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**AN EXTENDED STUDY - Redacted**

# Extended Study Confirms At Minimum Over 200,000 Mail Ballots With Mismatched Signatures Counted Without Review ("Curing") in Maricopa County, Arizona 2020 General Election


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**Delivered to:**

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President of the Senate
Arizona State Senate
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# AUTHOR'S BIO

Dr. Shiva Ayyadurai, MIT PhD, S.M.M.E., S.M.V.S., S.B.E.E., 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 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

[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/

# AUTHOR'S BIO (CONT.)

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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## A Publication of the Election Systems Integrity Institute

The Election Systems Integrity Institute ("ESII") is dedicated to providing independent research and infrastructure to support Election Systems Integrity. This publication documents the work completed by EchoMail, Inc., which was commissioned by the Arizona State Senate to perform the work in this study.





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# Notes on Update

- This updated Extended Study advances on the previous version published on March 2, 2022
- Specifically, the updates in this version are as follows:
  1) A refinement of the pooled consensus measure is done based on every time an *individual* pairwise signature is reviewed by either a set of FDEs or non-FDEs. This measure is the probability out of how many times among a set of either FDEs or non-FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match. This obviates the need for average signature mismatch rate and the previous pooled consensus. This refinement is applied to the calculation of the signature mismatch rates in Experiment I, Experiment II, and the Two-Step Review, across all 2,770 pairwise signatures.
  2) Application of additional constraints on which signatures from the Deeds repository are included
  3) Relative to (2), these constraints include:
     a) Restrictions on middle initial comparison when acquiring signatures from the Deeds repository
     b) Removal of **all** 290 signature mismatches that all reviewers classified as No Match
  4) Based on (3), **391 were removed** from the original data set of 2,770. This reduced the data set to 2,379, which is used re-calculate Experiment I, Experiment II, and the Two-Step Review in Analysis B.

# Table of Content

# Executive Summary

# Executive Summary

- At minimum, 215,856 early voting mail ballots (EVBs) should have been cured in Maricopa versus the ~25,000 cured by the County in the 2020 General Election.

| Measures | Mismatch Rate (%) | EVBs to be Cured | Maximum Cured by Maricopa | EVBs to be Disallowed Post-Curing | Maricopa Disallowed Post-Curing |
|---|---|---|---|---|---|
| **Non-FDEs Pooled Consensus** Analysis A – Expt I | 28.50% | 544,897 | 25,000 | 12,533 | 587 |
| **FDEs Pooled Consensus** Analysis A - Expt II | 48.98% | 936,840 | 25,000 | 21,547 | 587 |
| **2-Step Pooled Consensus** Analysis A | 22.27% | 425,784 | 25,000 | 9,793 | 587 |
| **Non-FDEs Pooled Consensus** Analysis B – Expt I | 18.02% | 344,528 | 25,000 | 18,025 | 587 |
| **FDEs Pooled Consensus** Analysis B – Expt II | 41.15% | 786,754 | 25,000 | 7,924 | 587 |
| **2-Step Pooled Consensus** Analysis B | 11.29% | 215,856 | 25,000 | 4,965 | 587 |

# Executive Summary

- At minimum, 215,856 early voting mail ballots (EVBs) should have been cured in Maricopa versus the ~25,000 cured by the County in the 2020 General Election.
- This updated Extended Study ("the Study") along with the Pilot Study are the first to calculate signature mismatch rates of EVBs for Experts - Forensic Document Examiners (FDEs), Trained Novices (non-FDEs), and in a Two-Step Review process using non-FDEs and FDEs.
- One constraint of this Study in not having access to the signature files from the County.
- Given the nearly 10x difference in EVBs to be cured between this Study and the County's actually number cured, if the County were to provide their signature files, an update to this Study can be performed.

# Abstract

# ABSTRACT


- An initial Pilot Study was conducted using 499 EVB signature images that were randomly selected from a database of 1,911,918 EVB envelope images from Maricopa in order to have a 95% Confidence Level such that the real value would be within ±4.4% Margin of Error of the measured value.[3]
- In that Pilot Study, six reviewers – 3 experts (Forensic Document Examiners – FDEs) and 3 trained novices (non-FDEs) – who were presented pairwise images of signatures from the EVB envelope and a genuine signature, ALL concurred 60 of the 499 (12%) EVBs to be signature mismatches.[3]
- The Pilot Study concluded that 229,430 EVBs should have been cured versus the "upwards of 25,000" that Maricopa County reported cured.[3]
- Though the results from Pilot Study were compelling, it was decided an Extended Study should be conducted using a much larger sample size.



[3] Ayyadurai, Shiva, "Irreconcilable Differences – Over 200,000 Mail Ballots With Mismatched Signatures Counted Without Being Reviewed ("Cured") in Maricopa: First Study to Calculate Signature Matching Rates to Provide a Quantitative Framework for Assessing Signature Verification of Mail Ballots," Election Systems Integrity Institute (ESII), Cambridge, MA, February 22, 2022,

# ABSTRACT


- This Study used an initial sample size of 2,770 – five times larger than Pilot Study - having a 99% Confidence Level so the real value would be within ±2.5% Margin of Error of the measured value to perform a first set of analysis. This analysis is in the section marked “Analysis A.”
- This Study used a revised sample size of 2379 – after imposing additional constraints to ensure more genuine signatures from the Deeds’ repository – having a 99% Confidence Level so the real value would be within ±2.7% Margin of Error of the measured value to perform a second set of analysis. This analysis is in the section marked “Analysis B.”
- Specifically, in this update:
    1) Additional constraints are applied to the original 2,770 data set with greater restrictions on the name matching of signatures acquired from the Deeds repository.

# ABSTRACT

2) ALL pairwise signatures (290) wherein ALL six reviewers classified them to be No Match **are removed**. When ALL six reviewers believe a set of pairwise signatures are NO MATCH, it could be one of two possibilities: either the pair are indeed a NO MATCH or the genuine signature from the Deeds' repository is not genuine. Herein, the latter possibility is applied across all the 290. This choice may lead to false negatives – pairwise sets with genuine signature being removed; however, it significantly reduces the possibility for error i.e. the probability of this Study having signatures which are not genuine.

3) Relative to point (2), some examples of false negative pairs that were removed but indeed had genuine signatures are provided.

# ABSTRACT


- This Study found:
  - If Experts - Forensic Document Examiners (FDEs) – alone were used to review the EVBs, then at a minimum 786,753 EVBs should have been cured or at a maximum 936,457 EVBs.
  - If Trained Novices – non-FDEs – alone were used to review the EVBs, then at a minimum 344,528 EVBs should have been cured or at a maximum 544,897 EVBs.
  - If non-FDEs and FDEs BOTH were used to review the EVB signatures in a two-step process (non-FDEs reviewing first, then FDEs), then at a minimum 215,856 EVBs should have been cured or at a maximum 425,784 EVBs.

# ABSTRACT


- The Study reveals that at minimum 215,856 early voting mail ballots (EVBs) should have been cured in Maricopa versus the ~25,000 in the 2020 General Election.
- If the County were to provide its signature file used in the 2020 General Election, this study can not only be updated but also enable our machine learning algorithms to perform a full analysis of all 1.9M+ EVBs.

