods are applied to determine the anomalous states or "Abnormal State" of a system as denoted below on Figure 12.

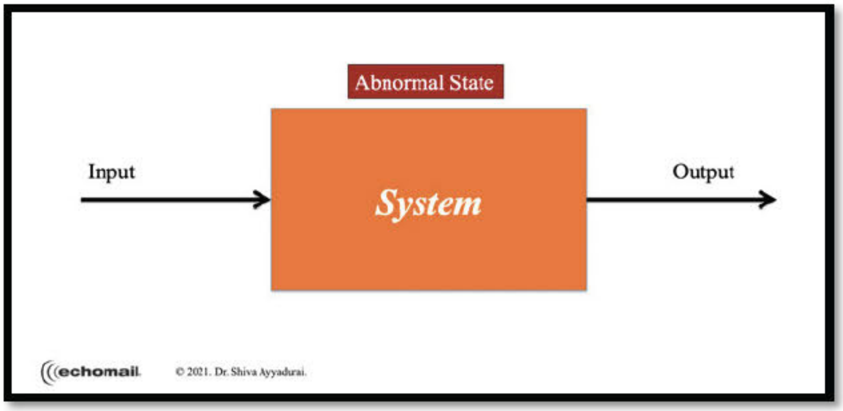



**Figure 12:** A system in an "Abnormal State" as a function of its input-output behavior.

Feature extraction approaches are used to develop a signature/signal to identify the states of a system, be they the Normal State or the Abnormal State. For example, in Figure 13, a signal representing the Normal State of a cardiovascular system is illustrated.

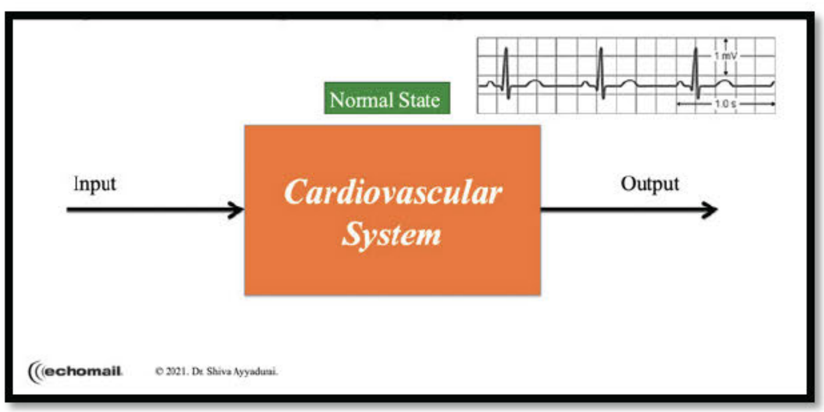



**Figure 13:** The cardiovascular system in its Normal State.

In Figure 14, a signature/signal of the cardiovascular system reflecting its Abnormal State is illustrated; in this case, the system's signature represents the heart in distress e.g.

ventricular fibrillation.

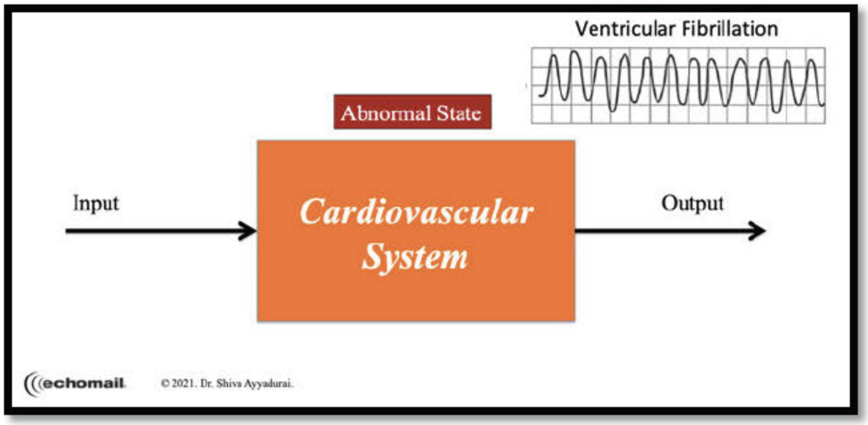



**Figure 14**: The cardiovascular system in an Abnormal State: ventricular fibrillation.

Figure 15 illustrates for a cardiovascular system, signature for the Normal State and several signatures for the Abnormal State.

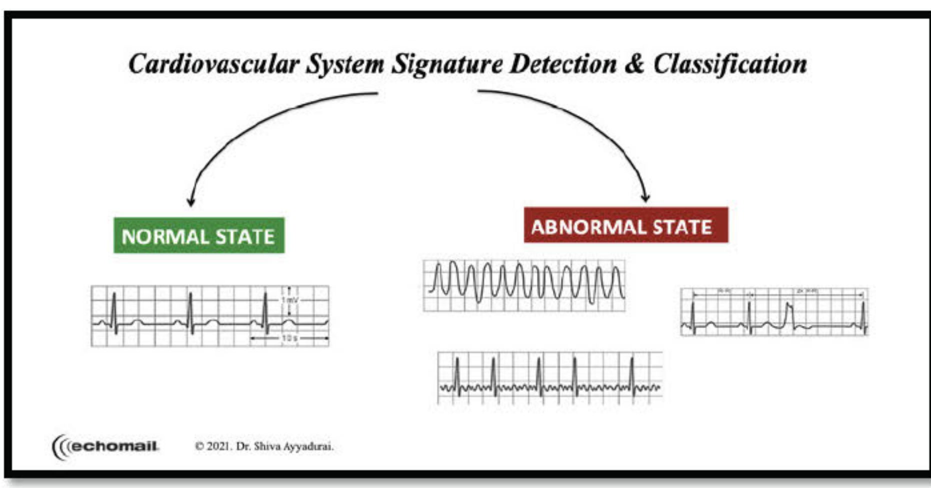



**Figure 15**: Pattern recognition classification of cardiac signatures in Normal and Abnormal States.

For the audit herein, the same approach is employed to define the Normal State as a Signature Region with a Signature, and the Abnormal States as those Signature Regions with Blank, Likely Blank, and Scribble, as illustrated in Figure 16.

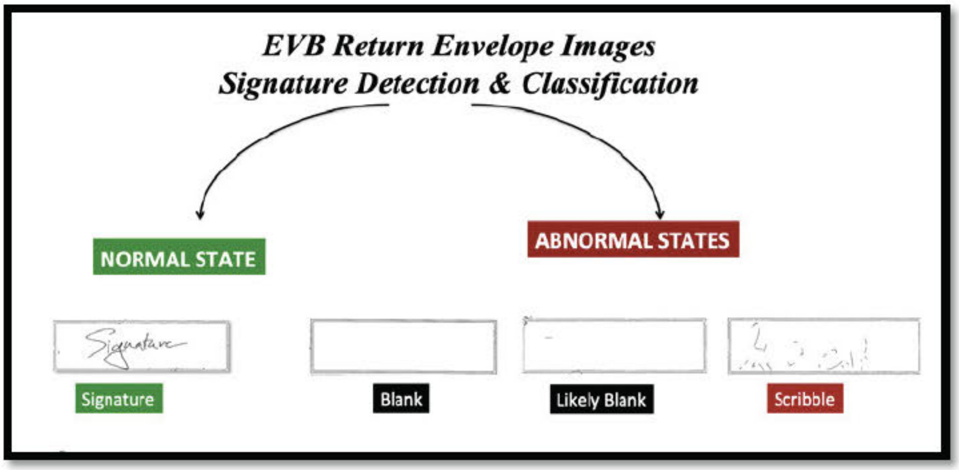



**Figure 16**: Pattern recognition classification of EVB return envelope images into Normal State with Signature, and Abnormal States: with Blank, Likely Blank and Scribble.

## PATTERN RECOGNITION EXAMPLES

Pattern recognition classification methods can be applied to a diversity of problems. Sharing the portfolio of the author's research and development efforts in the field will provide the reader with a glimpse of that diversity, which traverse signals and signatures across a range of industries: biology and medicine, engineering (e.g. aeronautical, civil, mechanical, and electrical), banking, finance, and, government.

**Sudden Infant Death Syndrome (SIDS) Research (1978 – 1984)**

Sudden Infant Death Syndrome (SIDS) is the leading cause of death in babies between one month and one year of age. In 1978, Dr. Shiva's interest in pattern recognition first began, when as a 14-year-old he was recruited by the University of Medicine and Dentistry of New Jersey (UMDNJ) in Newark, NJ as a Research Fellow.

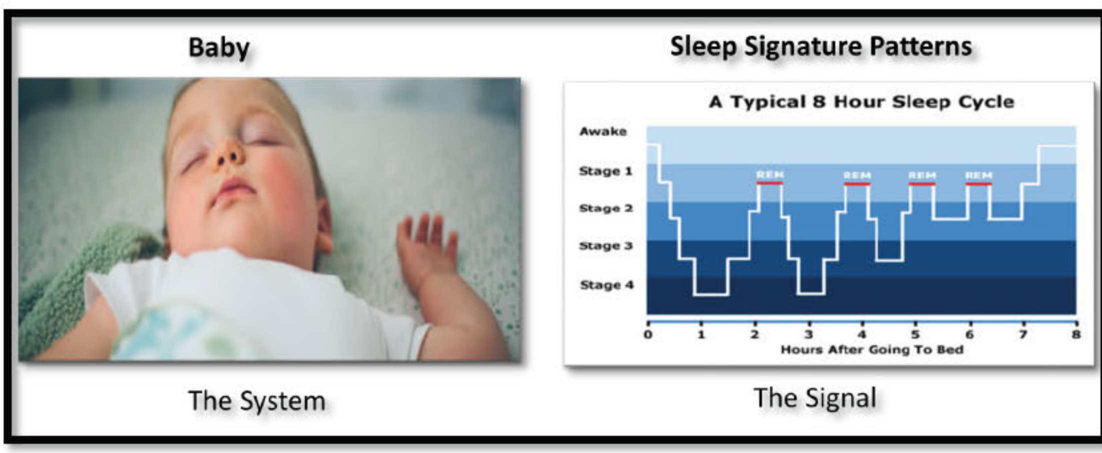



**Figure 17**: Signature Detection and Classification of Abnormal Sleep Patterns in Babies with Sudden Infant Death Syndrome (SIDS) – (1978 – 1984).

His medical research at UMDNJ focused on developing pattern recognition classification methods for categorization of sleep signature patterns from babies with SIDS. His research identified certain signatures of waiting times of babies' sleep transition states i.e. the Abnormal States, that appeared to occur before the onset of apneas i.e. when the baby stops breathing. His work led to a scientific paper published and presented at the IEEE/EMBS International Conference in Espoo, Finland.

### Tadoma Research (1983 – 1986)

Tadoma is a means of communication used by the deafblind. In this approach, the deafblind person places their right or left hand, and the fingers on the face of a person. The tactile functions of the hand are able to perceive the airflow, vibrations, jaw locations, lip location, and protrusions to sense speech, as illustrated in Figure 18,

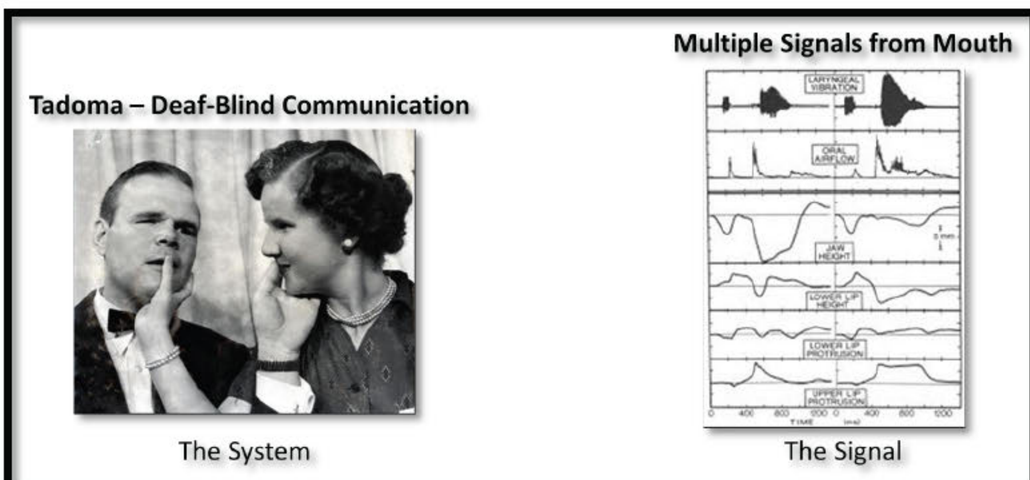



**Figure 18**: Signal Detection in Tadoma of Non-Vocal Communication for Supporting Deaf-Blind (1983-1986).

During 1983 to 1986, Dr. Shiva's research at the MIT Speech Laboratory, through the MIT Undergraduate Research Opportunities Program (UROP), served to help categorize specific signatures of these facial movements towards aiding researchers to identify the mechanisms of Tadoma.

## Non-Destructive Evaluation (NDE) for Bridge Deck Deterioration (1986 - 1988)

It is estimated that more than 50,000 bridges in the United States are falling apart with varying types of decay and failure. Identifying the nature of these failures, using non-invasive approaches can save time and money. In 1986, under an NSF funded project in the MIT Department of Civil Engineering, Dr. Shiva created algorithms for classification of bridge deck deterioration signatures acquired from radar analysis.

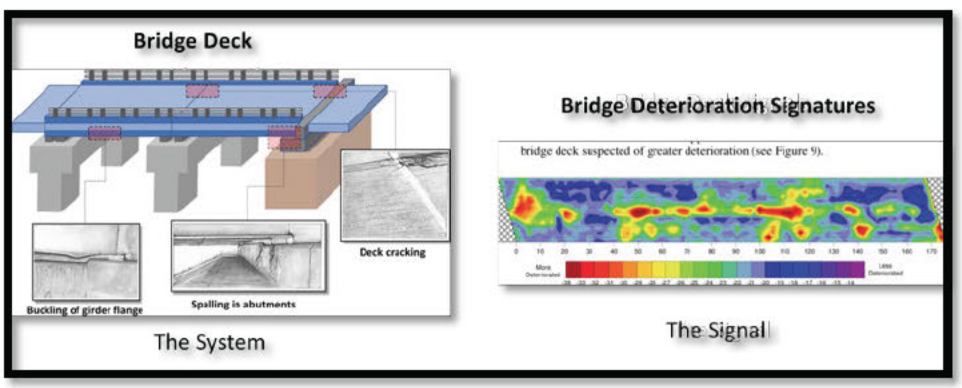



**Figure 19**: Signal Detection of Flaws in Bridges for Prediction of Bridge Deck Failures (1986-1988).

Such research known as Non-Destructive Evaluation (NDE) aimed to identify flaws in large structures such as bridges, without invasive interventions, to prevent damage and potentially save lives by addressing structural issues before onset of a failure.

**Non-Destruction Testing (NDT) of Composite Parts of Aircraft Wings (1988-1990)**

Aerospace parts, such as the wings of an aircraft, may consist of flaws and incongruencies that can lead to catastrophic failures.

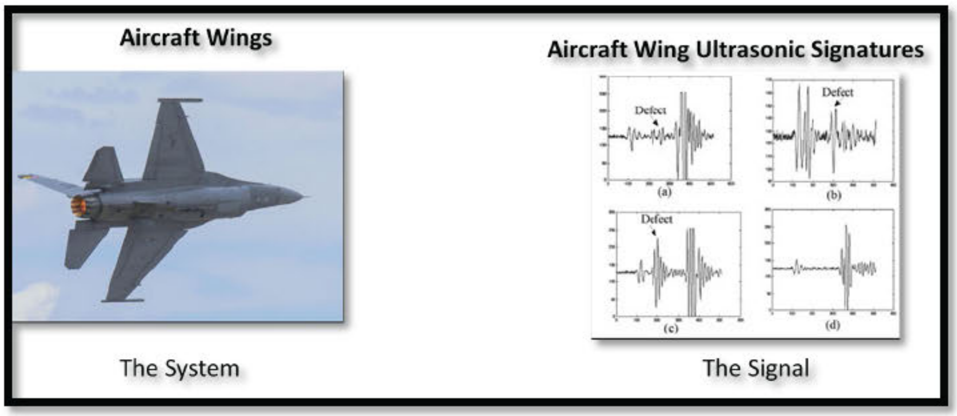



**Figure 20**: Signal Detection of Ultrasonic Signals for Preventative Maintenance of Composite Aircraft Wings (1988-1990).

In the aerospace industry, non-destructive testing (NDT) is a critical component in efforts to decrease the risk of potentially fatal failures. Dr. Shiva's research in applying pattern recognition for NDE of bridge decks evolved to his Masters work at MIT in the Department of Mechanical Engineering where he developed a computational model of wave propagation in composite materials, that he used to create unsupervised pattern recognition classification methods for NDT of composites in order to characterize flaws and irregularities in objects such as aircraft wings. The research aimed to classify signals in order to support preventative maintenance of structures like aircraft wings without disrupting their integrity.

**Handwritten Numerals on Bank Checks (1992-1994)**

Even though online banking has grown, there still continues to be a need for processing paper checks.