# Background

# What Is Signature Verification?

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- Signature verification is a multi-step process aimed to verify a signature based on review of two signatures side-by-side: one being genuine, the other being questionable.

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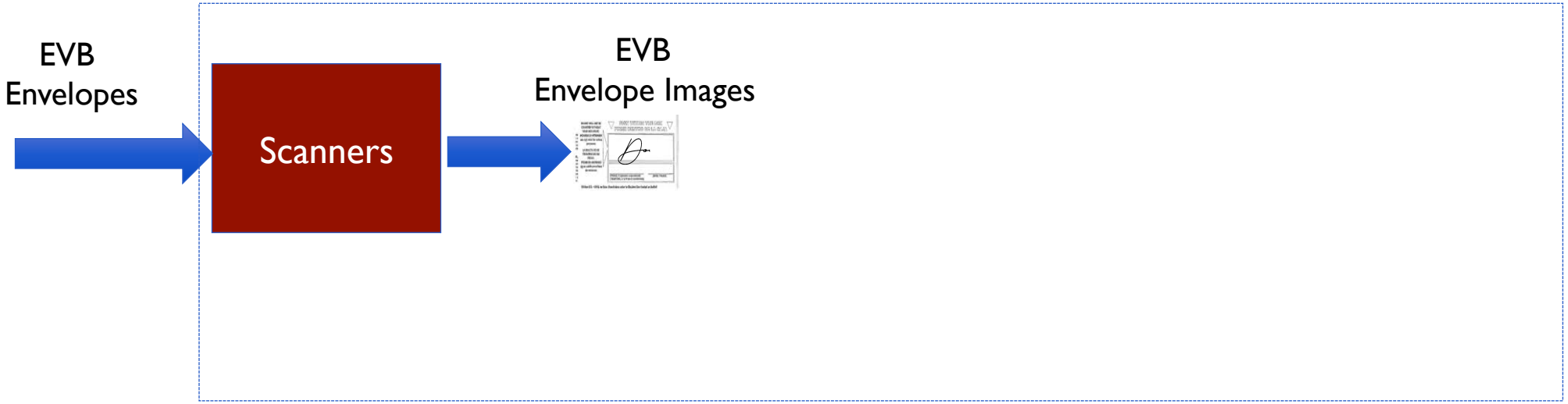


- EVB envelopes are scanned to produce EVB envelope images

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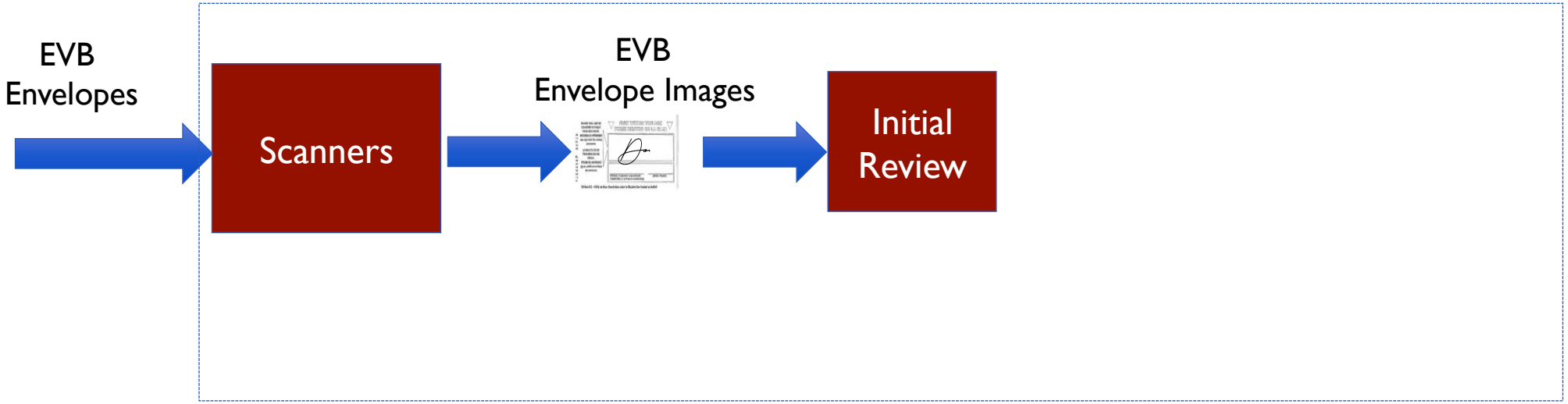


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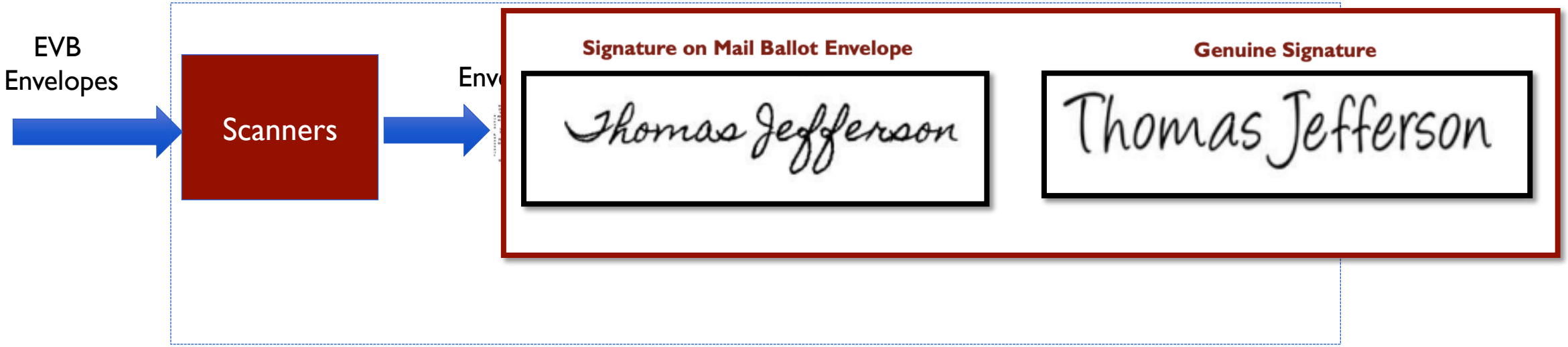


- EVB envelopes are scanned to produce EVB envelope images
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  - Trained Staff review 100% of all EVB envelope images following County's procedures to determine if EVB signature is a *Match* or *No Match* with genuine signature on file