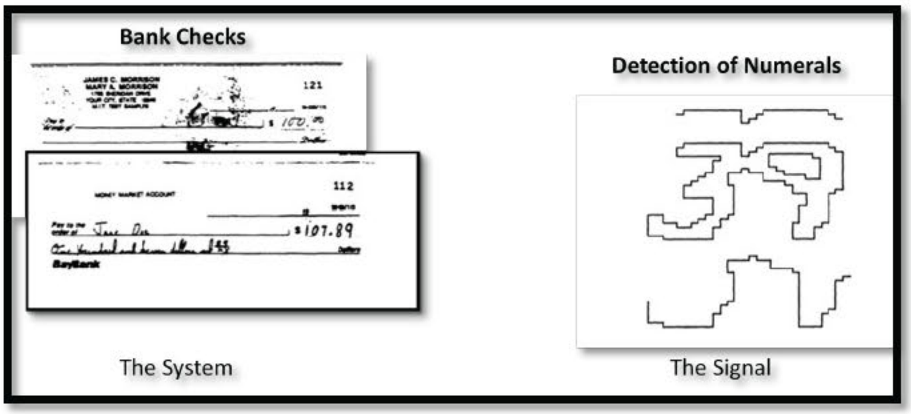



**Figure 21**: Integrated Architecture for Recognition of Handwritten Numerals on Bank Checks (1992-1994).

For his PhD work, starting in 1990, Dr. Shiva set out to create a generalized framework, which he termed *Information Cybernetics*, for solving diverse pattern recognition problems. In 1992, he began work with researchers at the MIT Sloan School on a project to automatically recognize the courtesy amount on bank checks. This effort resulted in his leading an MIT team to architect and create a fully working prototype of a hybrid neural network based system for pattern recognition of the courtesy amount on bank checks, which he successfully demonstrated to NatWest Bank. The work resulted in a pioneering paper in the *International Journal of Pattern Recognition and Artificial Intelligence (IJPRAI)* in 1993.

**EchoMail®: Automatic Document Analysis and Classification (1993-Present)**

Following the invention of email by Dr. Shiva in 1978, and up until 1993, email was an inter- and intra- office business application. However, after the advent of the World Wide Web (WWW) in 1992, web-based email applications made email a consumer application resulting in an explosive growth of email usage.

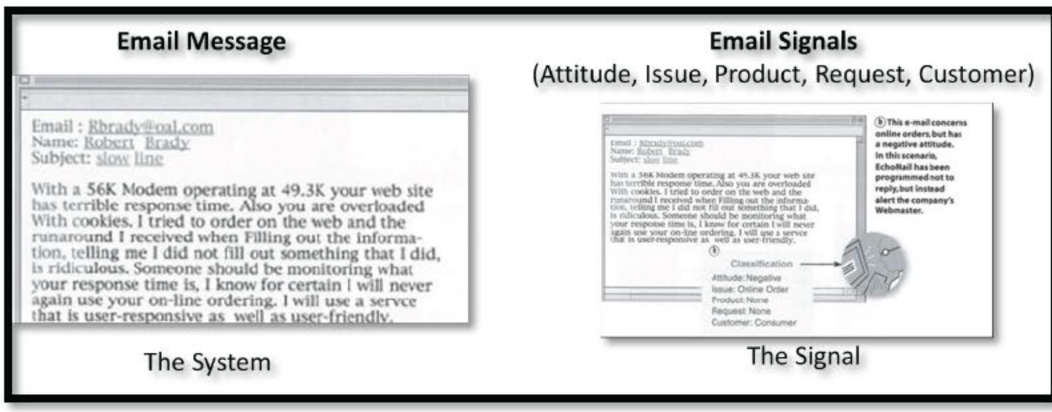



**Figure 22**: Signal Detection of Email Signals for Automatic Categorization (1992 - Present).

In 1993, the White House, Executive Office of the President, sponsored an industry-wide competition to automatically to analyze and classify President Clinton's email to assist in handling the deluge of email. While in the midst of his PhD work, after being selected as the only student participant, Dr. Shiva won this industry-wide competition. This resulted in his being awarded a number of foundational patents in pattern recognition (one of which is shown in Figure 23) and developing EchoMail® - a platform for enabling pattern recognition classification of electronic documents, which led to his starting EchoMail, Inc., a company that grew to nearly $200 million in market valuation. EchoMail was featured in a front-page article in *The MIT Technology Review*, the leading magazine for technology.[21]

EchoMail enabled the automatic classification and routing of large volumes of email for Global 2000 companies such as Nike, American Express, P&G, Citigroup, to enable rapid response to customer inquiries, as well as to increase levels of customer service.

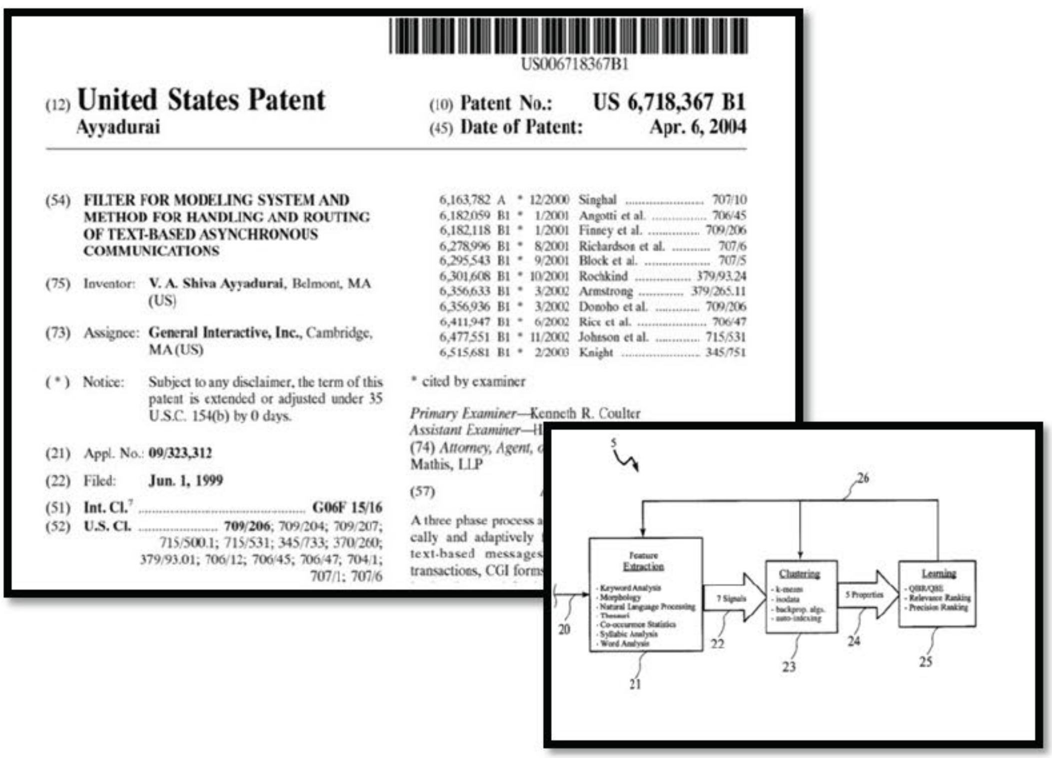



**Figure 23**: One of Dr. Shiva Ayyadurai's U.S. patents for pattern recognition classification.

The approach here, as aforementioned, was to identify the Normal State as well as the Abnormal States of an email, as illustrated in Figure 24.

[21] Dr. Email Will See You Now, MIT Technology Review, https://vashiva.com/wp-content/uploads/2019/12/2000_tech_review.pdf, accessed September 15, 2021

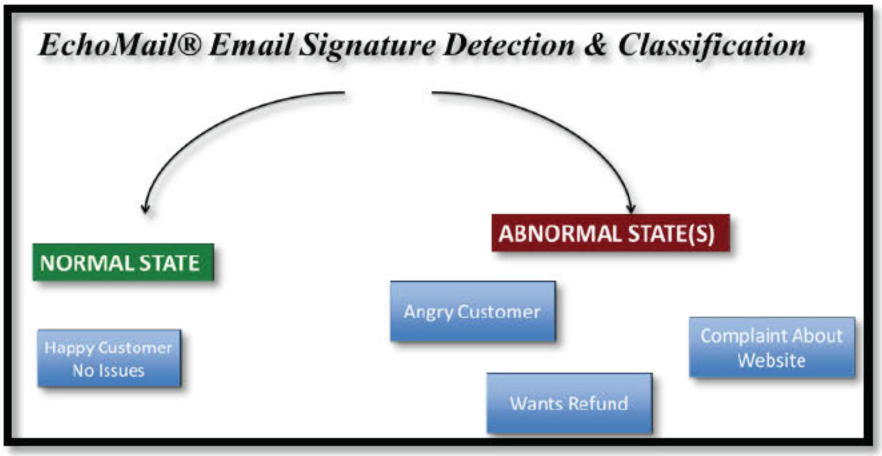



**Figure 24**: Signal Detection of Email Signals for Automatic Categorization into Normal and Abnormal States.

## CytoSolve®: Discovering Combinations That Work (2007-Present)

Modern pharmaceutical companies spend upwards of $5 billion and up to 13 years of research and development to discover and get a single molecule drug to market. However, the future of medicine demands the need for multi-combination therapies i.e. "cocktails," which are not possible with conventional approaches. Such efforts require a computational systems biology approach integrating pattern recognition methods.

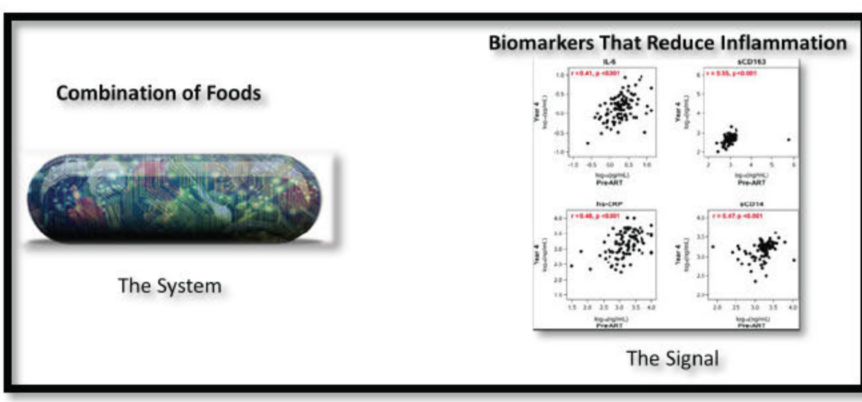



**Figure 25**: Signal Detection of Combination Therapies that Alleviate Disease (2007 - Present).

In 2003, Dr. Shiva returned to MIT to complete his doctoral work in computational systems biology in the department of Biological Engineering, where he developed CytoSolve®, a scalable computational systems biology platform for modeling the whole cell by dynamic integration of molecular pathways models. CytoSolve computationally models complex diseases and biomolecular processes to discover multi-combination therapeutics by identifying biomarker signatures that are associated with optimal combinations. CytoSolve earned an FDA allowance in a record 11 months for a multi-combination therapy for pancreatic cancer. Today, CytoSolve is being used to develop a diverse range of innovative multi-combination products from natural sources, across a variety of indications including pain, inflammation, oral health, brain health, and relaxation, to name a few.

As should be evident, from these examples, pattern recognition classification methods can be applied to a range of problems.

## MATHEMATICAL MODELING

Pattern recognition is reliant on two aspects: mathematical modeling and signature/signal detection and classification. Mathematical modeling, as illustrated in Figure 26, involves observing a system, making hypothesis, manipulating the system, measuring input and output behavior, from which data is mined, to create mathematical models to understand why and how the system operates.

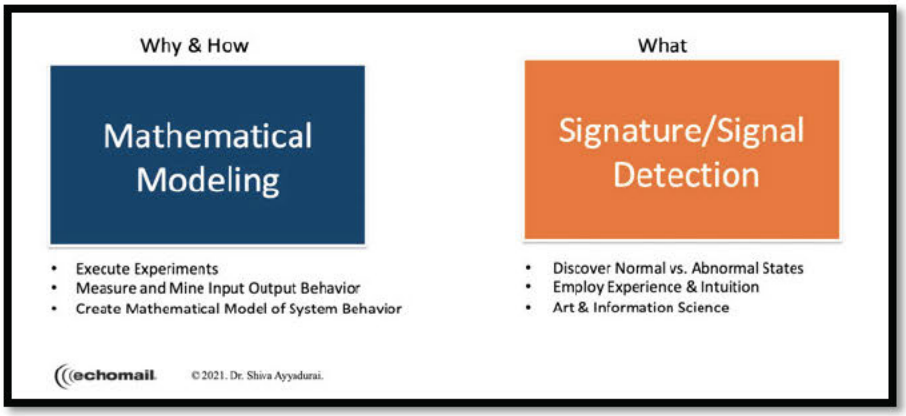



**Figure 26**: The two aspects of pattern recognition.

Here, the scientific method is employed, as best exemplified in Newton's observation of a pattern of behavior in the natural world between two masses, to elicit a mathematical model, known as Newton's Law of Universal Gravitation, as illustrated in Figure 27.

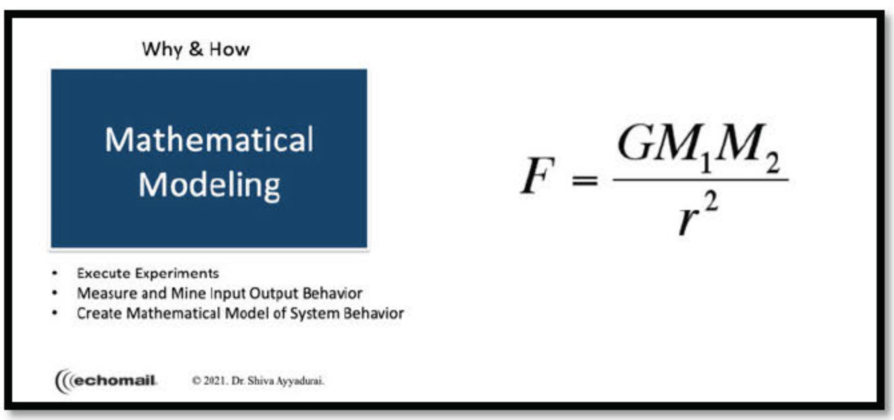



**Figure 27**: Newton's application of pattern recognition and use of mathematical modeling let to Newton's Law of Universal Gravitation.

Mathematical modeling provides the ability to simulate potential input and output behavior as a vehicle to understand potential states of a system. Such models can provide insights into likelihood of normal or anomalous behavior.

## SIGNATURE/SIGNAL DETECTION & CLASSIFICATION

Signature or (signal) detection and classification methods, the other aspect of pattern recognition, aims to document and characterize the signatures or signals of a system, some which may reflect normal, and others, abnormal behavior. Signature detection, unlike mathematical modeling, is derived from domain and subject matter expertise using intuition, and an integration of art and information science, as shown in the right hand side of Figure 26. The reductionist application of mathematical techniques, simple or sophisticated, without knowledge of the domain can lead to significant and serious errors. Mathematics is not a sufficient knowledge base to solve real life problems in the domain of pattern recognition.

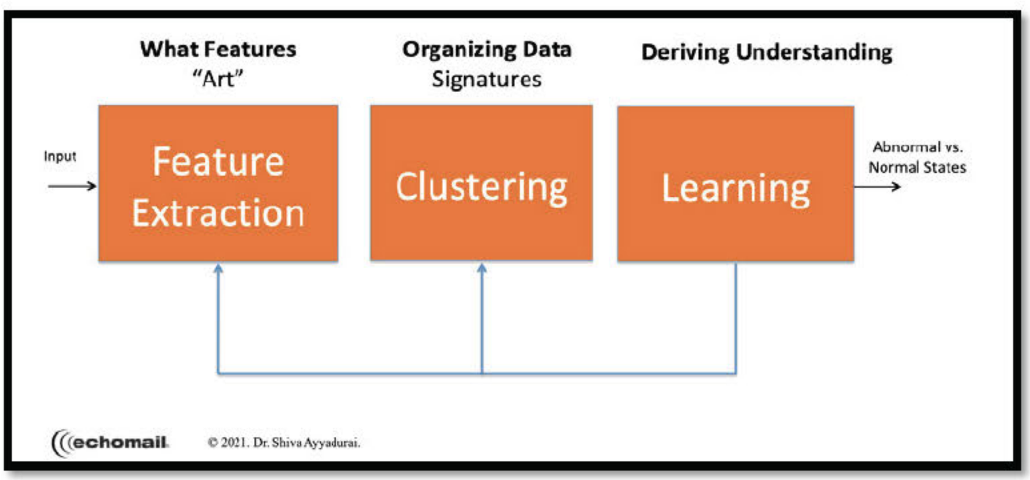



**Figure 28**: Signature/signal detection and classification are both an art and an information science relying on feature extraction, clustering and learning.

In this aspect, feature extraction – the art of pattern recognition –, as illustrated in Figure 28, becomes critical to deriving features that can best be used to describe the signature or signal of the system. For example, in the field of face detection, prior to this foundational understanding, researchers focused on two-dimensional image processing methods, brute force computations methods to capture and process as much image pixel information as possible, believing more resolution the better. However, pattern recognition reveals the need to focus on the art of identifying key features, as shown in Figure 30, where a handful of numbers could capture critical features for classification, such as the overall shape of the face e.g. square, oval, rectangular; distance measurements between the eyes, nose and mouth; or, combinations thereof, that could be sufficient to derive a reasonable identification of a face using other contextual data.

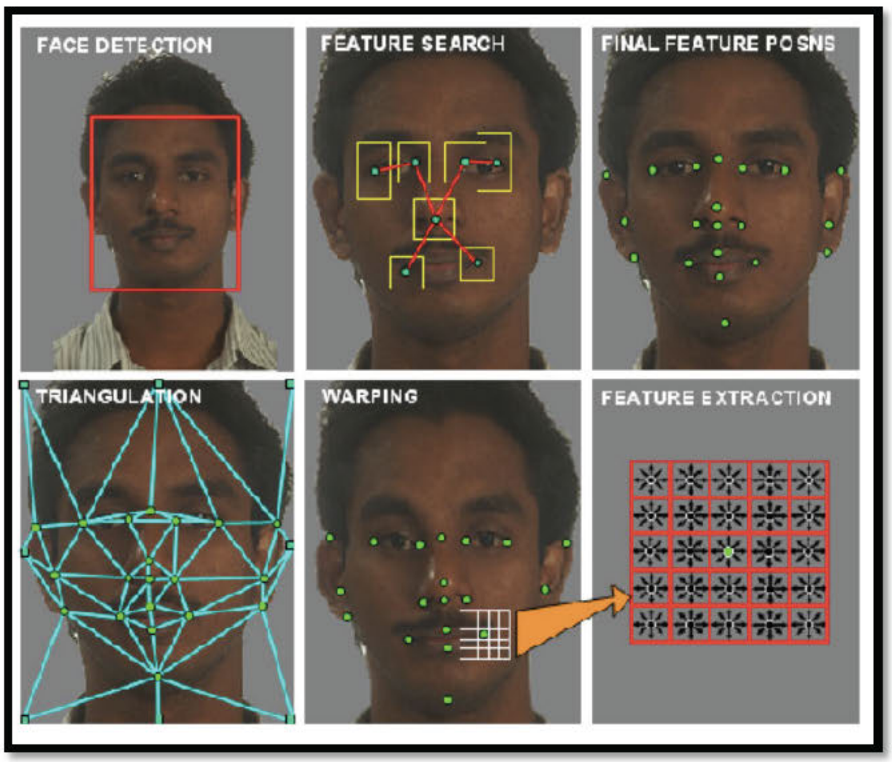



**Figure 30**: Feature extraction process to enable face detection. [22]

[22] Prince, Simon & Elder, James & Hou, Yunhe & Sizinstev, M. & Olevsky, E.. (2006). Towards Face Recognition at a Distance. 570 - 575. 10.1049/ic:20060363.