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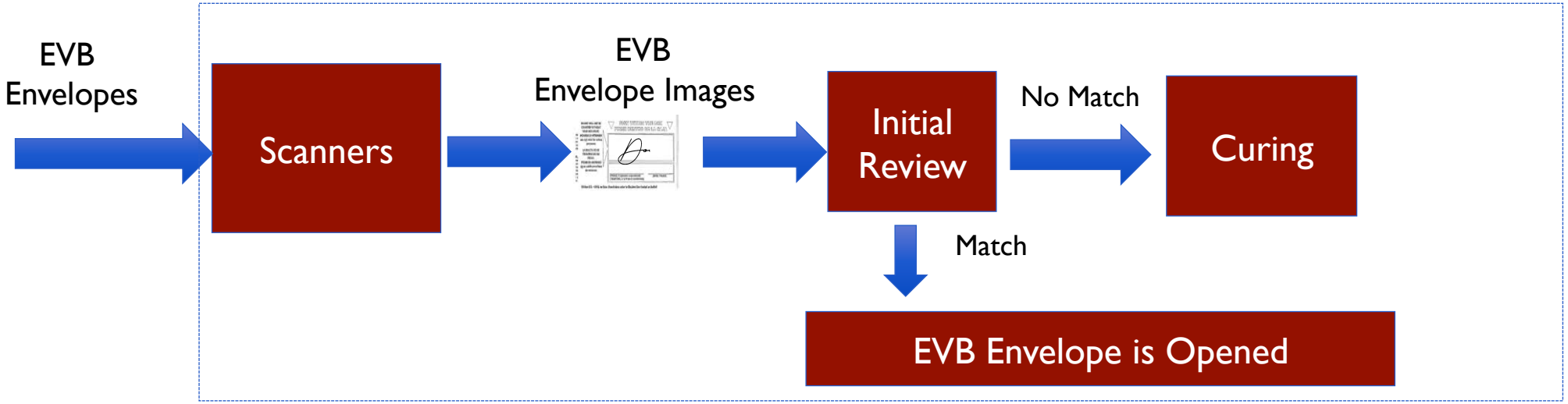


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  - Trained Staff review 100% of all EVB envelope images following County's procedures to determine if EVB signature is a *Match* or *No Match* with genuine signature on file (takes 4 to 30 seconds)
  - Any *No Match* is sent to Manager (with more expertise) to determine if it should be cured or not

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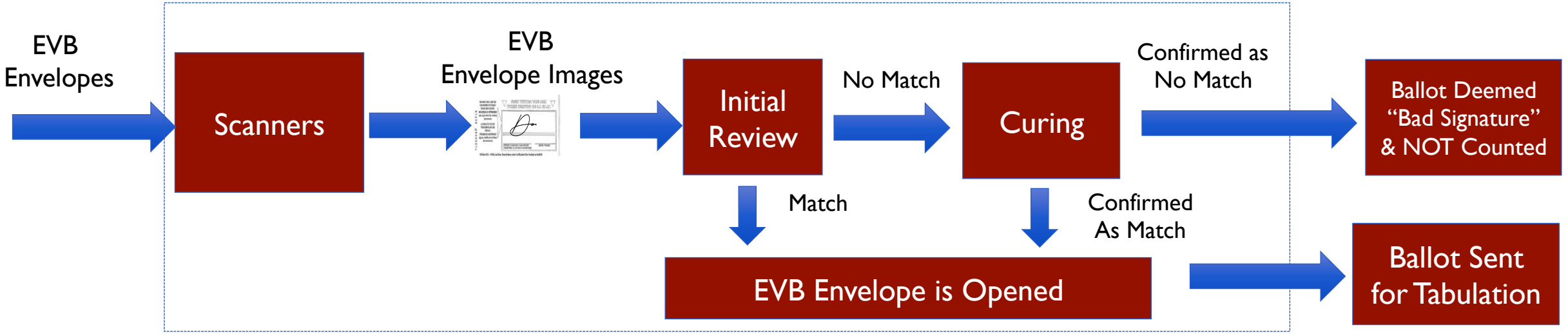


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  - Trained Staff review 100% of all EVB envelope images following County's procedures to determine if EVB signature is a *Match* or *No Match* with genuine signature on file (takes 4 to 30 seconds)
  - Any *No Match* is sent to Manager (with more expertise) to determine if should it be cured or not
- Curing includes review by bipartisan teams & contacting voter to determine if *No Match* Initial Review is a "Bad Signature" or a *Match*

# Results of Signature Verification In Maricopa County

## 2020 General Election

| | |
|---|---|
| **Total Number of Voters Submitting EVBs** | **1,911,918** |
| **Maximum Number of EVBS that Were Cured by Maricopa** | **25,000*** |
| Percentage Cured as a Total of All EVBs | 1.31% |
| **EVBs Determined to be "Bad Signatures" AFTER Curing** | **587** |
| Percentage "Bad Signatures" as a Total of All EVBs | 0.031% |
| Percentage "Bad Signatures" as a Total of EVBs Cured | 2.3% |

*County reported "upwards of 25,000" were cured. EchoMail in its earlier report [4] presented to the Arizona State Senate that it uncovered 17,322 duplicate EVB envelope images from17,126 unique voters. The County stated these duplicate images were an artifact of the curing process, which means that 17,126 EVBs were cured. The County has yet to report the exact number of EVBs cured.

[4] Ayyadurai, Shiva, "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," Presented to AZ State Senate, September 24, 2021.

# Methodology

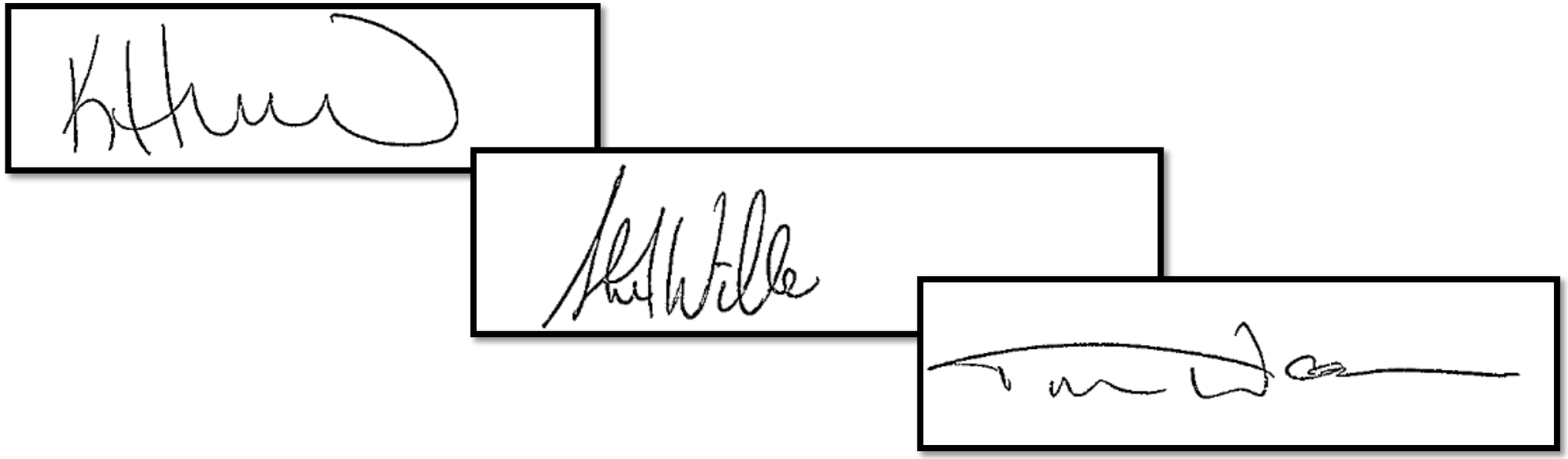
# Methodology

- **Step 1**: Select a representative statistical sample from population of 1,911,918 early voting mail ballots (EVBs) to have a **Confidence Level of 99%** and a **Margin of Error of ±2.5%;**

- To achieve this, a **Sample Size of 2,770** is selected

# Methodology

- **Step 2**: Organize a data set of 2,770 envelope signatures by random sampling of Maricopa's 1.9M+ EVB envelope images:



# Methodology

- **Step 3**: Create data set of 2,770 genuine signatures matching first, middle initial, and last name 2,770 envelope signatures:
  - Genuine signatures are sourced from Maricopa's publicly accessible Deeds' repository
  - 2,770 Deeds' genuine signatures are extracted
  - It should be noted that the source of genuine signatures used in this study may be different from source of genuine signatures used by County; however, experts in forensic document examination share that signatures from a Deeds repository may likely be more valid given such signatures are Notarized

**If the County provides the genuine signatures in their files for the 2,770 samples used herein, this Extended Study can be updated.**

# Methodology

- **Step 4**: Create pairwise dataset of 2,770 envelope signatures and 2,770 genuine signatures

**Signature on Mail Ballot Envelope**

**Genuine Signature**

  - Reviewer is given TWO choices: ***Match*** or ***No Match***

# Methodology

- **Step 5**: Given the County did not provide their signatures on file to EchoMail, additional constraints are applied to remove non-genuine signatures in the Deeds repository from the original 2,770 data set. These constraints are: 1) restrictions on name matching; and, 2) removal of pairwise signatures classified as ***No Match*** by ALL six reviewers as these are assumed **conservatively not** be a ***No Match*** but rather an error in the signature acquired from the Deeds repository.
- Relative to (1), a combination of technology and human is employed to assess if the person in Deeds repository is the person on the EVB envelope. This is done by matching the first name, middle name/initial, and last name and address when needed and if possible. The middle initial is essential to match (along with first and last name). Close review was performed on the middle name/initial match. When that match is found to be correct, it is accepted; otherwise, the address is then checked. If the address does not match, then the signature is not used.

# Analysis A: Initial Set of 2,770 Samples

# Experiment I

## Determination of Signature Mismatching Rates of EVBs Using Experts - Forensic Document Examiners (FDEs)

# Experiment I

## Experts: Forensic Document Examiners (FDEs)

- Three FDEs were recruited and asked to apply their training
- Presented 2,770 pairwise images to review for no more than 30 sec
- Recorded each FDEs **Match** and **No Match** selections
- Calculate **FDEs Pooled Consensus Signature Mismatch** rate

# Experiment I

## Experts: Forensic Document Examiners (FDEs)

"Pooled Consensus" means the probability out of how many times among ALL three FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.

# Experiment I

## Experts: Forensic Document Examiners (FDEs)

- Three FDEs were recruited and asked to apply their training
- Presented 2,770 pairwise images to review for no more than 30 sec
- Step 1: Record each FDEs **Match** and **No Match** selections
- Step 2: Calculate **FDEs Pooled Consensus Signature Mismatch** rate
  - For each pairwise signature set, across the 2,770 pairwise images, calculate the probability that a FDE concludes it is a mismatch
  - Determine the distribution of probabilities
  - Determine the mean of the probabilities across the 2,770 to determine the FDEs pooled consensus signature mismatch rate

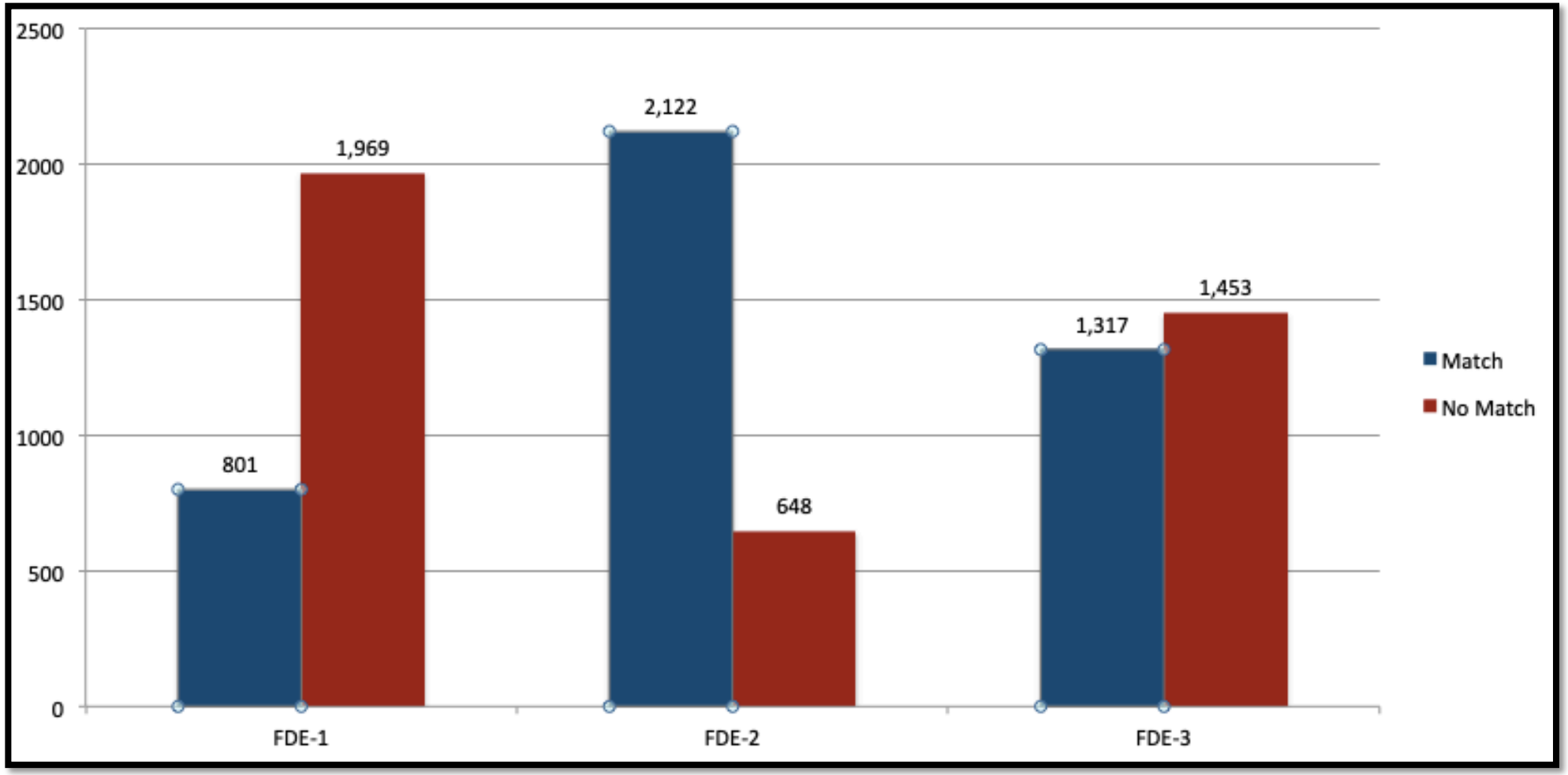
# Experiment I

## Step 1 Results: Match and No Match Counts for FDEs

| FDEs | Match | No Match | Signature Mismatch Rate (%) |
|---|---|---|---|
| FDE-1 | 801 | 1,969 | 71.1% |
| FDE-2 | 2,122 | 648 | 23.4% |
| FDE-3 | 1,317 | 1,453 | 52.5% |