# EVB RETURN ENVELOPE IMAGE CLASSIFICATION

Pattern recognition classification methods are employed in this audit by EchoMail using the aforementioned foundational processes to identify the specific Signature Region of EVB return envelope images. and classify it into one of four specific categories: Signature, Blank, Likely Blank, and Scribble as illustrated in Figure 31.

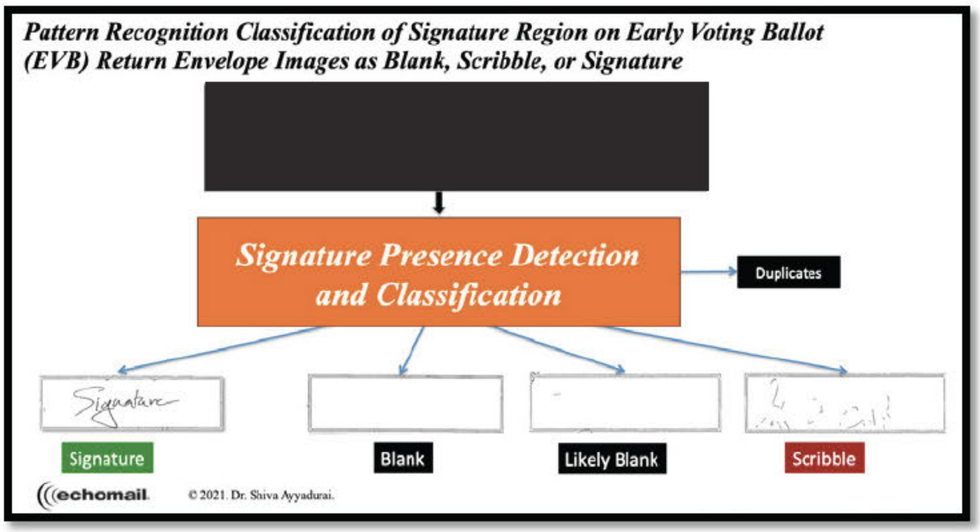



**Figure 31**: Pattern recognition classification of Signature Region of EVB return envelope images into Signature, Definitive Blank, Likely Blank, and Scribble.

The first step in this classification process is the acquisition and data warehousing of the data set of EVB return envelope image files, as discussed below in *Date Set of EVB Return Envelope Images*. The second step is the execution of the EchoMail Signature Presence Detection System (SPDS) to: 1) identify Duplicates among EVB return envelope images; 2) identify the Signature Region; and, 3) classify the Signature Region into Signature, Blank, Likely Blank or Scribble. This process is discussed below in *EchoMail EVB Signature Presence Detection System.*

# DATA SET OF EVB RETURN ENVELOPE IMAGES

The data set containing the EVB return envelope image files was delivered to EchoMail from the Arizona State Senate on a hard drive. The hard drive contained the following two main directories as shown in Figure 30.

| Name | Date modified | Type |
|---|---|---|
| Alternate Return - Format Early Affidavits | 8/17/2021 6:41 PM | File folder |
| EarlyVotingSignatures | 8/2/2021 1:53 PM | File folder |

**Figure 32**: Two main directories on hard drive received from the Arizona State Senate.

The "EarlyVotingSignatures" directory contained 182 sub-folders, as shown in Figure 31.

| Name | Date modified | Type |
|---|---|---|
| PBSigVar_1377_RTNIMAGOUT_10092020_0001 | 8/2/2021 5:07 PM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10102020_0002 | 8/2/2021 7:41 PM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10102020_0003 | 8/3/2021 2:55 AM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10122020_0004 | 8/2/2021 7:38 PM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10122020_0005 | 8/3/2021 12:21 AM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10122020_0006 | 8/3/2021 6:08 AM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10122020_0007 | 8/3/2021 9:48 AM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10132020_0008 | 8/2/2021 2:31 PM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10132020_0009 | 8/2/2021 6:07 PM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10142020_0010 | 8/2/2021 10:41 PM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10142020_0011 | 8/2/2021 8:15 PM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10142020_0012 | 8/3/2021 1:39 AM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10142020_0013 | 8/3/2021 6:39 AM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10142020_0014 | 8/3/2021 10:15 AM | File folder |
| PBSigVar_1377_RTNIMAGOUT_10142020_0015 | 8/3/2021 11:45 AM | File folder |

**Figure 33**: Structure of the EarlyVotingSignatures main directory and example of its sub-folders. There are 182 sub-folders, in total.

Each sub-folder contained the vast majority of the EVB return envelope files, which are denoted as standard image files (SIF), in TIFF format and look as shown in Figure 34.

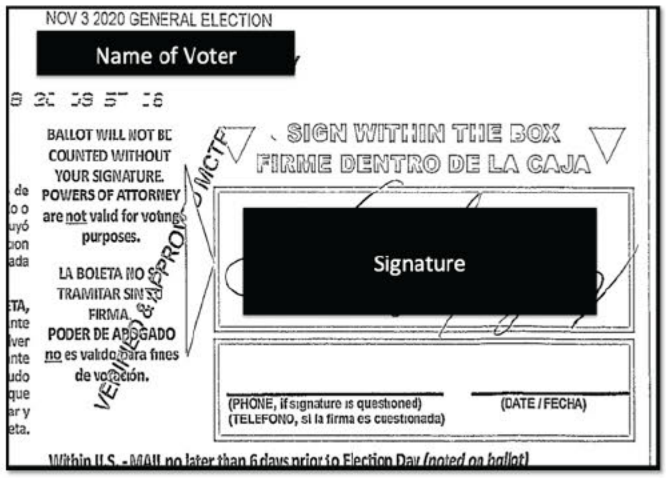



**Figure 34**: Standard Image Files in TIFF format.

The second main directory named “Alternate Return – Format Early Affidavits” contained six PDF files as shown in Figure 35.

| Name | Date modified | Type | Size |
|---|---|---|---|
| 1 - UOCAVA - SEB Early Ballot Affidavits Box 1 | 8/17/2021 4:51 PM | Microsoft Edge P... | 343,250 KB |
| 2 - UOCAVA - SEB Early Ballot Affidavits Box 2 | 8/17/2021 4:53 PM | Microsoft Edge P... | 292,112 KB |
| 3 - UOCAVA - SEB Early Ballot Affidavits Box 3 | 8/17/2021 4:56 PM | Microsoft Edge P... | 389,393 KB |
| 4 - UOCAVA - SEB Early Ballot Affidavits Box 4 | 8/17/2021 5:48 PM | Microsoft Edge P... | 390,773 KB |
| 5 - Large Print Affidavits Box 5 | 8/17/2021 5:55 PM | Microsoft Edge P... | 50,877 KB |
| 6 - Braille Affidavits Box 6 | 8/17/2021 5:57 PM | Microsoft Edge P... | 369 KB |

**Figure 35**: “Alternate Return – Format Early Affidavits” directory.

The first four PDF files are the UOCAVA image files (UIF) containing three types of image files denoted as UIF-A, UIF-B, and UIF-C, shown in Figures 36-38, respectively.

[redacted]

**Figure 36**: UOCAVA Image File, Type A (UIF-A).

[redacted]

**Figure 37**: UOCAVA Image File, Type B (UIF-B).

[redacted]

**Figure 38**: UOCAVA Image File, Type C (UIF-C).

The fifth PDF file, Large Print Affidavits contains Large Image Files, denoted as "LIF," and is shown in Figure 39. The sixth PDF file, Braille Affidavits contains Braille Image Files, denoted as "BIF," and is shown in Figure 40.

[redacted]

**Figure 39**: Large Print Image File, (LIF).

**Figure 40**: Braille Image File, (BIF).

All of the above image formats were extracted from the directories, subfolders, and files into EchoMail's relational database. Once this process was complete, the EchoMail EVB Signature Presence Detection System (SPDS) is deployed. The rapid deployment of this system for this audit was made possible given the rich history of Dr. Shiva's expertise and EchoMail's capabilities.

# ECHOMAIL EVB SIGNATURE PRESENCE DETECTION SYSTEM

The pattern recognition infrastructure at EchoMail was used to deploy the EchoMail EVB Signature Presence Detection System (SPDS) as illustrated in Figure 41. The system consists of multiple processes. The first process is the automatic classification and detection of the EVB return envelope type, among the six image formats.

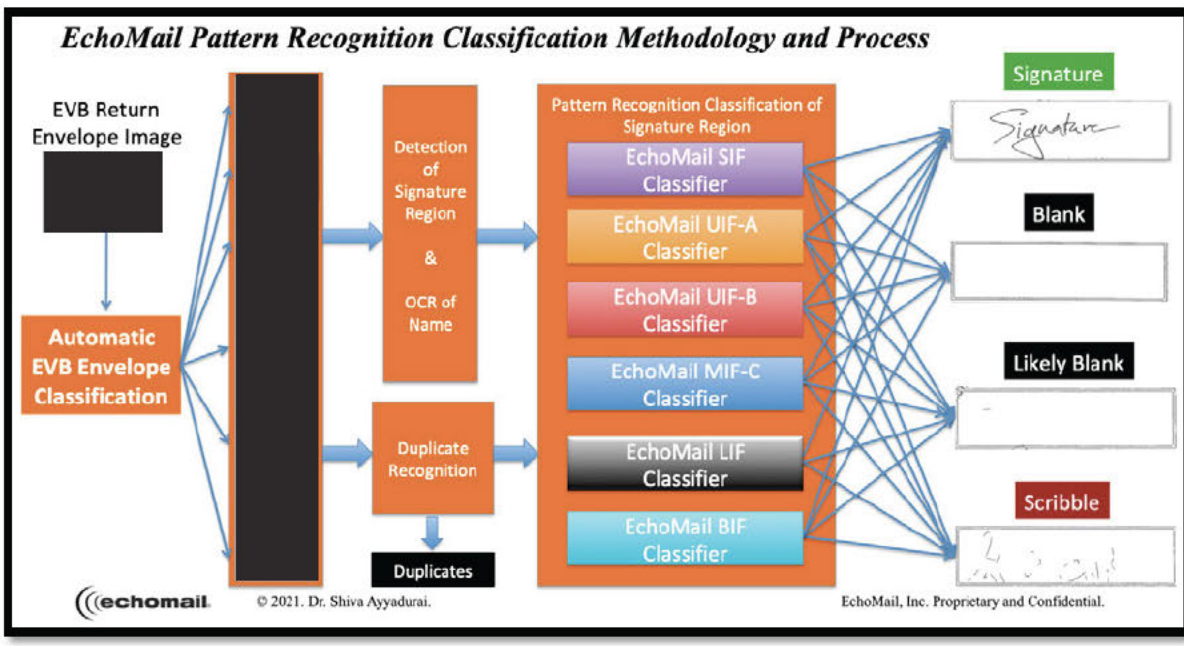



**Figure 41**: EchoMail EVB Signature Presence Detection System.

As aforementioned, there are six potential image formats. Once this classification – Automatic EVB Envelope Classification – is complete, then the system performs Duplicate Recognition to detect Duplicate EVB return envelope images. Duplicates are properly classified and tagged. Following this, the system performs a variety of feature extraction methods to detect the Signature Region. For each of the six image types, there are different EchoMail Classifiers as shown in Figure 41 for classifying the different morphologies of Signature Regions.

If the Signature Region has a non-white pixel density of 0%, the EVB return envelope image is classified as a Blank; if the Signature Region has a non-white pixel density of 0%+ to 0.1%, the EVB return envelope image is classified as a Likely Blank; if the Signature Region has a non-white pixel density of 0.1%+ to 1%, the EVB return envelope image is classified as a Scribble; and, finally, if the Signature Region has a non-white pixel density of greater than 1%, the EVB return envelope image is classified as a Signature.

***It is important to note that some voters submitted EVB return envelopes with their signature in other areas e.g. in the phone area; however, per the Scope of Audit, only the Signature Region was used for analysis. The EchoMail Analysis offered a relatively low non-white pixel density threshold e.g. 1%+ for Signature Region to be classified as having a Signature.***

Though not within the *Scope of Audit*, if possible, EchoMail attempted to find the region with the name of the voter, and performed OCR to capture and store the name in the database.

Once the images are classified, Duplicates are further classified as shown in Figure 42.

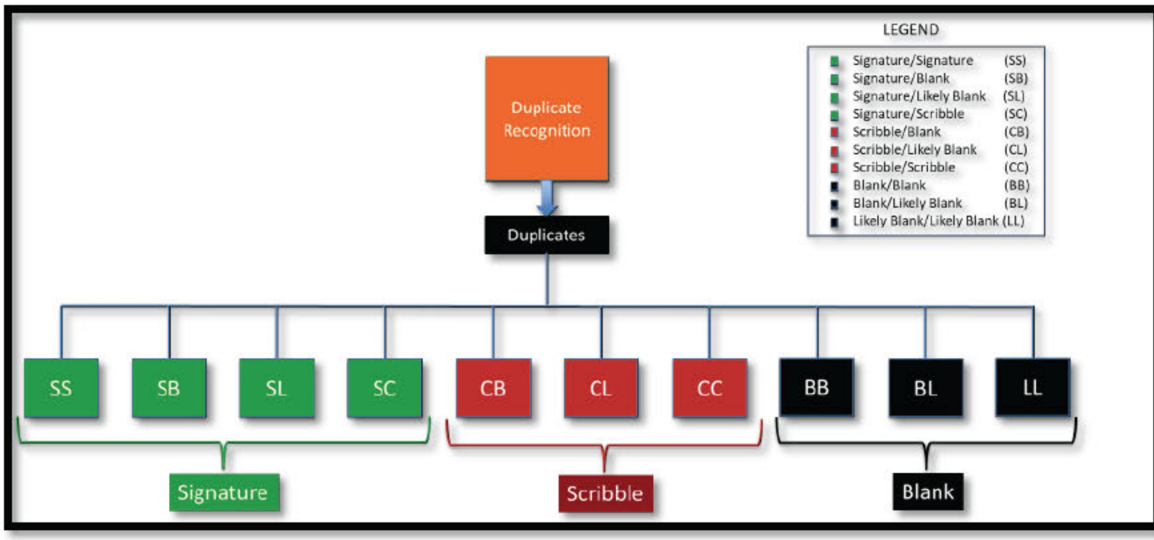



**Figure 42**: Duplicate Classification of 2-Copy Duplicates.

# RESULTS

There are multiple sets of results, that are directly an outcome of a particular process executed from the EchoMail EVB Signature Presence Detection System

## EVB RETURN ENVELOPE IMAGES COUNT

A total of 1,929,240 EVB return envelope images were received by EchoMail as summarized in Table 4.

| Type of Image | Count | Percent |
|---|---|---|
| SIF | 1,919,598 | 99.5% |
| UIF-A | 8,849 | 0.459% |
| UIF-B | 277 | 0.014% |
| UIF-C | 12 | 0.001% |
| LIF | 475 | 0.024% |
| BIF | 29 | 0.002% |
| **TOTAL** | **1,929,240** | **100%** |

**Table 4:** Total Count of EVB Return Envelope Image Files Received by EchoMail.

There were 1,919,598 SIFs across the 182 sub-folders of the main directory. In the other main directory, there were six files in PDF format containing a total of 9,642 image files. More specifically, there are 9,138 UOCAVA Image Files denoted as "UIF" in the first four PDFs: 8,849 UIF-A type, 277 UIF-B type, and 12 UIF-C type. In the fifth PDF, there are 475 Large Print Affidavits denoted as Large Image Files "LIF." Finally, in the sixth PDF, there are 29 Braille Affidavits (6) denoted as Braille Image Files "BIF."

## DUPLICATES ANALYSIS

The results of Duplicate analysis of the EVB return envelope images are summarized in Table 5. As the table reveals 17,126 unique voters submitted a total of 34,448 2-Copy, 3-Copy, and 4-Copy Duplicates.

| Type | Total Images | Duplicate Images | Unique # of Voters |
|---|---|---|---|
| 2-Copy Duplicates | 33,868 | 16,934 | 16,934 |
| 3-Copy Duplicates | 564 | 376 | 188 |
| 4-Copy Duplicates | 16 | 12 | 4 |
| **Total** | 34,448 | 17,322 | 17,126 |

**Table 5:** EchoMail Analysis results of 2-Copy, 3-Copy, and 4-Copy Duplicates. 17,126 unique voters submitted 34,448 Duplicates.