# Experiment I

## Step 1 Results: Match and No Match Counts for FDEs





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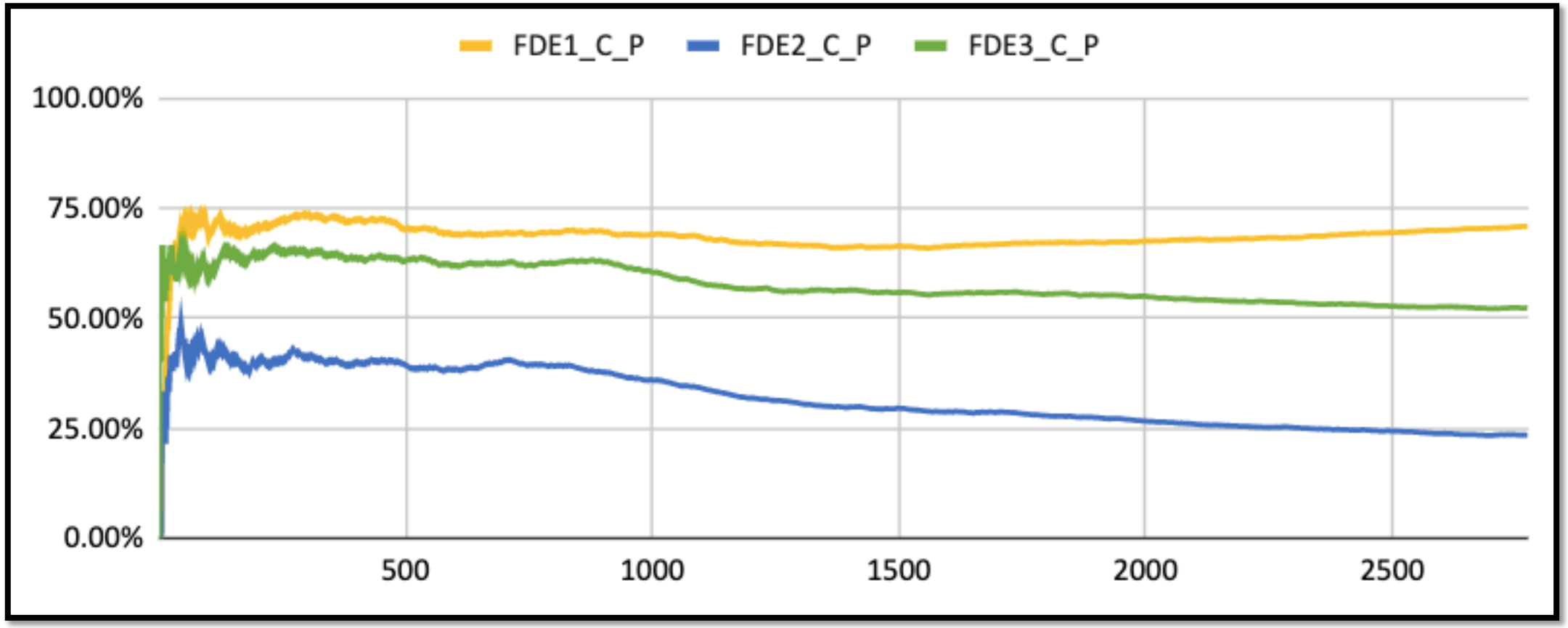
# Experiment I

## Step 1 Results: Temporal Match and No Match Counts of FDEs





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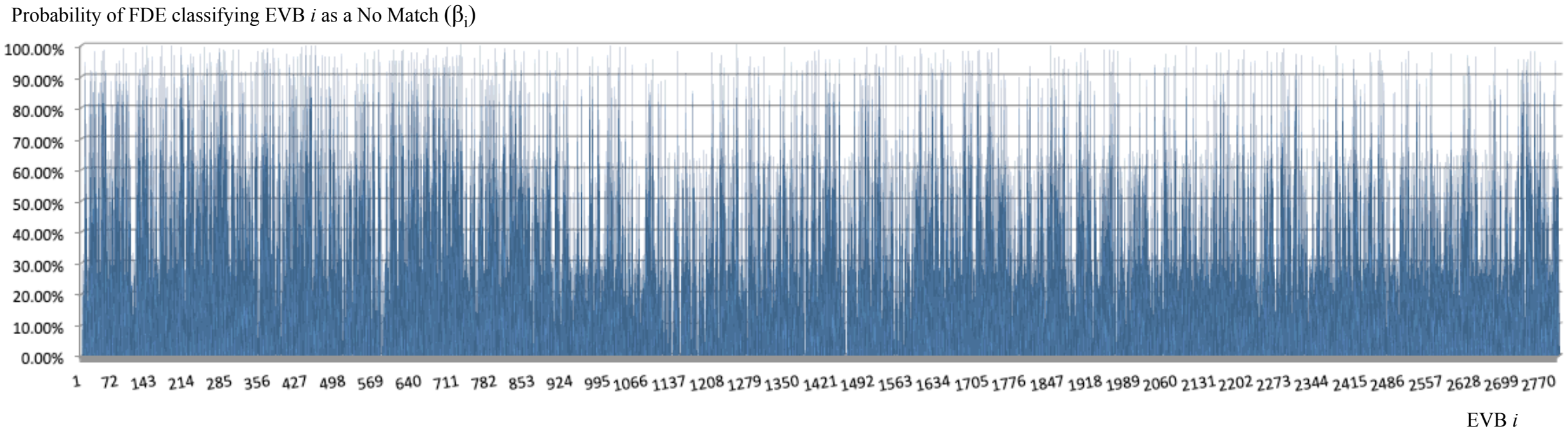
# Experiment I

## Step 2 Results: Probability of an FDE classifying a particular EVB as mismatch*




*Each bar denotes the "pooled consensus" –the probability out of how many times among ALL three FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.





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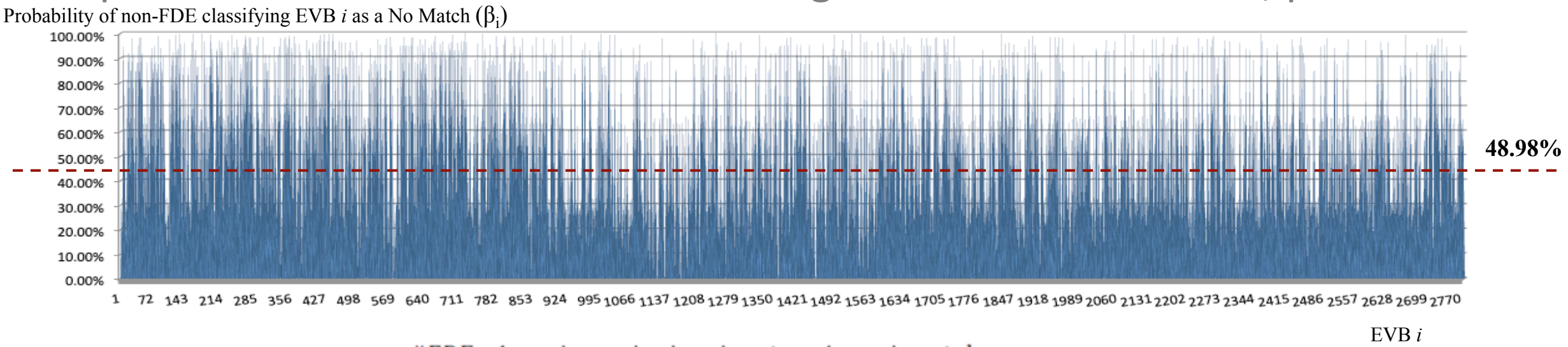
# Experiment I

## Step 2 Results: FDE Pooled Consensus Signature Mismatch Rate, β = 48.98%

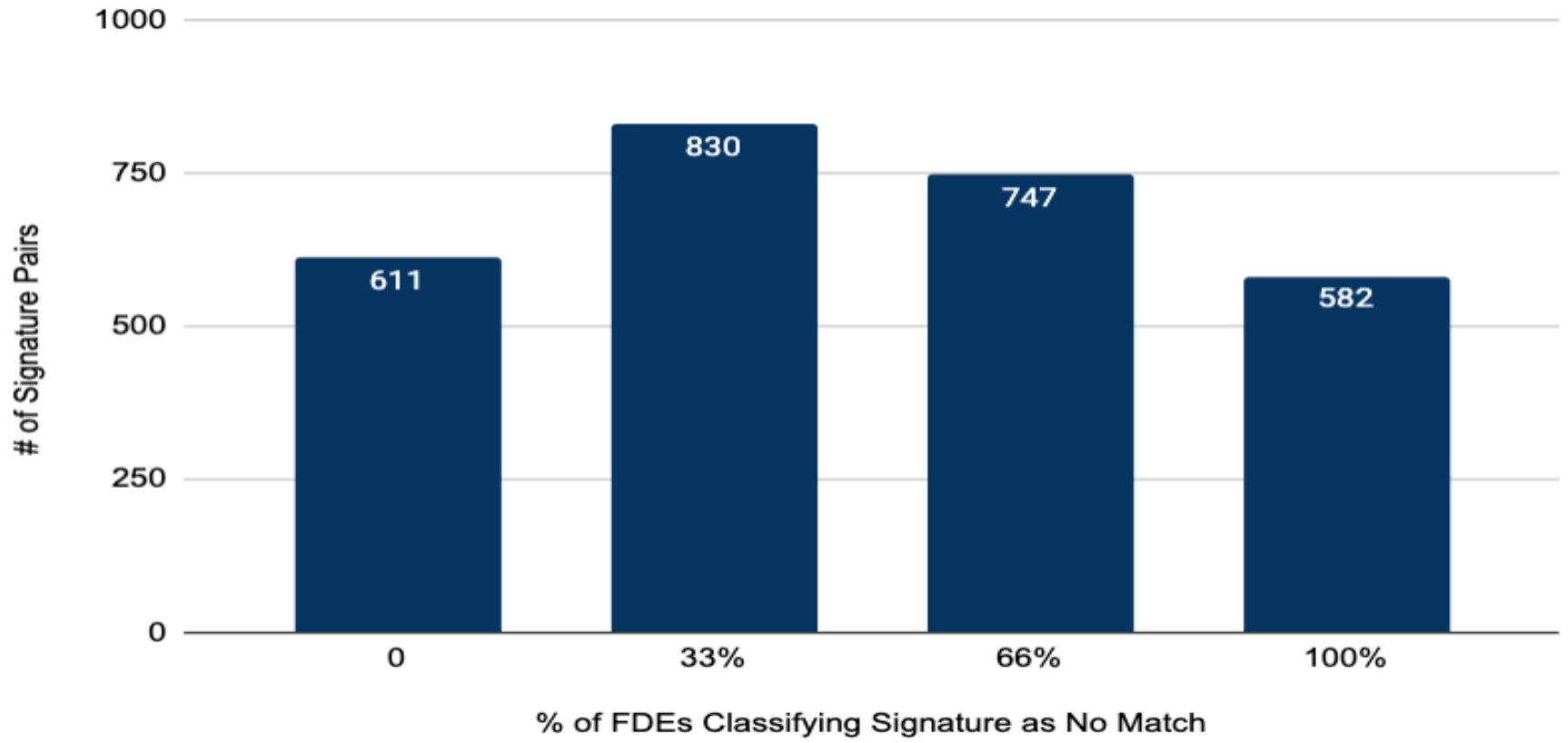



$$\beta_i = \frac{\#FDEs\ Agreeing\ pairwise\ signature\ is\ a\ mismatch}{3}$$

$$\beta = \frac{1}{2770}\sum_{i=1}^{2770}\beta_i \quad = \mathbf{48.98\%}$$

# Experiment I

Step 2 Results: Grouping of Pooled Consensus Probabilities of FDEs by Counts of Signature Pairs





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# Experiment I

## Result: FDEs Would Have Flagged 936,457 EVBs for Curing

| | |
|---|---|
| **Total Number of Voters Submitting EVBs** | **1,911,918** |
| **Maricopa Mismatch Rate Before Curing** | **1.31%** |
| Maximum Number of EVBs Actually Cured | 25,000 |
| | |
| **FDEs Pooled Consensus Signature Mismatch Rate** | **48.98%** |
| Number of EVBs That Should Have Been Cured | 936,457 |

# Experiment II

## Determination of Signature Mismatching Rates of EVBs Using Trained Novices – non-Forensic Document Examiners (non-FDEs)

# Experiment II

## Trained Novices: non-FDEs (non-Forensic Document Examiners)

- Three non-FDEs were given the County's Signature Verification Guide[5]:


[5] Maricopa County Elections Department, "Signature Verification Training," Powerpoint Presentation.

# Experiment II

## Trained Novices: non-Forensic Document Examiners (non-FDEs)

- Three non-FDEs were recruited and asked to apply their training
- Presented 2,770 pairwise images to review for no more than 30 sec
- Recorded each non-FDEs **Match** and **No Match** selections
- Calculate **non-FDEs Pooled Consensus Signature Mismatch** rate

# Experiment II

## Trained Novices: non-Forensic Document Examiners (non-FDEs)

"Pooled Consensus" means the probability out of how many times among ALL three non-FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.

# Experiment II

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- Step 1: Record each non-FDEs **Match** and **No Match** selections
- Step 2: Calculate non-**FDEs Pooled Consensus Signature Mismatch** rate
  - For each pairwise signature set, across the 2,770 pairwise images, calculate the probability that a non-FDEs concludes it is a mismatch
  - Determine the distribution of probabilities
  - Determine the mean of the probabilities across the 2,770 to determine the non-FDEs pooled consensus signature mismatch rate