## UNIQUE EVB RETURN ENVELOPE IMAGES

Per the results in Table 5, 17,322 Duplicates are removed to produce a count of the total unique EVB return envelope images, which are 1,911,918, as shown in Table 6 below.

| | **EchoMail Analysis** |
|---|---|
| **EVB Return Envelopes Received** | 1,929,240 |
| | |
| **Duplicate Analysis** | |
| **Duplicates** | (17,322) |
| **Total Unique EVB Return Envelopes** | **1,911,918** |

**Table 6**: EchoMail Identified 17,322 Duplicates.

# DUPLICATE IMAGE EXAMPLES

Below are provided a sampling of the ten (10) different kinds of Duplicates' examples corresponding to the classifications identified earlier in Figure 42. Some of the examples document EVB return envelopes in which, after adjudication, they are stamped with **"VERIFIED & APPROVED MCTEC"**

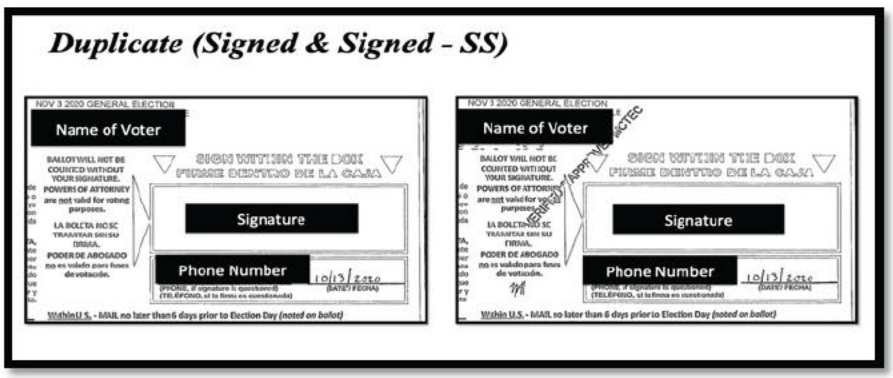



**Figure 43**: Signed-Signed Duplicate.

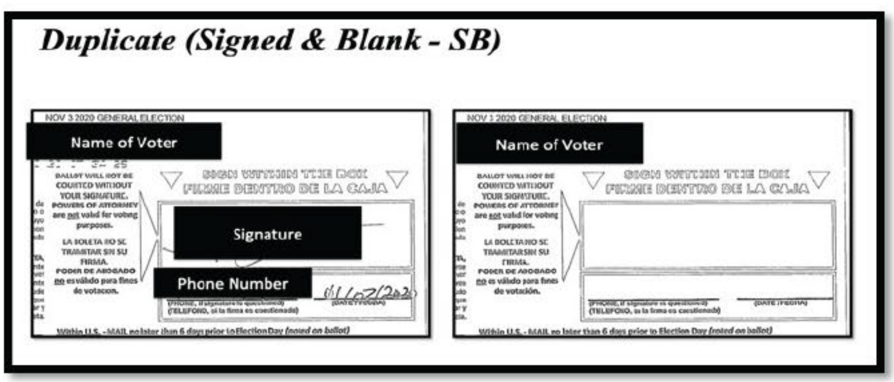



**Figure 44**: Signed & Blank Duplicate.

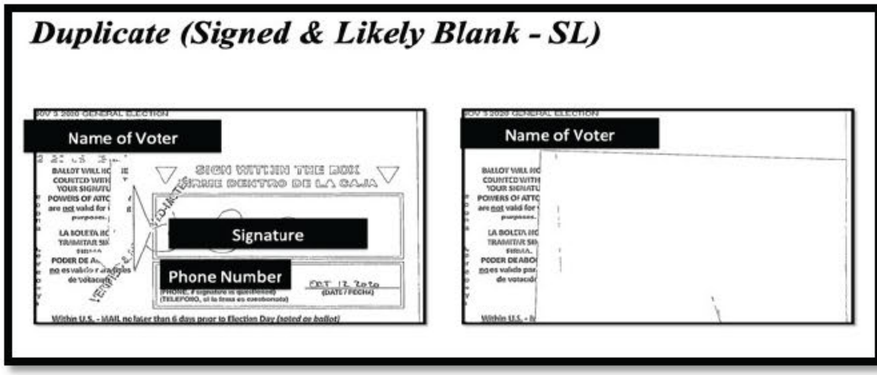



**Figure 45**: Signed & Likely Blank Duplicate.

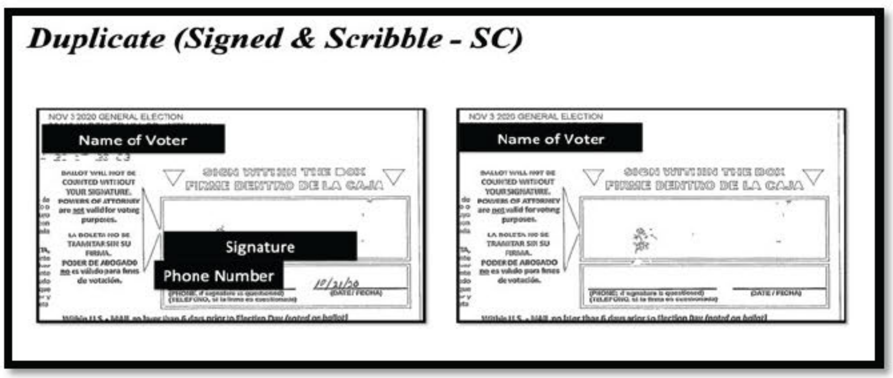



**Figure 46**: Signed & Scribble Duplicate.

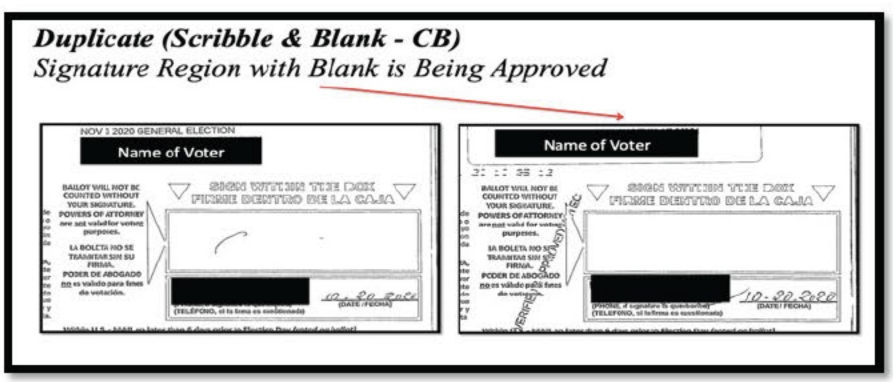



**Figure 47**: Scribble & Blank Duplicate.[23]

[23] Per the *Scope of Audit*, EchoMail solely analyzes the Signature Region. The Signature Region on the right image, by EchoMail, is classified as Blank regardless of the voter placing their signature elsewhere. During Signature Verification, reviewers may resolve such issues when voters do not follow the explicit instructions, **"SIGN WITHIN THE BOX or FIRME DENTRO DE LA CAJA,"** through a process called adjudication.

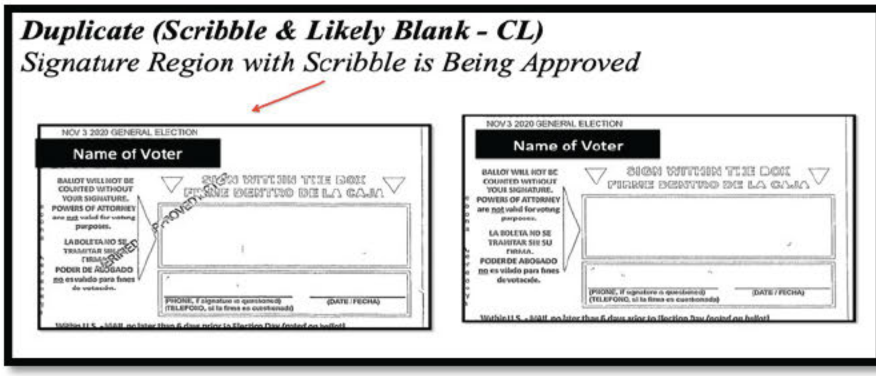



**Figure 48**: Scribble & Likely Blank Duplicate.

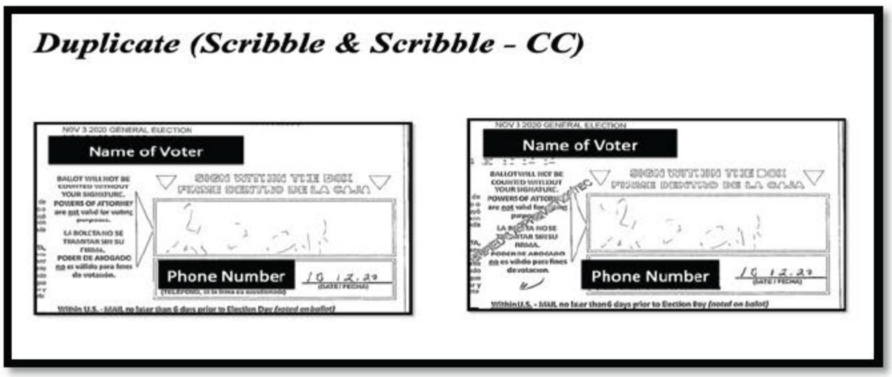



**Figure 49**: Scribble & Scribble Duplicate.

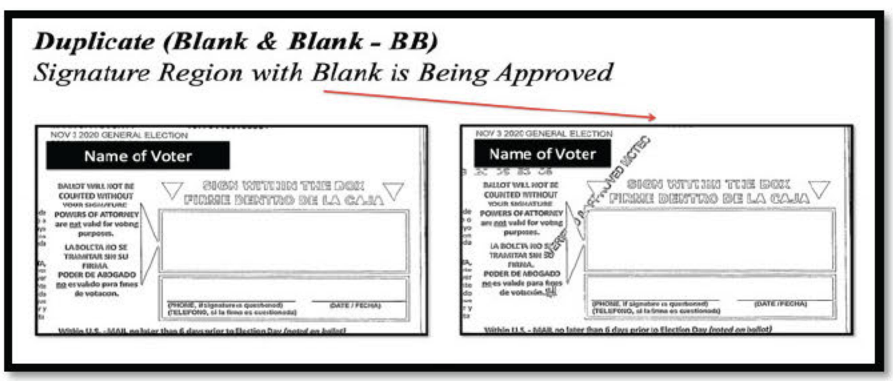



**Figure 50**: Blank & Blank Duplicate.

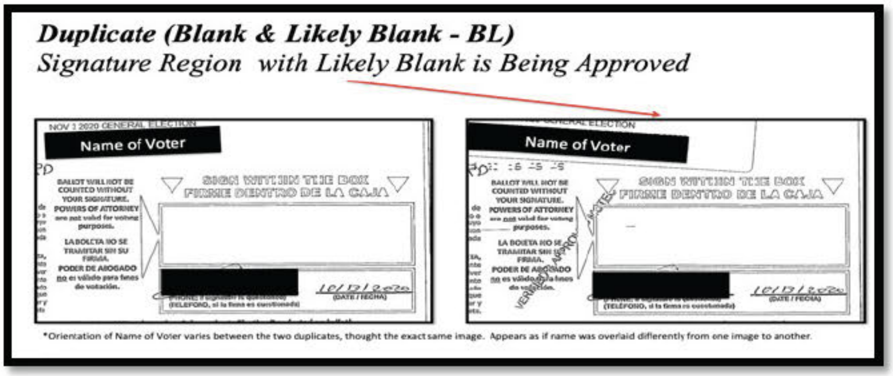



**Figure 51**: Blank & Likely Blank Duplicate.[24]

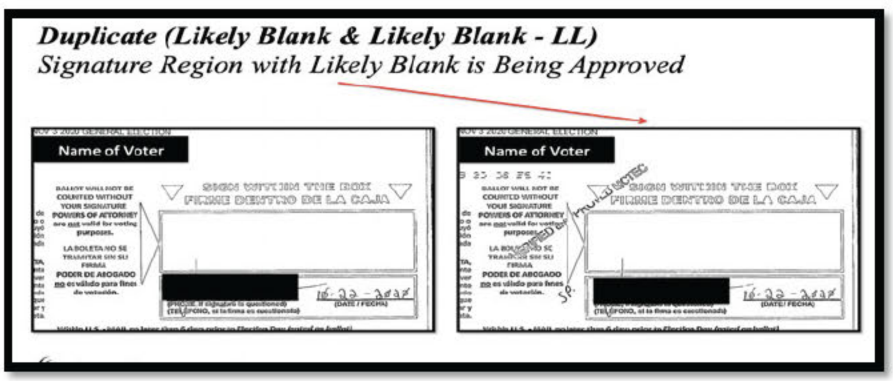



**Figure 52**: Likely Blank & Likely Blank Duplicate.

[24] Per the *Scope of Audit*, EchoMail solely analyzes the Signature Region. Herein, the Signature Region in the right image, by EchoMail, is classified as a Likely Blank, regardless of the voter placing their signature elsewhere, since non-white pixels of density 0%+ to 0.1% are within the Signature Region. During Signature Verification, reviewers resolve such issues when voters do not follow the explicit instructions, **"SIGN WITHIN THE BOX or FIRME DENTRO DE LA CAJA,"** through a process called adjudication.

# SIGNATURE PRESENCE DETECTION RESULTS

There are a total of 1,929,240 EVB return envelope images received by EchoMail. EchoMail Signature Presence Detection was executed on all of these received images. Herein, the results of the EchoMail Analysis are presented. Of these, there are two groups. The first group is the set of 1,894,792 non-Duplicates. The second group is the set of 34,448, 2-Copy, 3-Copy, and 4-Copy Duplicates, as classified and tabulated in Table 5.

## *Classification of Non-Duplicate EVB Return Envelope Images*

Concerning the first group of Non-Duplicates, EchoMail Signature Presence Detection produced the results shown in Table 7. 99.77% of the Non-Duplicate EVB return envelope images' Signature Regions were classified as having Signatures, 0.13% as Scribble, and 0.1% as Blank and Likely Blanks.

| Classification of Non-Duplicate EVB Return Envelope Images | Count | Percentage |
|---|---|---|
| Signature | 1,890,500 | 99.77% |
| Scribble | 2,420 | 0.13% |
| Blank | 1,771 | 0.09% |
| Likely Blank | 101 | 0.01% |
| **TOTAL** | **1,894,792** | **100.00%** |

**Table 7**: Non-Duplicate Signature Presence Detection Results.

## *Classification of Duplicate 2-Copy EVB Return Envelope Images*

Concerning the second group, there are three sub-groups: 2-Copy Duplicates, 3-Copy

Duplicates, and 4-Copy Duplicates. Herein is provided the results of EchoMail Signature Presence Detection on the 33,868 2-Copy Duplicates. Table 8 summarizes the counts.

| Image Copy I | Image Copy II | Classification | Count |
|---|---|---|---|
| Signature | Signature | SS | 15,288 |
| Signature | Blank | SB | 1,348 |
| Signature | Likely Blank | SL | 26 |
| Signature | Scribble | SC | 72 |
| Scribble | Blank | CB | 6 |
| Scribble | Likely Blank | CL | 7 |
| Scribble | Scribble | CC | 142 |
| Blank | Blank | BB | 36 |
| Blank | Likely Blank | BL | 5 |
| Likely Blank | Likely Blank | LL | 4 |
| | | **TOTAL** | **16,934** |

**Table 8**: 2-Copy Duplicate Signature Presence Detection Results.

## *Classification of Duplicate 3-Copy, 4-Copy EVB Return Envelope Images*

Finally, of the Duplicates, the results of EchoMail Signature Presence Detection on the 564 3-Copy Duplicates, and 16 4-Copy Duplicates are presented in Table 9.

| Type | Definitive Blanks | Likely Blanks | Scribbles | Signatures | Totals |
|---|---|---|---|---|---|
| 3-Copy | 40 | 2 | 16 | 506 | **564** |
| 4-Copy | 2 | 0 | 0 | 14 | **16** |

**Table 9**: Three- & Four-Copy Duplicate Signature Presence Detection Results.

Table 10 provides the total number of Blanks e.g. "No Signatures" detected in the Signature Region that includes those Signature Regions categorized as Blank and Likely Blank.

| | Blanks |
|---|---|
| Non-Duplicate Blanks | 1,872 |
| 2-Copy Duplicate Blanks | 45 |
| 3-Copy Duplicate Blanks | 2 |
| **Total** | 1,919 |

**Table 10**: Total number of Signature Regions with Blanks.

Table 11 provides the total number of Scribbles detected in the Signature Region that includes those Signature Regions categorized as Scribble.

| | Scribbles |
|---|---|
| Non-Duplicate Scribbles | 2,420 |
| 2-Copy Duplicate Scribbles | 155 |
| 3-Copy Duplicate Scribbles | 5 |
| **Total** | 2,580 |

**Table 11**: Total number of Signature Regions with Scribbles.

## SUMMARY OF ECHOMAIL ANALYSIS

Finally, Table 12 provides the consolidated results of EchoMail's Analysis integrating all the results of EchoMail Signature Presence Detection.

| | EchoMail Analysis |
|---|---|
| EVB Return Envelope Images Received | 1,929,240 |
| | |
| Duplicate Analysis | |
| Duplicates | (17,322) |
| Unique EVB Return Envelopes | 1,911,918 |
| | |
| Signature Presence Detection | |
| No Signatures | (1,919) |
| Scribbles | (2,580) |
| **EVBs Ready for Signature Verification** | **1,907,419** |

**Table 12**: Summary of results from EchoMail Analysis

## EVB RETURN ENVELOPE IMAGES OF SCRIBBLES AND BLANKS

EchoMail delivered to the Arizona State Senate a USB flash drive containing the EVB return envelope images that the EchoMail Signature Presence Detection determined to be Blanks and Scribbles.

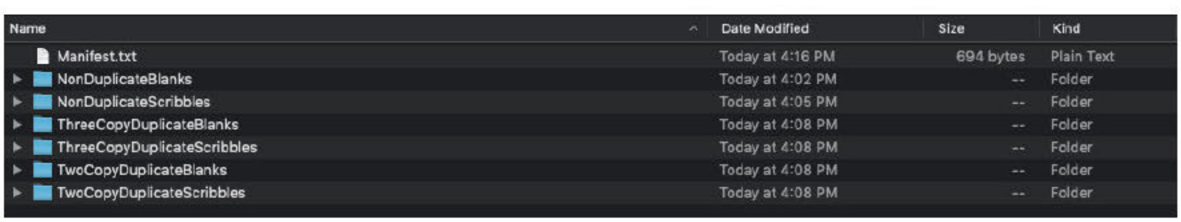



**Figure 53**: Directory structure of USB flash drive delivered to Arizona State Senate containing the EVB return envelope images of Blanks and Scribbles per the SOW.

The directory structure of the USB flash drive sent to the Arizona State Senate is shown in Figure 53. The main directory contains a manifest of the files, with the filename "Manifest.txt." There are six (6) top-level directories as shown in Figure 53. Each top-level directory contains two (2) sub-directories names: FullImage and SignatureRegion. The FullImage sub-directory contains the original image received by EchoMail from the Arizona State Senate. The SignatureRegion sub-directory contains the portion of the Signature Region extracted by EchoMail from the original image.

Table 13 provides the breakdown of the files across the directories, and identifies which directories contain multiple versions of images in the case of 2-Copy and 3-Copy Duplicates. Table 13 indicates that there are a total of 9,426 files delivered to the Arizona State Senate on the USB flash drive containing the Blanks and Scribbles.

| Directory Name | Full Image | Signature Region Image |
|---|---|---|
| **Non-Duplicate Blanks** | 1872 | 1872 |
| **NonDuplicateScribbles** | 2420 | 2420 |
| **TwoCopyDuplicateBlanks** | 45 (2 versions) | 45 (2 versions) |
| **TwoCopyDuplicateScribbles** | 155 (2 versions) | 155 (2 versions) |
| **ThreeCopyDuplicateBlanks** | 2 (3 versions) | 2 (3 versions) |
| **ThreeCopyDuplicateScribbles** | 5 (3 versions) | 5 (3 versions) |

**Table 13:** The breakdown of the 9,426 image files containing Blanks and Scribbles delivered to the Arizona State Senate on the USB flash drive.

# GLOBAL TEMPORAL SIGNALS ANALYSIS

In Table 14, are the results of ordering the 1,919,598 SIF, EVB return envelope images, by the date stamp on the batches of EVB return envelope images provided to EchoMail.

| Date | EVBRE | Blanks | Blanks% | Scribbles | Scribbles% | Duplicates | Duplicates% |
|---|---|---|---|---|---|---|---|
| **10/9/20** | 5454 | 6 | 0.1100% | 4 | 0.0733% | 13 | 0.2384% |
| **10/10/20** | 27978 | 90 | 0.3217% | 34 | 0.1215% | 291 | 1.0401% |
| **10/12/20** | 45203 | 144 | 0.3186% | 41 | 0.0907% | 347 | 0.7676% |
| **10/13/20** | 28453 | 46 | 0.1617% | 43 | 0.1511% | 237 | 0.8330% |
| **10/14/20** | 190517 | 640 | 0.3359% | 236 | 0.1239% | 2079 | 1.0912% |
| **10/15/20** | 126004 | 383 | 0.3040% | 163 | 0.1294% | 1392 | 1.1047% |
| **10/16/20** | 97118 | 295 | 0.3038% | 138 | 0.1421% | 1131 | 1.1646% |
| **10/17/20** | 80924 | 183 | 0.2261% | 105 | 0.1298% | 779 | 0.9626% |
| **10/18/20** | 43185 | 121 | 0.2802% | 65 | 0.1505% | 567 | 1.3130% |
| **10/19/20** | 2778 | 2 | 0.0720% | 5 | 0.1800% | 272 | 9.7912% |
| **10/20/20** | 121404 | 242 | 0.1993% | 173 | 0.1425% | 1599 | 1.3171% |
| **10/21/20** | 93313 | 193 | 0.2068% | 136 | 0.1457% | 1269 | 1.3599% |
| **10/22/20** | 76339 | 177 | 0.2319% | 119 | 0.1559% | 932 | 1.2209% |
| **10/23/20** | 76053 | 148 | 0.1946% | 104 | 0.1367% | 1577 | 2.0736% |
| **10/24/20** | 80451 | 80 | 0.0994% | 105 | 0.1305% | 976 | 1.2132% |
| **10/25/20** | 62768 | 63 | 0.1004% | 71 | 0.1131% | 916 | 1.4593% |
| **10/26/20** | 7053 | 8 | 0.1134% | 17 | 0.2410% | 341 | 4.8348% |
| **10/27/20** | 105905 | 97 | 0.0916% | 185 | 0.1747% | 1086 | 1.0254% |
| **10/28/20** | 116391 | 115 | 0.0988% | 148 | 0.1272% | 1982 | 1.7029% |
| **10/29/20** | 84920 | 80 | 0.0942% | 151 | 0.1778% | 1182 | 1.3919% |
| **10/30/20** | 69062 | 55 | 0.0796% | 104 | 0.1506% | 1295 | 1.8751% |
| **10/31/20** | 63356 | 36 | 0.0568% | 90 | 0.1421% | 999 | 1.5768% |
| **11/1/20** | 67120 | 39 | 0.0581% | 127 | 0.1892% | 1860 | 2.7712% |
| **11/2/20** | 16377 | 22 | 0.1343% | 50 | 0.3053% | 1332 | 8.1334% |
| **11/3/20** | 67170 | 28 | 0.0417% | 118 | 0.1757% | 2197 | 3.2708% |
| **11/4/20** | 157904 | 82 | 0.0519% | 232 | 0.1469% | 3392 | 2.1481% |
| **11/5/20** | 1874 | 5 | 0.2668% | 13 | 0.6937% | 1595 | 85.1121% |
| **11/6/20** | 2380 | 7 | 0.2941% | 12 | 0.5042% | 744 | 31.2605% |
| **11/7/20** | 1512 | 2 | 0.1323% | 10 | 0.6614% | 1459 | 96.4947% |
| **11/9/20** | 632 | 4 | 0.6329% | 6 | 0.9494% | 607 | 96.0443% |
| **Total** | **1919598** | **3393** | **0.1768%** | **2805** | **0.1461%** | **34448** | **1.79%** |

**Table 14:** SIF's by Date, EVBRE, EVBRE%, and Count and Percentage of Blanks, Scribbles, and Duplicates.

The total number of SIF's in Table 14 represents 99.5% all EVB return envelopes (as previously reported in Table 4). This analysis does not include the 9,642 UIF's, LIF and BIF EVB return envelope images. Column 2 denoted by "EVBRE" is the EVB return envelope images per day. The date is assumed, for the purpose of this discussion, to represent the day on which Maricopa officials received the EVB return envelope images (below in the *Questions* section, one of the inquiries to Maricopa officials is to confirm this assumption). Columns 3, 5, and 7, are the total number of Blanks, Scribbles, and Duplicates, received for that Date, respectively. Columns 4, 6, and 8 are the percentage of Blanks, Scribbles, and Duplicates, as a function of the total number of daily EVBRE's, respectively.

## *Control Signal – Plot of EVBRE by Day*

In Figure 54, a graph of the EVBRE by day is provided. This plot serves as a control signal for subsequent comparisons.

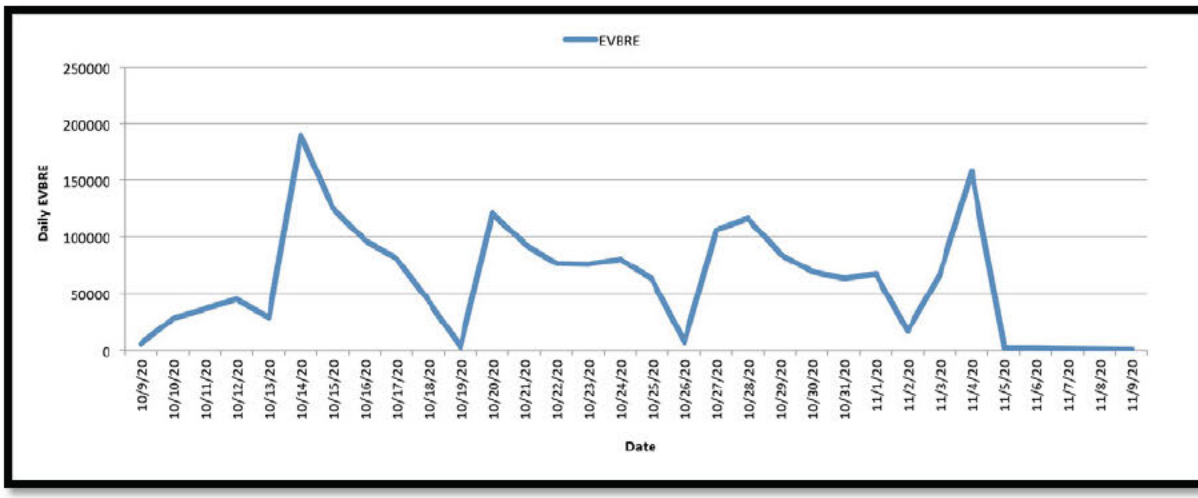



**Figure 54**: Daily EVB Return Envelope Images (EVBRE).

## *Daily EVBRE Compared to Daily Blanks, Scribbles, and Duplicates*

In Figure 55, the daily EVBRE is plotted using a scale on the right y-axis, along with the Blanks, Scribbles, and Duplicates by day with a different scale on the left y-axis. This graph provides a visualization of the daily Blanks, Scribbles, and Duplicates as compared to the control signal of the daily EVBRE. It appears, based on the scaling, the Blanks and the Scribbles correlate with the EVBRE daily trends. However, the daily Duplicates signal appears to diverge from the control signal at various points.

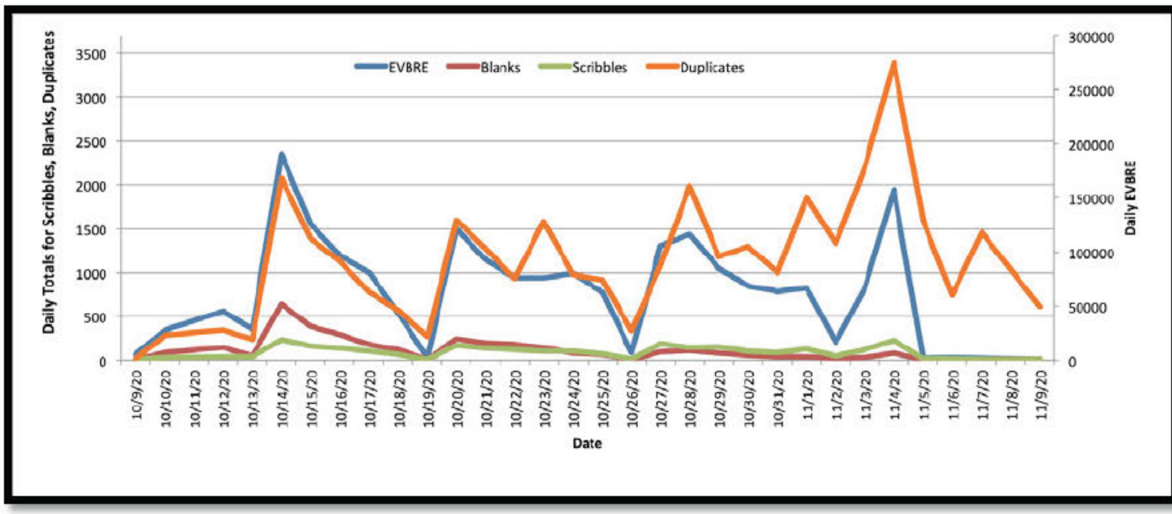



**Figure 55**: Daily EVB Return Envelope Images (EVBRE)
Compared to Daily Blanks, Scribbles, and Duplicates.

## *Daily EVBRE Comparison to Daily Duplicates as % of Daily EVBRE*

To investigate more closely the daily Duplicates relative to daily EVBRE, a signal is developed that plots the daily Duplicate counts as a percentage of the daily EVBRE. This signal is shown alongside the daily EVBRE using two different scales in Figure 56. The left y-axis is used to plot daily Duplicates as a percentage of daily EVBRE, while the right y-axis is used to plot the daily EVBRE. The graph reveals a significant surge of 7,797 Duplicates during the six days from 11/04/2020 to 11/09/2020.

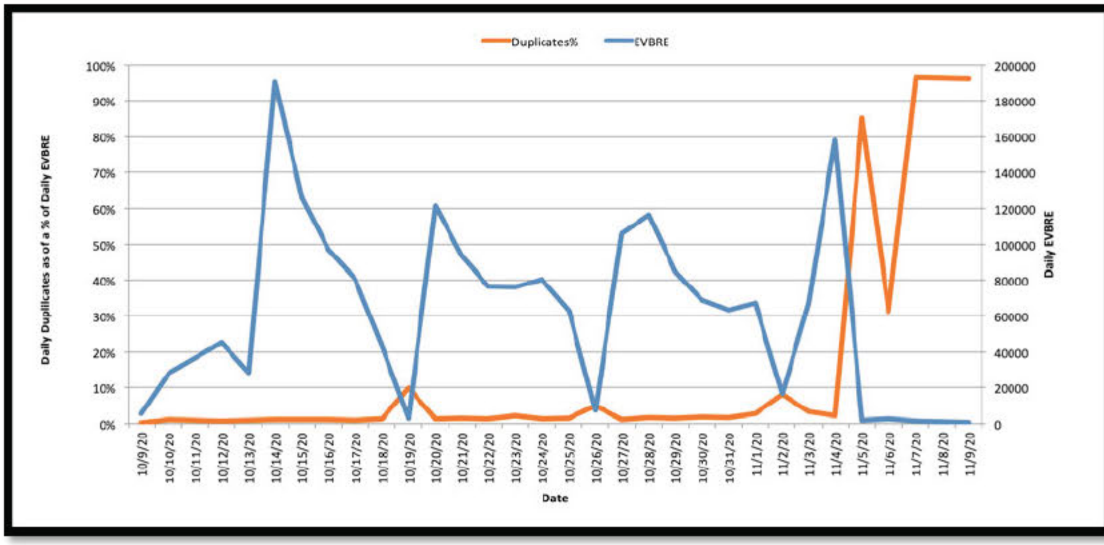



**Figure 56**: Daily EVB Return Envelope Images (EVBRE)
Compared to Daily Duplicates as a Percentage of Daily EVBRE.

This count of Duplicates represents 22.6% of the total number of 34,448 Duplicates for the entire election. Moreover, here are other observations from the graph in Figure 56:

- On 10/19/2020, the daily Duplicate percentage of EVBRE has a local maxima while the daily EVBRE has a local minima.
- Similarly, on 10/26/2020, the daily Duplicate percentage of EVBRE has a local maxima while the daily EVBRE has a local minima.
- Similarly, on 11/02/2020, the daily Duplicate percentage of EVBRE has local a maxima while the daily EVBRE has a minima.
- On 11/05/2020, over 85% of the daily EVBRE are Duplicates
- For the two (2) days, on 11/07/2020 and on 11/09/2020, over 96% of the daily EVBRE are Duplicates.
- On the days of 11/05/2020, 11/07/2020, and 11/09/2020, the daily Duplicates

percentage is nine to ten times more than the highest previous daily Duplicate percentage recorded on 10/19/2020.

## *Daily EVBRE Compared to Daily Blanks, Scribbles as % of Daily EVBRE*

The above investigation of daily Duplicates as a percentage of daily EVBRE motivated a closer investigation of the daily Blanks and Scribbles as a percentage of daily EVBRE.

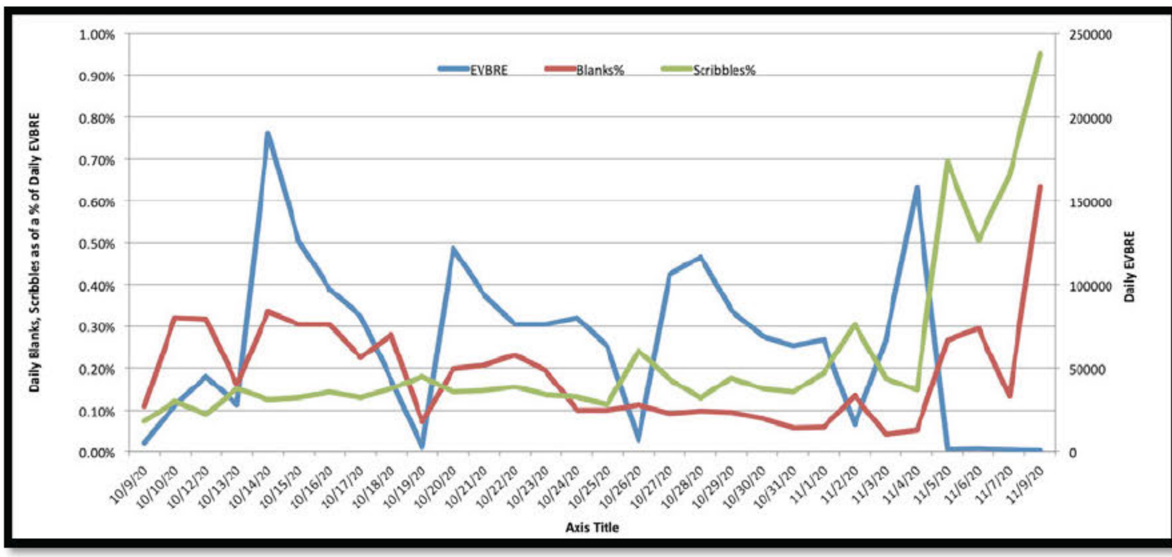



**Figure 57**: Daily EVBRE Compared to Daily Duplicates as a Percentage of Daily EVBRE.

In Figure 57, a signal is developed that plots the daily Blanks and Scribbles as a percentage of the daily EVBRE. This signal is shown alongside the daily EVBRE using two different scales in Figure 57. The left y-axis is used to plot daily Blanks and Scribbles as a percentage of daily EVBRE, while the right y-axis is used to plot the daily EVBRE. Though the numbers of Blanks and Scribbles are relative small, the graph reveals a similar pattern to the increase in daily Duplicates, shown in Figure 53 during the period of 11/04/2020 to 11/09/2020.