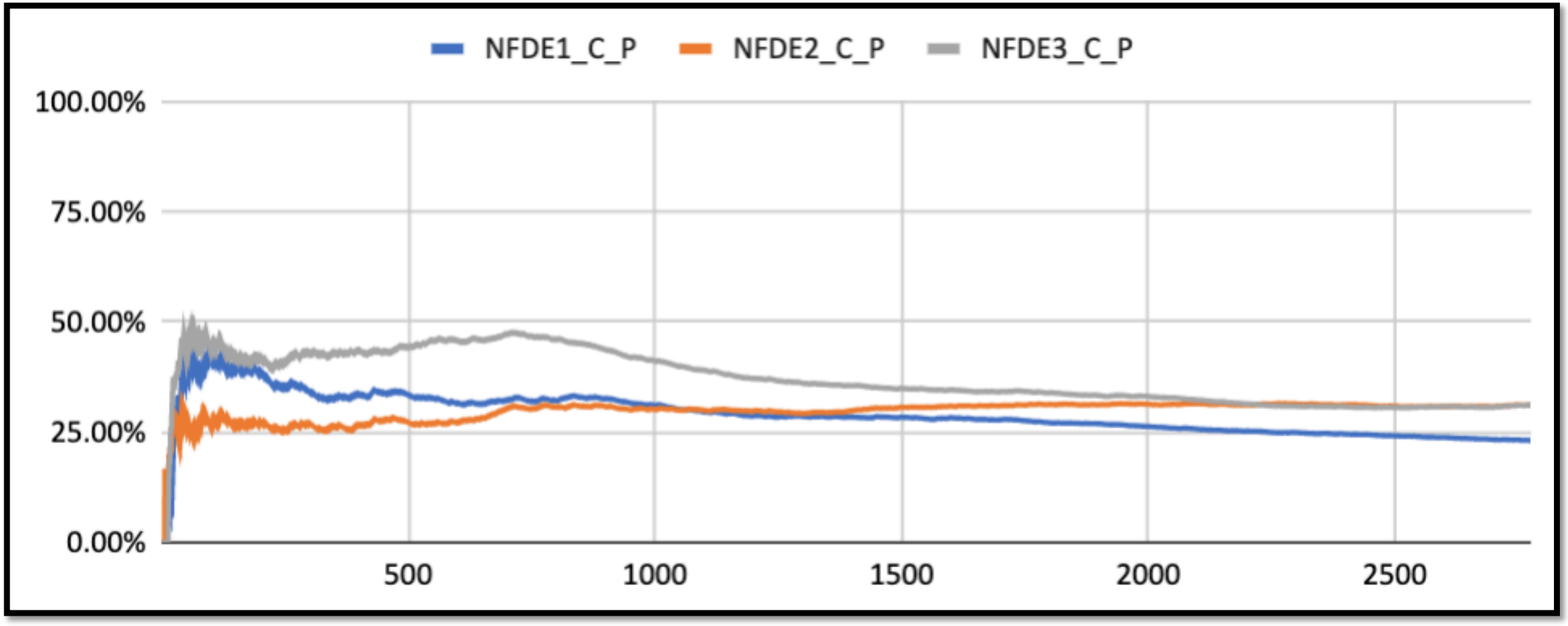
# Experiment II

## Step 1 Results: Match and No Match Counts for non-FDEs

| Non-FDEs | Match | No Match | Signature Mismatch Rate (%) |
|---|---|---|---|
| non-FDE-1 | 2,129 | 641 | 23.1% |
| non-FDE-2 | 1,906 | 864 | 31.2% |
| non-FDE-3 | 1,907 | 863 | 31.2% |

# Experiment II

## Step 1 Results: Temporal Match and No Match Counts of non-FDEs




31.2%

23.1%





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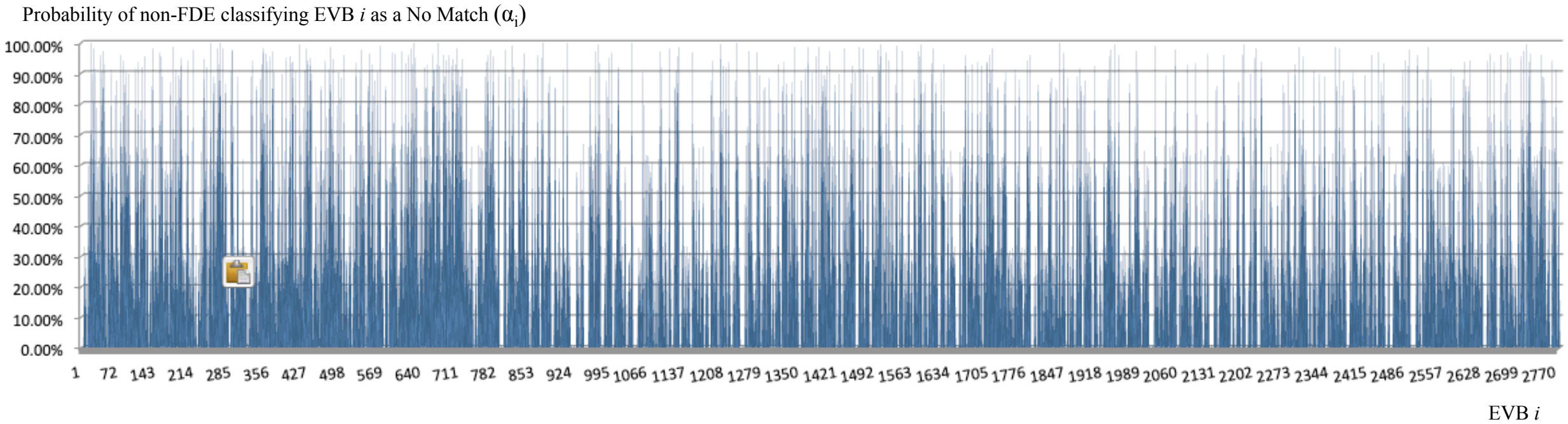
# Experiment II

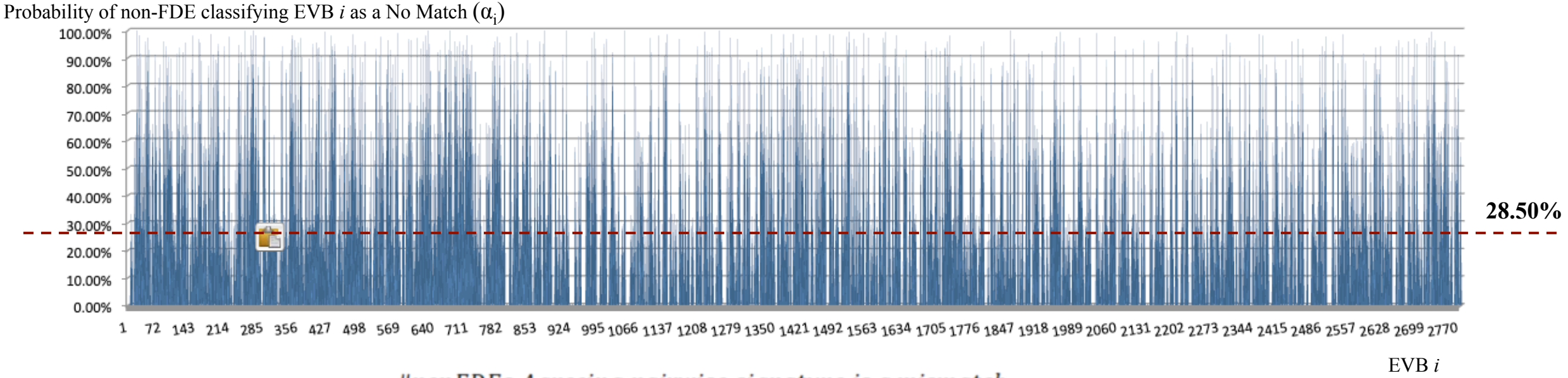
## Step 2 Results: Probability of an non-FDE classifying a particular EVB as mismatch*




*Each bar denotes the "pooled consensus" –the probability out of how many times among ALL three FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.