## SUPERVISED IMAGE REVIEW

The above temporal results motivated a supervised (human review) of a sample of the Duplicates, and various images. Below are examples of some significant anomalies.

### *Duplicate Blanks Stamped and Approved*

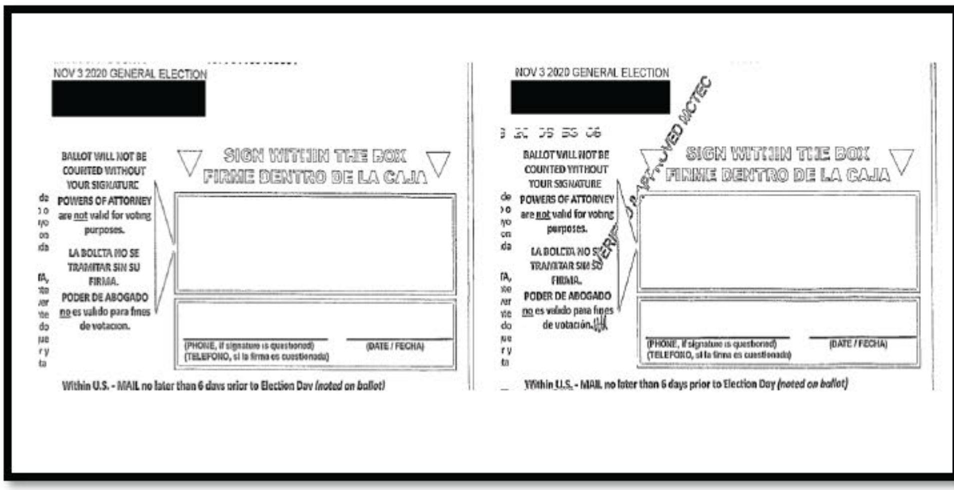

NOV 3 2020 GENERAL ELECTION
[redacted]
BALLOT WILL NOT BE COUNTED WITHOUT YOUR SIGNATURE
POWERS OF ATTORNEY are not valid for voting purposes.
LA BOLETA NO SE TRAMITAR SIN SU FIRMA.
PODER DE ABOGADO no es valido para fines de votacion.
SIGN WITHIN THE BOX
FIRME DENTRO DE LA CAJA
(PHONE, if signature is questioned) (TELEFONO, si la firma es cuestionada) (DATE / FECHA)
Within U.S. - MAIL no later than 6 days prior to Election Day (noted on ballot)

**Figure 58**: #1: Blank Duplicate being STAMPED: VERIFIED & APPROVED MCTEC.

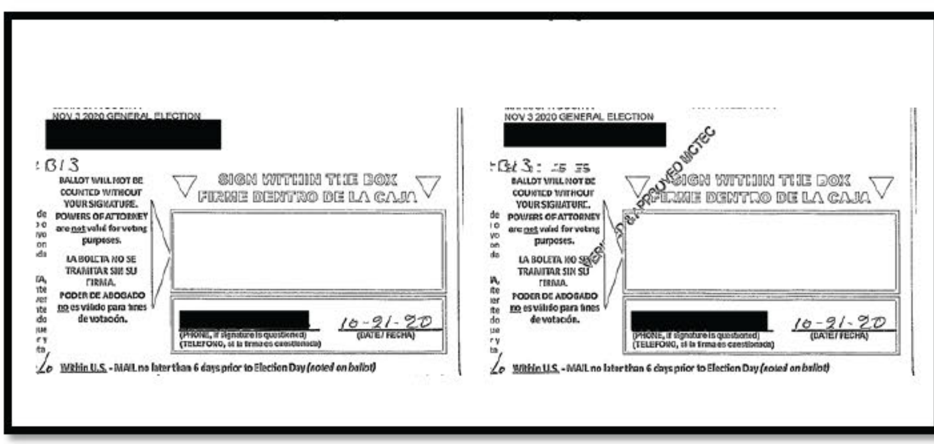

NOV 3 2020 GENERAL ELECTION
[redacted]
BALLOT WILL NOT BE COUNTED WITHOUT YOUR SIGNATURE.
POWERS OF ATTORNEY are not valid for voting purposes.
LA BOLETA NO SE TRAMITAR SIN SU FIRMA.
PODER DE ABOGADO no es válido para fines de votación.
SIGN WITHIN THE BOX
FIRME DENTRO DE LA CAJA
[redacted] 10-21-20
(PHONE, if signature is questioned) (TELEFONO, si la firma es cuestionada) (DATE / FECHA)
Within U.S. - MAIL no later than 6 days prior to Election Day (noted on ballot)

**Figure 59**: #2: Blank Duplicate being STAMPED: VERIFIED & APPROVED MCTEC.

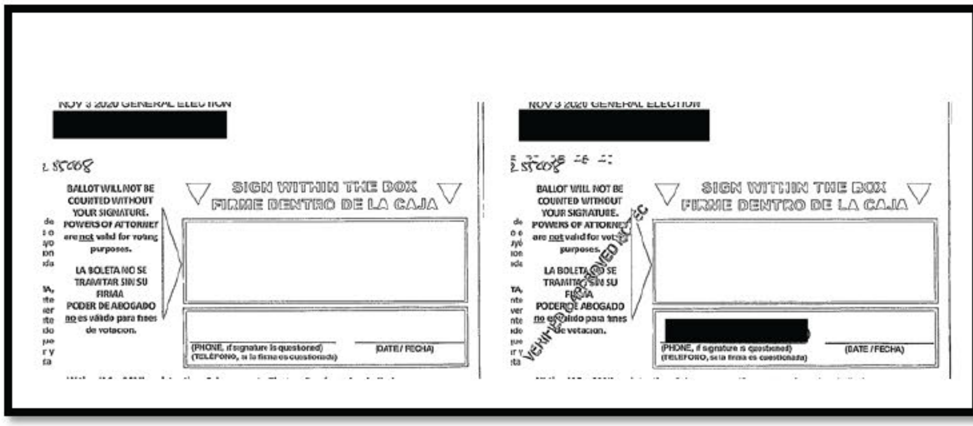



**Figure 60**: #3: Blank Duplicate being STAMPED: VERIFIED & APPROVED MCTEC.

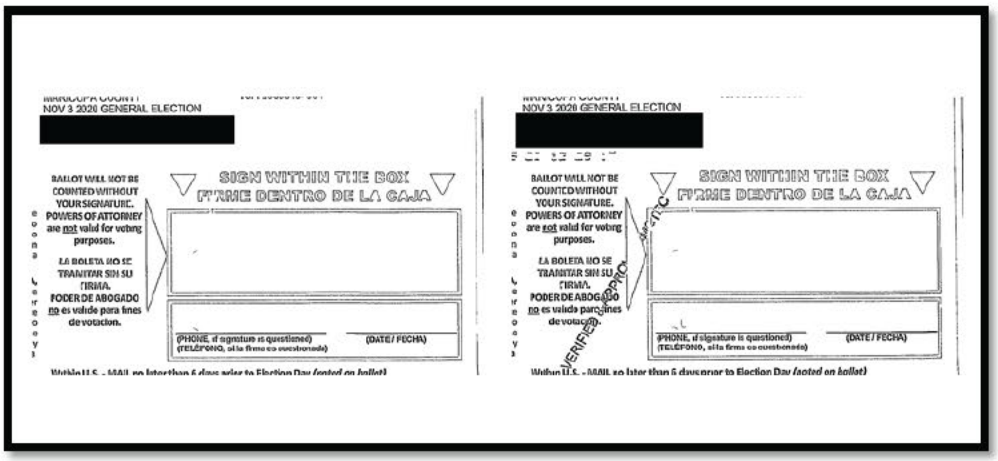



**Figure 61**: #4: Blank Duplicate being STAMPED: VERIFIED & APPROVED MCTEC.

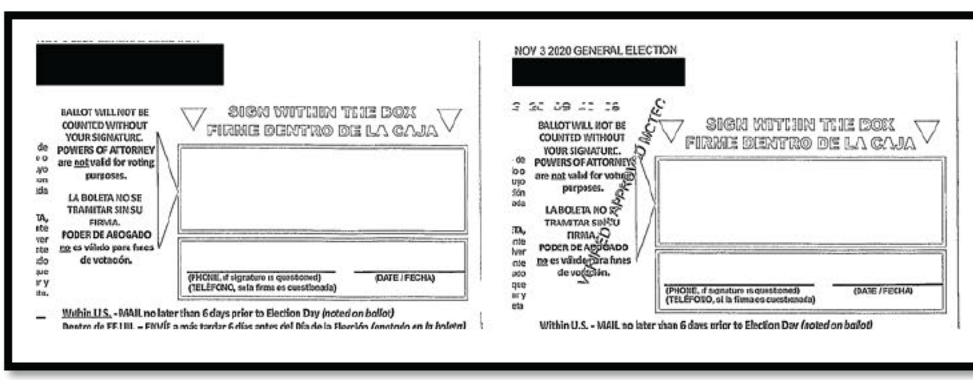



**Figure 62**: #5: Blank Duplicate being STAMPED: VERIFIED & APPROVED MCTEC.

## *Stamped in Signature Region (Non-Duplicates, Two per image)*

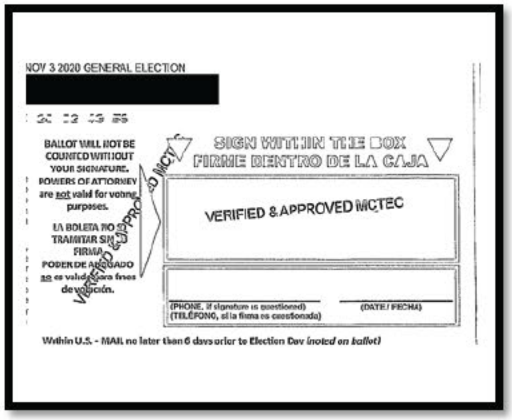



**Figure 63**: #1: Non-Duplicate VERIFIED & APPROVED MCTEC in Signature Region.

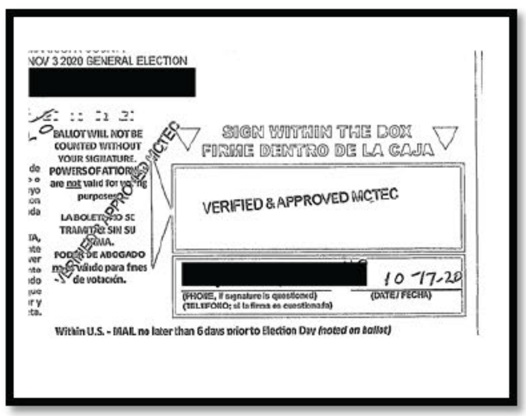



**Figure 64**: #2: Non-Duplicate VERIFIED & APPROVED MCTEC in Signature Region.

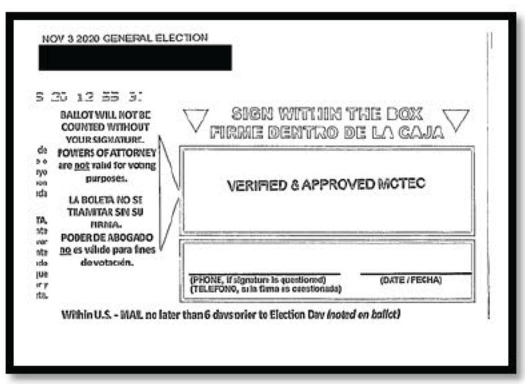



**Figure 65**: #3: Non-Duplicate VERIFIED & APPROVED MCTEC in Signature Region.

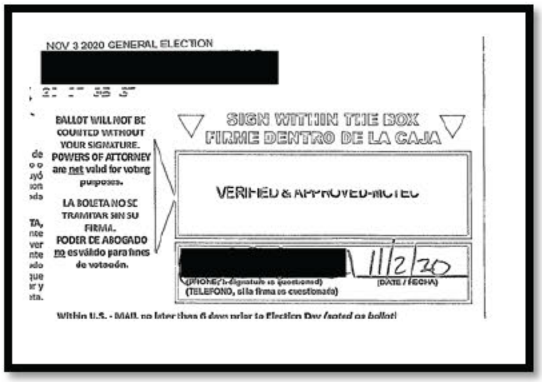



Figure 66: #4: Non-Duplicate VERIFIED & APPROVED MCTEC in Signature Region.

## *3-Copy Duplicate Blanks Stamped and Approved*

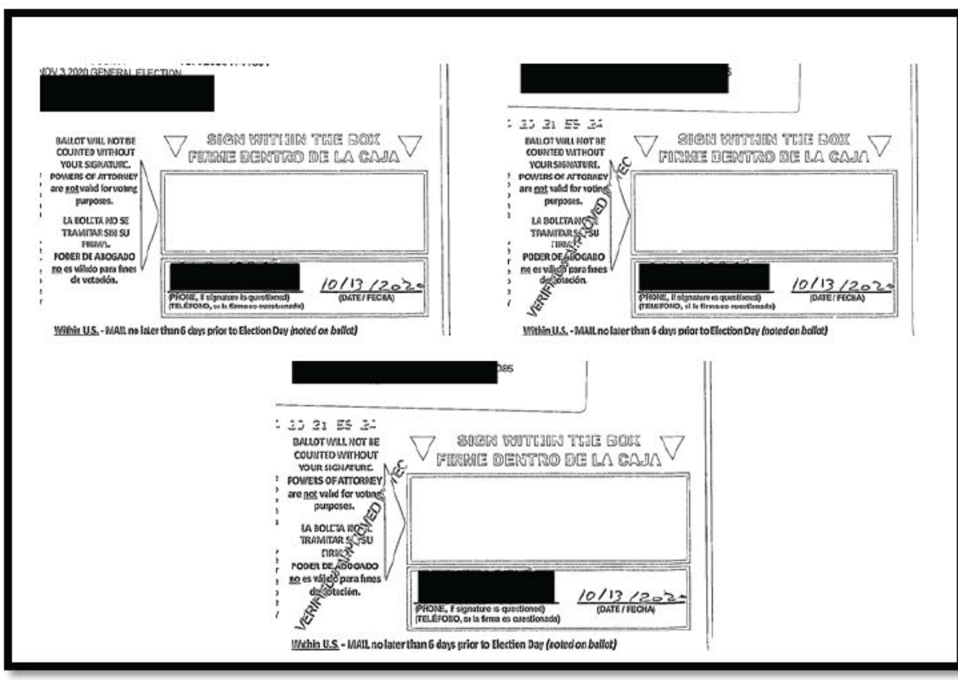



Figure 67: #1: 3-Copy Duplicate Blank being VERIFIED & APPROVED MCTEC.

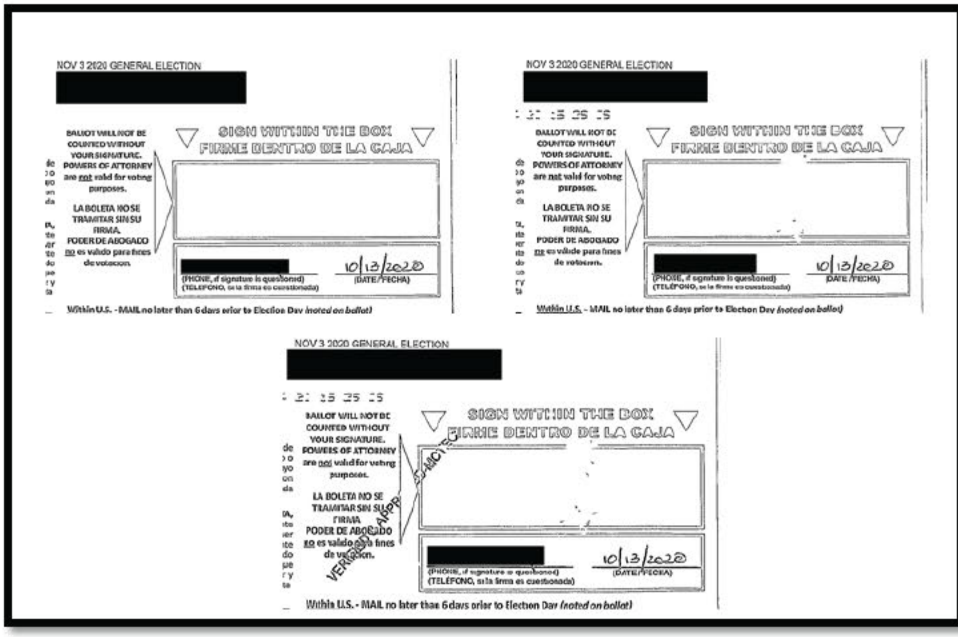



**Figure 68**: #2: 3-Copy Duplicate Blank being VERIFIED & APPROVED MCTEC.

## *3-Copy Duplicate Scribbles Stamped and Approved.*

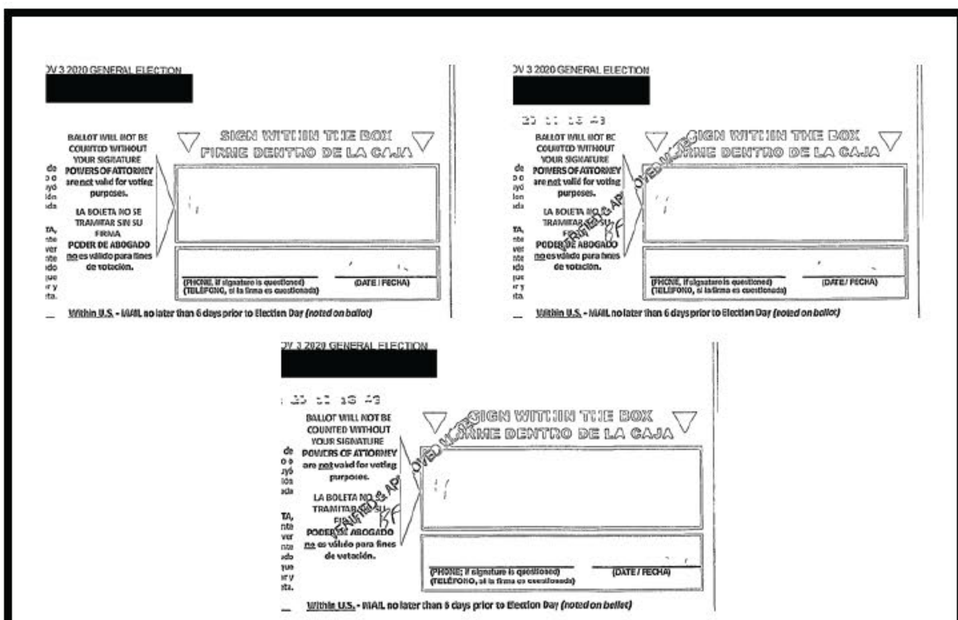



**Figure 69**: #1: 3-Copy Duplicate Scribble being VERIFIED & APPROVED MCTEC.

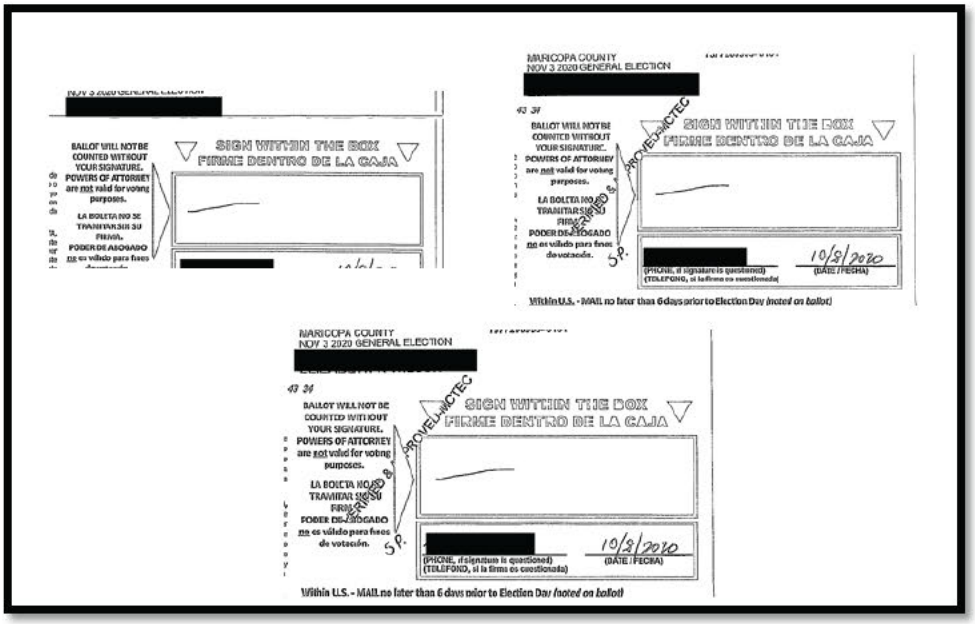



**Figure 70**: #2: 3-Copy Duplicate Scribble being VERIFIED & APPROVED MCTEC.

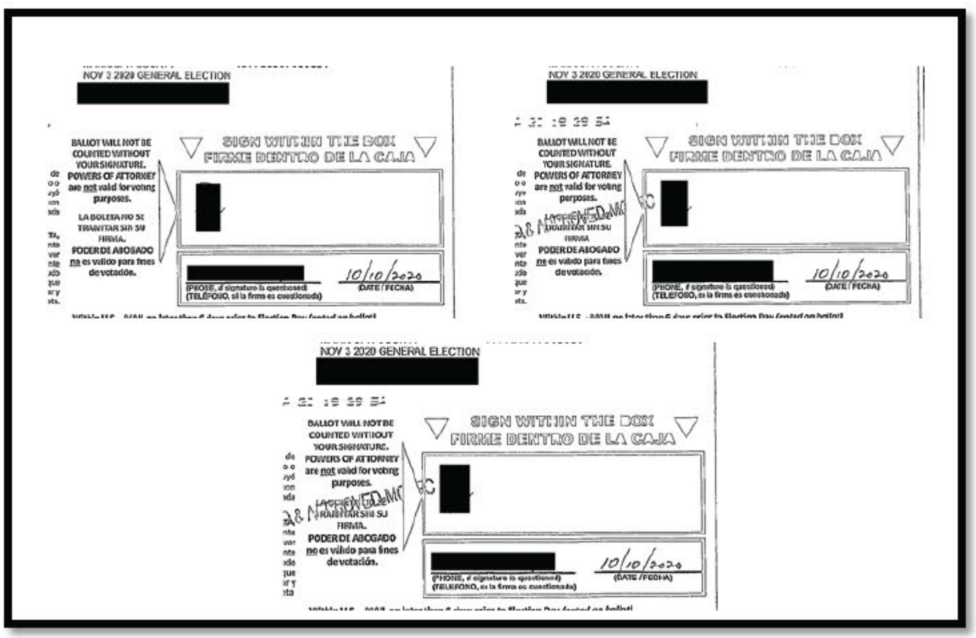



**Figure 71**: #3: 3-Copy Duplicate Scribble being VERIFIED & APPROVED MCTEC.

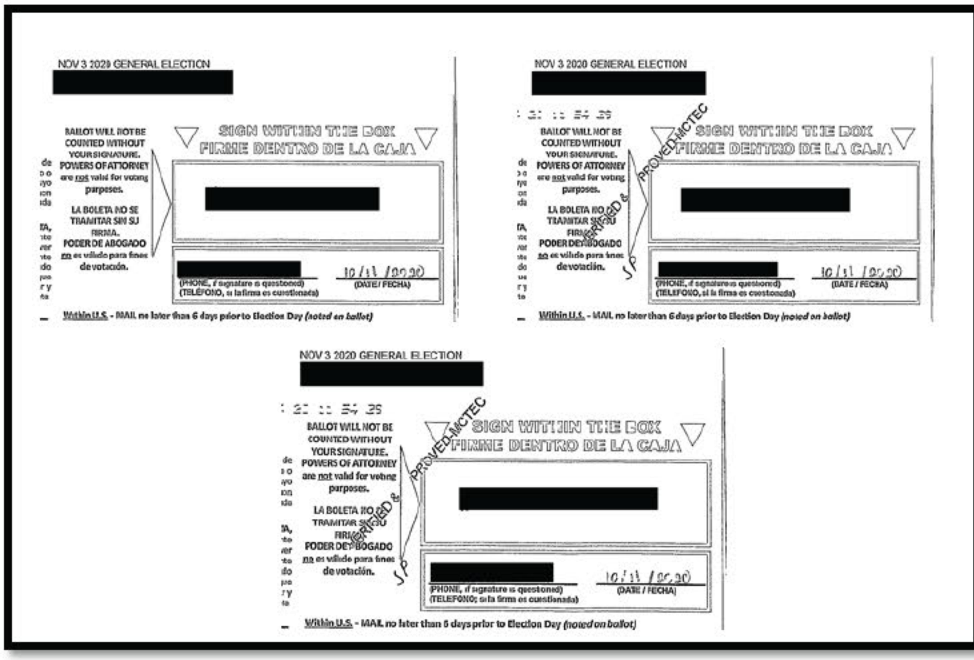



**Figure 72**: #4: 3-Copy Duplicate Scribble being VERIFIED & APPROVED MCTEC.

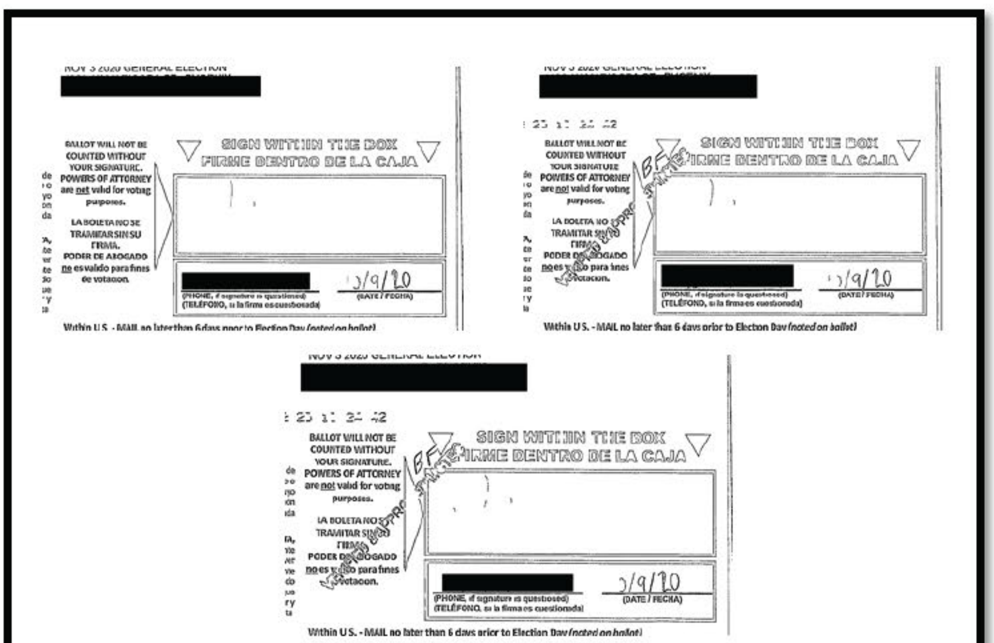



**Figure 73**: #5: 3-Copy Duplicate Scribble being VERIFIED & APPROVED MCTEC.

## *"VERIFIED & APPROVED STAMP" BEHIND Envelope Triangle*

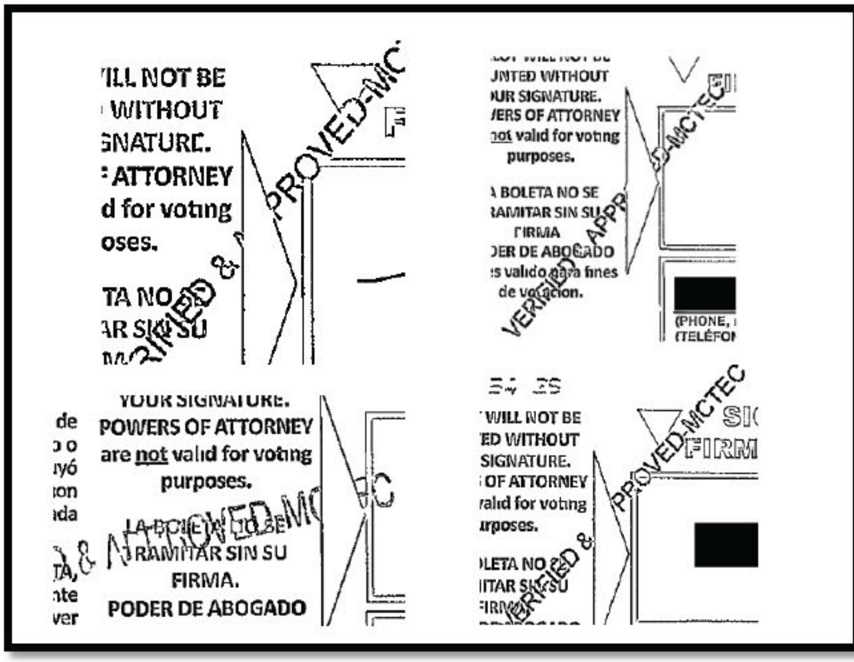



**Figure 74**: #1: VERIFIED & APPROVED MCTEC Behind Triangle

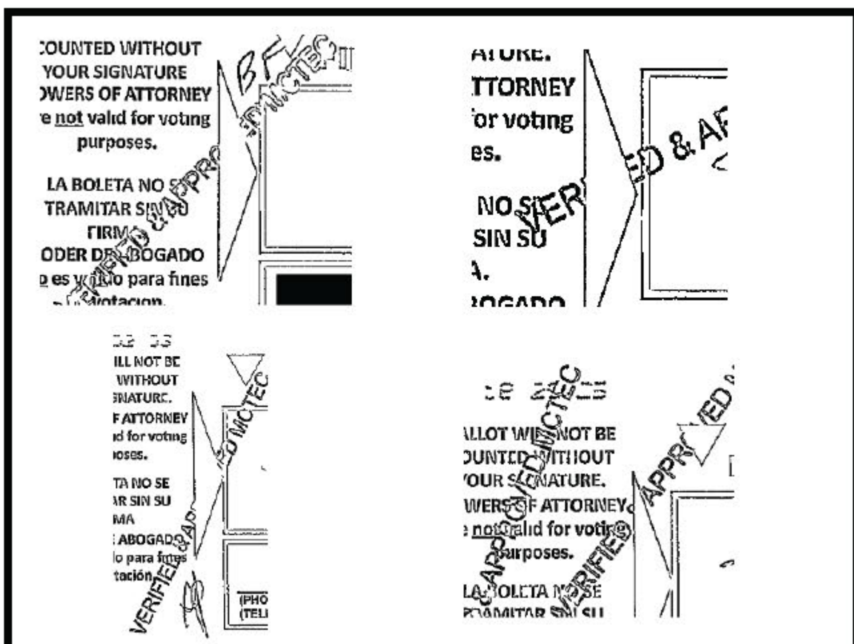



**Figure 75**: #2: VERIFIED & APPROVED MCTEC Behind Triangle.

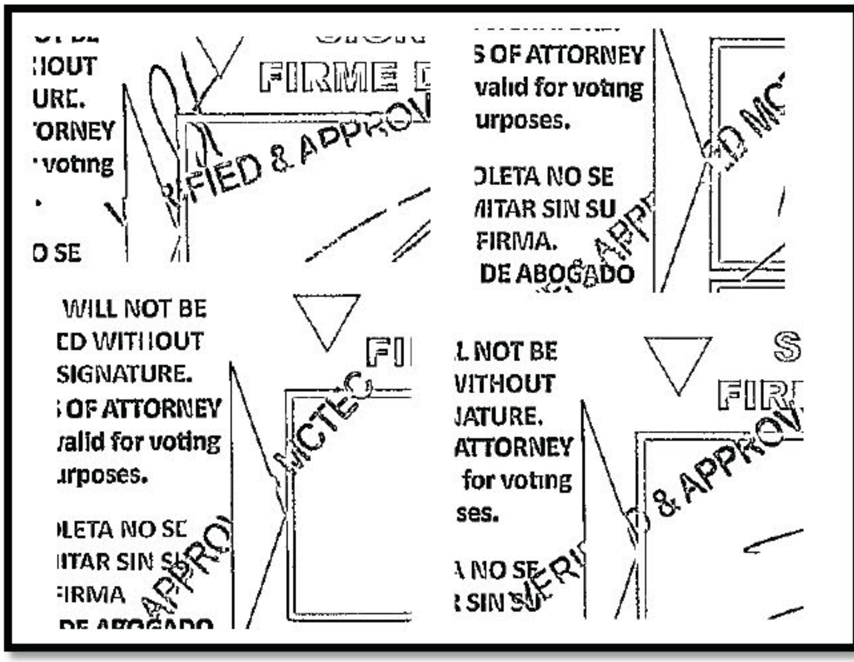



**Figure 76**: #3: VERIFIED & APPROVED MCTEC Behind Triangle.

## *Same Name, Same Signature, Same Phone, Two Different Voter-IDs*

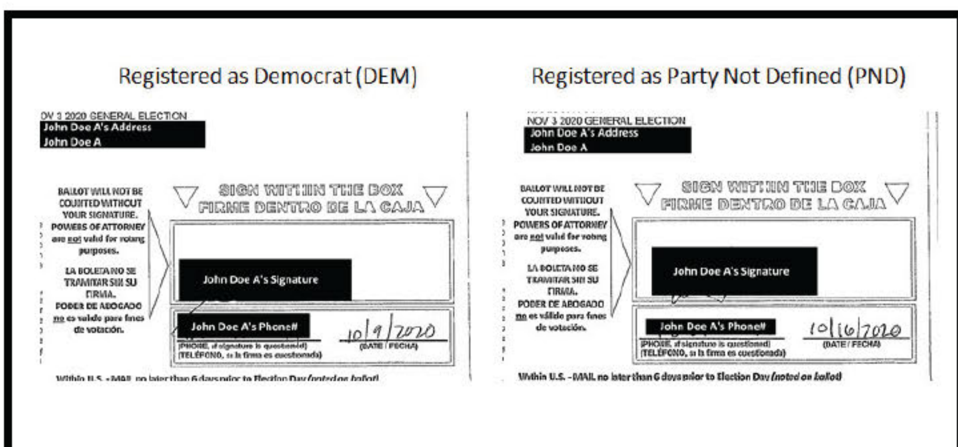



**Figure 77**: #1: Same Name, Same Signature, Same Phone, Two Different Voter-IDs

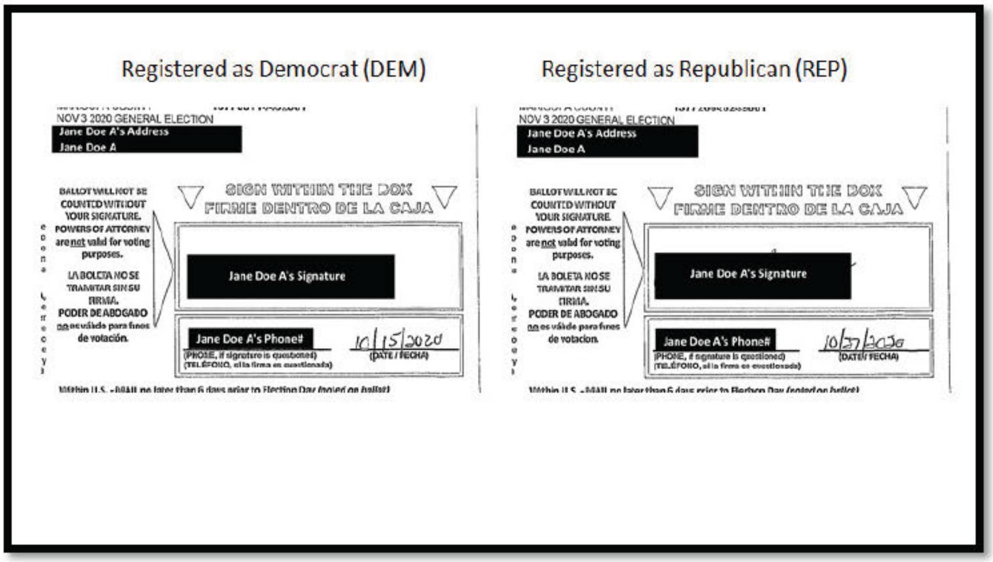



Figure 78: #2: Same Name, Same Signature, Same Phone, Two Different Voter-IDs

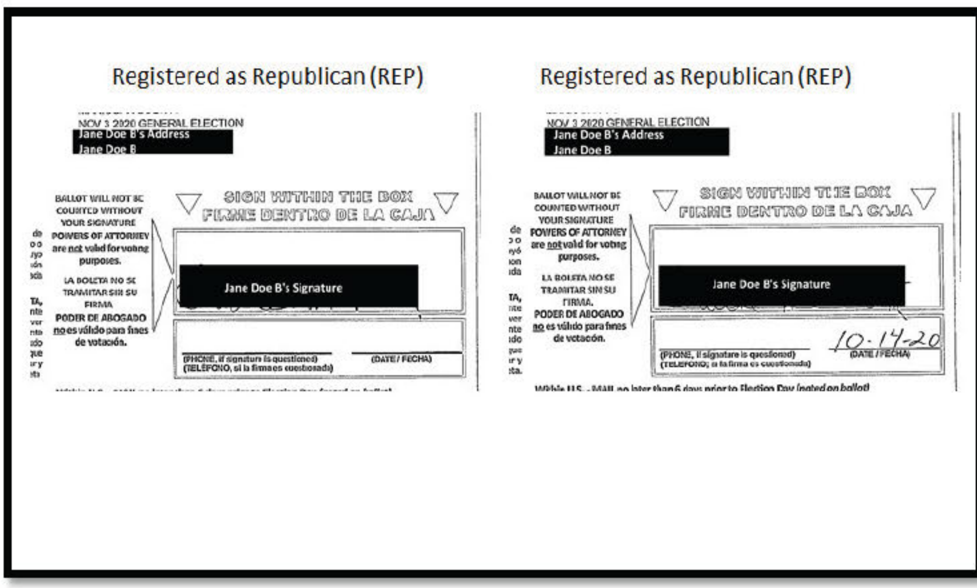



Figure 79: #3: Same Name, Same Signature, Same Phone, Two Different Voter-IDs

# DISCUSSSION

The discussion herein provides a comparative analysis of EchoMail results with Maricopa; offers questions for Maricopa election officials; and, proposes future research.

## COMPARATIVE ANALYSIS

| | EchoMail Analysis | Maricopa Reported | Variance |
|---|---|---|---|
| **EVB Return Envelopes Received** | **1,929,240*** | ***Unknown*** | **NA** |
| | | | |
| **Duplicate Analysis** | | | |
| **Duplicates**[25] | (17,322) | *Un-reported* | NA |
| **Unique EVB Return Envelopes** | **1,911,918** | **1,918,463****| **(6,545)** |
| | | | |
| **Signature Presence Detection** | | | |
| **No Signature Ballots**[26] | (1,919) | (1,455) | (464) |
| **Scribbles**[27] | (2,580) | NA | (2580) |
| **EVBs Ready for Signature Verification** | **1,907,419** | **1,917,008** | **(9,589)** |
| | | | |
| **Signature Verification** | | | |
| **"Bad Signatures"** | NA | (587) | NA |
| **"Late Returns"** | NA | (934) | NA |
| **Total EVBs Verified and Counted** | **NA** | **1,915,487** | **NA** |

**Table 15:** Summary report of EchoMail Analysis of EVB return envelope images compared with Maricopa's results reported in November General Election *CANVASS* report.

*This the total count of all EVB return envelope images received by EchoMail from Arizona State Senate.
**This count is all EVB return envelopes verified and counted by Maricopa (1,915,487) plus those classified by Maricopa as "No Signatures" (1455), "Bad Signatures" (587), and "Late Returns" (934), as documented in Maricopa County's November 2020 *CANVASS* report.

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25 In the EchoMail Analysis, those EVB return envelope images with same image file name were deemed "Duplicates." The EVB return envelope image file names are voter specific. 17,126 unique voters submitted 34,448 2-copy, 3-copy, 4-copy duplicate ballots. The *CANVASS* report filed by Maricopa election officials did not report Duplicates.

26 "No Signature Ballots" in EchoMail Analysis are those Signature Regions on EVB return envelope images classified to be "Blanks" based on a non-white pixel density of 0%, and "Likely Blanks" based on a non-white pixel density between 0%+ to 0.1%.

27 "Scribbles" in EchoMail Analysis are those EVB return envelope images containing likely illegible signatures in the Signature Region, wherein a scribble is defined as a Signature Region containing a non-white pixel density between 0.1%+ to 1%.

Based on the results in Table 15, here is the summary of findings:

- **It is unknown, per the *CANVASS* report, how many EVB return envelopes were *originally* received by Maricopa election officials.** EchoMail received a data set of 1,929,240 EVB return envelope images that were represented to EchoMail as being the set of *all* EVB return envelopes originally received by Maricopa. However, the *CANVASS* report does not document how many EVB return envelopes were originally received Maricopa election officials.[28]

- **EchoMail identified 34,448 EVB return envelope images being 2-Copy, 3-Copy and 4-Copy Duplicates** originating from 17,126 unique voters, while no Duplicates were reported in Maricopa's *CANVASS* report.[29]

- 6,545 ***more*** unique EVB return envelopes were processed by Maricopa than identified by EchoMail.

- 464 ***more*** "No Signature" EVB return envelopes were reported by EchoMail. EchoMail identified 1,919 EVB return envelope images with Blank or Likely Blank in the Signature Region i.e. "No Signature." Maricopa reported 1,455 "No Signature" EVB return envelopes.

- 2,580 Scribbles identified by EchoMail in the Signature Region of EVB return envelope images. A "Scribble" is when a Signature Region on an EVB return

[28] All EVBs reported that were received by Maricopa are assumed to have been accompanied by return envelopes or affidavits with signatures.
[29] The 2020 November General Election *CANVASS* report does not mention Duplicates. A search of the keyword "duplicate" reveals no instances in the *CANVASS* report.

envelope image contains a non-white pixel density between 0.1%+ to 1%, and may indicate a potential "Bad Signature." EchoMail was not commissioned with the task of performing Signature Verification.

- Maricopa reported 587 "Bad Signatures," which is 0.031% of the total EVB return envelopes received by Maricopa. Though EchoMail was not commissioned to perform Signature Verification, if EchoMail's identification of 2,580 Scribbles were all designated as "Bad Signatures," that would be 0.134% of Maricopa's total EVB return envelopes received. This percentage is at least four times more than the "Bad Signatures" percentage reported by Maricopa.

- While the number of EVB returns envelopes in Maricopa for the 2016 general election ***increased*** from 1,257,179 to 1,918,463 EVB return envelopes for the 2020 general election, representing a 52.6% ***increase*** (or by 661,284 EVB return envelopes), the number of rejections from Signature Mismatches of EVB return envelopes, from 2016 to 2020, ***decreased*** by 59.7%. This inverse relationship requires explanation.

- 9,589 ***more*** EVB return envelopes were submitted for Signature Verification by Maricopa than the EVB return envelope images identified by EchoMail as having signatures.

- A full audit of Maricopa's Signature Verification process is necessary, and can be accomplished by comparing each signature on EVB return envelope images with an image of the voter's signature from voter registration files. This will provide a quantitative metric to assess confidence level of Signature Verification.

- Disclosure of Maricopa's Standard Operating Procedure (SOP) for EVB processing, Chain of Custody, and Signature Verification methods, including the SOP and methodology for curing questionable signatures, is necessary.

## QUESTIONS FOR MARICOPA ELECTION OFFICIALS

- Did Maricopa County receive any duplicate EVBs?
  - EchoMail identified 34,448 EVB return envelope images being 2-copy, 3-copy and 4-copy Duplicates originating from 17,126 unique voters, while no Duplicates were reported in Maricopa's *CANVASS* report

- Is the reason that EchoMail has ***more*** "No Signatures" than reported by Maricopa because EchoMail analyzed solely the Signature Region? If not, why?
  - EchoMail identified 1,919 Blanks in Signature Region of EVB return envelopes
  - Maricopa reported 1,455 "No Signatures" in EVB return envelopes

- Why did EchoMail detect more Scribbles than Maricopa's reporting of "Bad Signatures"?
  - EchoMail identified 2,580 Scribbles in Signature Region of EVB return envelopes
  - Maricopa reported 587 "Bad Signatures" from its Signature Verification
  - Had EchoMail been commissioned to identify "Bad Signatures," at least 2,580 Scribbles would have been classified as "Bad Signatures;" 1,993 more "Bad Signatures" than the 587 identified by Maricopa

- Are the date stamps on the directories for SIFs, in the data set provided to EchoMail, the date in which the Maricopa election officials received the EVB return envelopes?

- Why does the approval stamp, ***"VERIFIED & APPROVED MCTEC"*** appear to exist only on a relatively small subset of EVB return envelopes?

- Did Maricopa stamp some EVB return envelopes as ***"VERIFIED & APPROVED MCTEC"*** **even though Signature Region is blank**, since they found a signature elsewhere i.e. outside of the Signature Region, during Signature Verification?

- What is the Standard Operating Procedure ("SOP") for the EVB processing?

- What is the SOP for Signature Verification and curing of questionable signatures?

- What is the Chain of Custody for EVB return envelopes?

- Why is the surge in Duplicates (and Blanks and Scribbles) during 11/04/2020 to 11/09/2020 incongruent with the trend of EVBRE daily counts during the same period?

- Why is the ***"VERIFIED & APPROVED MCTEC"*** stamp appearing "behind" the printed envelope triangle?

- Can Two Voter-IDs be associated with the same person at the same address with matching signatures?

- Why are Blanks being stamped as ***"VERIFIED & APPROVED MCTEC?"***

- Why is the stamp ***"VERIFIED & APPROVED MCTEC"*** appearing in a blank Signature Region?

# FUTURE RESEARCH

This audit has identified various anomalies and discrepancies enumerated above. Though the scope of this audit, as repeatedly clarified, was not to perform Signature Verification, a random sampling of over 200 signatures, 4-weeks before the 2020 Election Day and 4-days after Election Day, are shown in Figures 58 and 59, respectively.


**Figure 58**: Random selection of signatures from 4-weeks before Election Day. Approximately 3% appear as "Illegible" signatures, while approximately 97% appear as "Legible" signatures.


**Figure 59**: Random selection of signatures from 4-days ***after*** Election Day. Approximately 97% appear are "Illegible" signatures while approximately 3% appear as "Legible" signatures.

It is unclear what percentage of the signatures in Figure 58 versus those in Figure 59 were considered "Bad Signatures" or the signatures that required curing by Maricopa election officials. Of the ones in Figure 58, 4-weeks ***before*** Election Day, approximately 3% appear as "Illegible" signatures while approximately 97% appear as "Legible" signatures. Alternatively, of the ones in Figure 59, 4-days ***after*** Election Day, approximately 97% appear are "Illegible" signatures while approximately 3% appear as "Legible" signatures. Observations such as these, along with the discrepancies and anomalies identified from this audit suggest the following be considered for future research:

- Full systems analysis of the efficacy of Maricopa's Signature Verification process, which can be accomplished by comparing all signatures on EVB return envelope images with image of signatures from voter registration files. This can lead to a quantitative metric to assess confidence level of Signature Verification. The following next steps can be pursued in this effort:
  - Acquire Maricopa County's SOP for signature verification
  - Acquire Maricopa County's 27-point analysis algorithm for signature comparison
  - Replicate signature verification process to scientifically calculate false positives, false negatives, and error rate to determine a true confidence value of the signature verification of EVBs

- Disclosure of Maricopa's Standard Operating Procedure (SOP) for EVB processing, Chain of Custody, and Signature Verification methods, including the SOP and methodology for curing questionable signatures.

# CONCLUSION

Based on an engineering systems approach employing pattern recognition classification methods, this audit has delivered a comprehensive analysis of the Signature Region of the Early Voting Ballot (EVB) return envelope images, from Maricopa's November 2020 Election. The objective of this audit was to perform an analysis of these images to determine the counts of Signatures, Blanks, and Scribbles on the EVB return envelope images, and to compare these counts with the counts as reported in the *November General Election CANVASS* report by Maricopa County election officials.

This objective has been accomplished; however, the discussion herein has also aimed to motivate a grander objective: to inspire the reader to move beyond partisanship, vitriol, and controversy to appreciate the need for an *engineering systems approach*, particularly in the modern era of the 21st century, where complex engineering systems pervade every aspect of human existence. Our voting systems are complex engineering systems. Our ability to move beyond left and right and to appreciate the nature of these systems – interconnected systems of systems that serve a diversity of stakeholders – is critical to advancing the systems integrity of U.S. election processes.

This audit has uncovered anomalies in the EVB systems processes that provide all stakeholders a historic opportunity to address and resolve these issues with an engineering systems mindset: to discover the root cause, find the real solution, implement the solution, and monitor the systems ongoing performance.

Below, in Table 16, is an itemized list of the anomalies uncovered. Each anomaly is prefaced by a particular *engineering systems property* or "ility" that can be enhanced if the anomaly is addressed.

| System Property ("ility") | Anomaly | Pages |
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| **Transparency** | There is a lack of visibility of how many EVB return envelopes were received by the Maricopa election officials. EchoMail shared that it had received a total of **1,929,240** EVB return envelope images. However, it is not clear how many EVB return envelopes were received by Maricopa. | p. 62 |
| **Verifiability** | EchoMail's analysis revealed that 17,126 unique voters submitted 34,448 2-copy, 3-copy, and 4-copy Duplicates of EVB return envelopes. However, the *CANVASS* report's lack of disclosure on the number of Duplicates processed, does not allow for an immediate verification of this audit's Duplicates' count. | p. 63 |
| **Auditability and Chain of Custody** | EchoMail identified ten (10) different kinds of 2-Copy Duplicate classifications, and provided their examples. What emerges from these examples is a lack of clarity on why one copy was stamped **"VERIFIED AND APPROVED MCTEC"** and why the other was not. If adjudication took place, is there a communications record of which reviewer contacted the voter and how the matter was resolved? | pp. 64-67 |
| **Reliability** | What is the Standard Operating Procedure (SOP) for denoting when an EVB return envelope is classified as a "No Signature?" The instructions on the EVB return envelopes are unequivocal: the voter MUST sign their name in the Signature Region; however, when there is a signature elsewhere, there are | pp. 64-67 |

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| | **"VERIFIED AND APPROVED MCTEC"** stamps on the envelopes. Disclosure of the SOP, or augmenting the SOP to define the rules of engagement in such instances may improve reliability in this process. | |
| **Precision** | The existence of 34,448 Duplicates: 2-copy, 3-copy, and 4-copy indicates opportunities for process improvements in ensuring that one voter gets only one EVB return envelope. | p. 62 |
| **Testability** | One would assume that as the number of EVB return envelopes increases, there would be concomitantly more "Bad Signatures" i.e. Signature Mismatches. However, results indicate that the inverse took place in Maricopa in the general elections of 2016 and 2020. While the number of EVB return envelopes increased by 52%, the number of Signature Mismatches decreased by 59%. | pp. 29-31 |
| **Reproducibility** | Only 587 – 0.031% of all EVB return envelopes – were identified by Maricopa election officials as "Bad Signatures." EchoMail classified 2,850 EVB return envelopes as having Scribbles. If EchoMail had been commissioned to perform Signature Verification, (which it had not), and deemed 2,850 Scribbles as "Bad Signatures" that would result in at least four times more "Bad Signatures" than reported by Maricopa. Given the Signature Verification process in Maricopa exceeded over 1.9 Million EVB return envelopes, 587 for "Bad Signatures" appears to be an exceedingly low number. | p. 29<br>pp. 67-68 |
| **Scalability** | The receipt and processing of EVB return envelopes appear to have temporal periods of peaks and valleys. Sudden surges, for example, in certain classes of EVB return envelopes – such as Duplicates, Blanks and Scribbles – during the 11/04/2020 to 11/09/2020 have been observed. Are these observations systemic to the inability to handle large volumes during short periods or due to something else? | pp. 72-76 |
| **Robustness** | The Signature Mismatch Rate in the State of Arizona for 2016 general election with EVB return envelopes of approximately 2 Million was 0.131%; however, in Maricopa County for the 2020 general | pp. 26-25<br>pp. 29-31<br>pp. 82-84 |

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| | election with approximately 1.9 Million EVB return envelopes, the Signature Mismatch Rate is 0.031%. Maricopa's 2020 Signature Mismatch Rate is 4 times less than the State of Arizona's Signature Mismatch Rate for 2016. Did new policies or legislation have an impact on this Signature Mismatch Rate reduction? Signatures vary immensely from highly legible to high illegible. There is a 27-point signature verification process in place in Maricopa to perform Signature Matching. Building confidence in Signature Matching can facilitate constituent confidence in Signature Verification process. | |

**Table 16**: Systems properties ("ilities") that can be enhanced from the resolution of anomalies identified in this audit.

Table 16 has derived a set of engineering systems properties or "ilities": Transparency, Verifiability, Auditability (Chain of Custody), Reliability, Precision, Testability, Reproducibility, Scalability, and Robustness, that can advance the current EVB systems processes by addressing the anomalies detected in this audit. Enabling such advancement of election voting systems, however, demands both a culture where attention to detail, constant monitoring of anomalies – small or large, seemingly insignificant or monumental – is fostered, as well as nurturing leadership that inspires a systemic and pervasive attitude that welcomes feedback: positive or negative. The future efforts towards addressing these anomalies, therefore, provide a unique and historic opportunity for an engineering systems approach to advance the systems integrity of U.S. election processes.