# Experiment II

## Step 2 Results: non-FDE Pooled Consensus Signature Mismatch Rate, α = 28.5%




$$\alpha_i = \frac{\#nonFDEs\ Agreeing\ pairwise\ signature\ is\ a\ mismatch}{3}$$

$$\alpha = \frac{1}{2770}\sum_{i=1}^{2770}\alpha_i = \mathbf{28.50\%}$$





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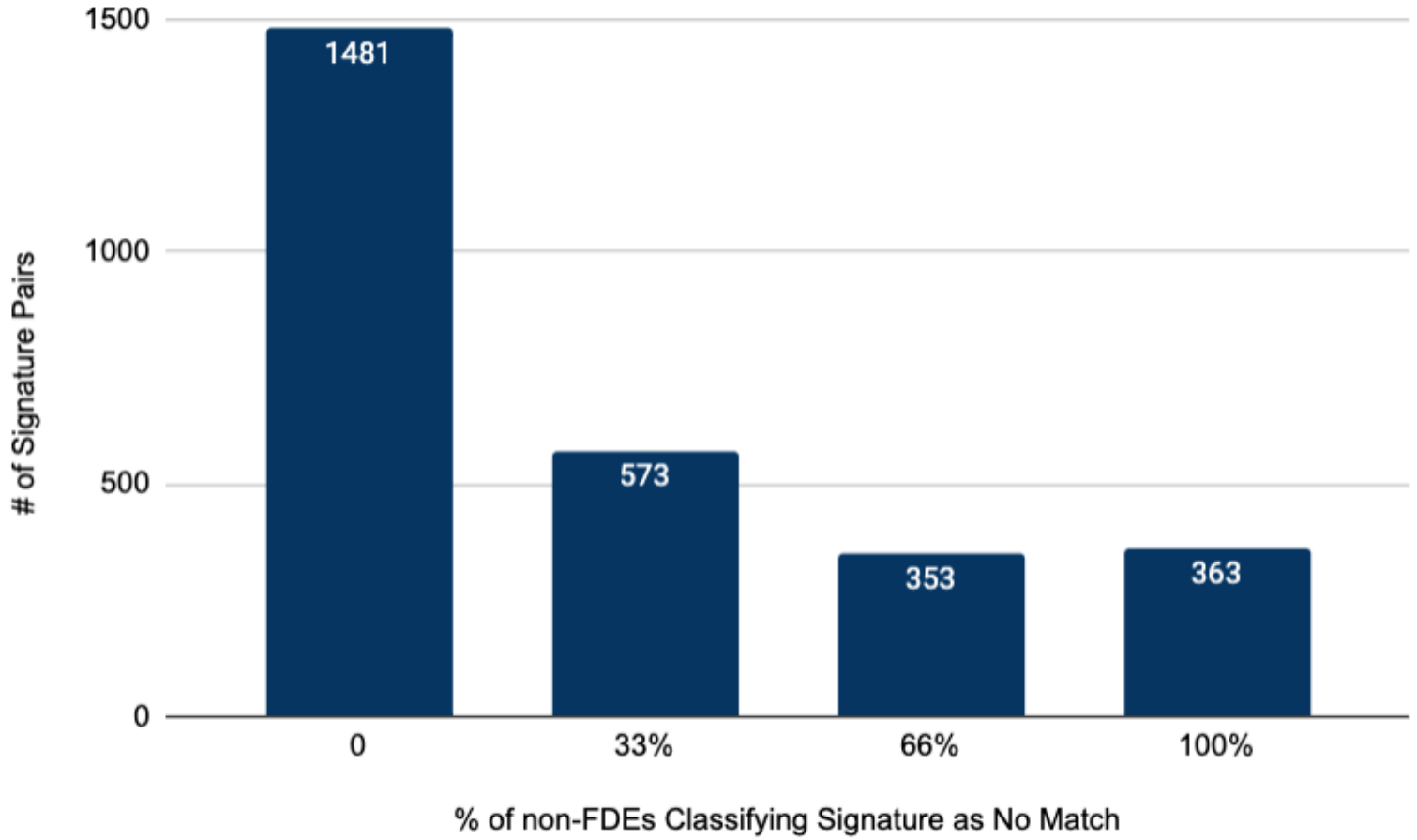
# Experiment II

Step 2 Results: Grouping of Pooled Consensus Probabilities of non-FDEs by Counts of Signature Pairs



# Experiment II

## Result: non-FDEs Would Have Flagged 544,897 EVBs for Curing

| | |
|---|---|
| **Total Number of Voters Submitting EVBs** | **1,911,918** |
| **Maricopa Mismatch Rate Before Curing** | **1.31%** |
| Maximum Number of EVBs Actually Cured | 25,000 |
| | |
| **non-FDE Pooled Consensus Signature Mismatch Rate** | **28.50%** |
| Number of EVBs That Should Have Been Cured | 544,897 |

# Determining Two-Step Review Signature Mismatch Rate

## First Trained Novices (non-FDEs) Review, Then Experts (FDEs)

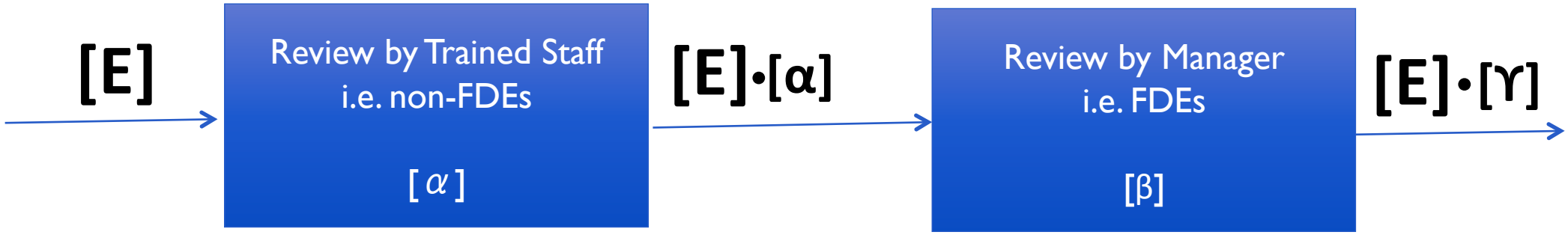
# Determining Two-Step Review Signature Mismatch Rate

- In Maricopa, the Initial Review involved Trained Staff first assessing pairwise signatures. If a ***No Match*** was detected by any one of them, the EVB was sent to a Manager with greater expertise to determine if indeed it was a ***No Match*** and needed to be cured.

- In this Study, the non-FDEs are assumed to be equivalent to the Trained Staff; and, the FDEs are assumed to be equivalent to the Manager.

# Determining Two-Step Review Signature Mismatch Rate

The goal is to determine the *two-step review signature mismatch rate, ϒ,* to determine the number of EVBs that would have been sent to curing after the two-step process.




Where: **[E]** is unit vector of size 2,770 representing the pairwise signatures reviewed by each non-FDE

**[α]** is a vector of the pooled consensus mismatch rates $\alpha_i$ for each $EVB_i$ for *i* = 1 to 2,770

**[E]•[α]** is the total number of EVBs classified as ***No Match*** by non-FDEs

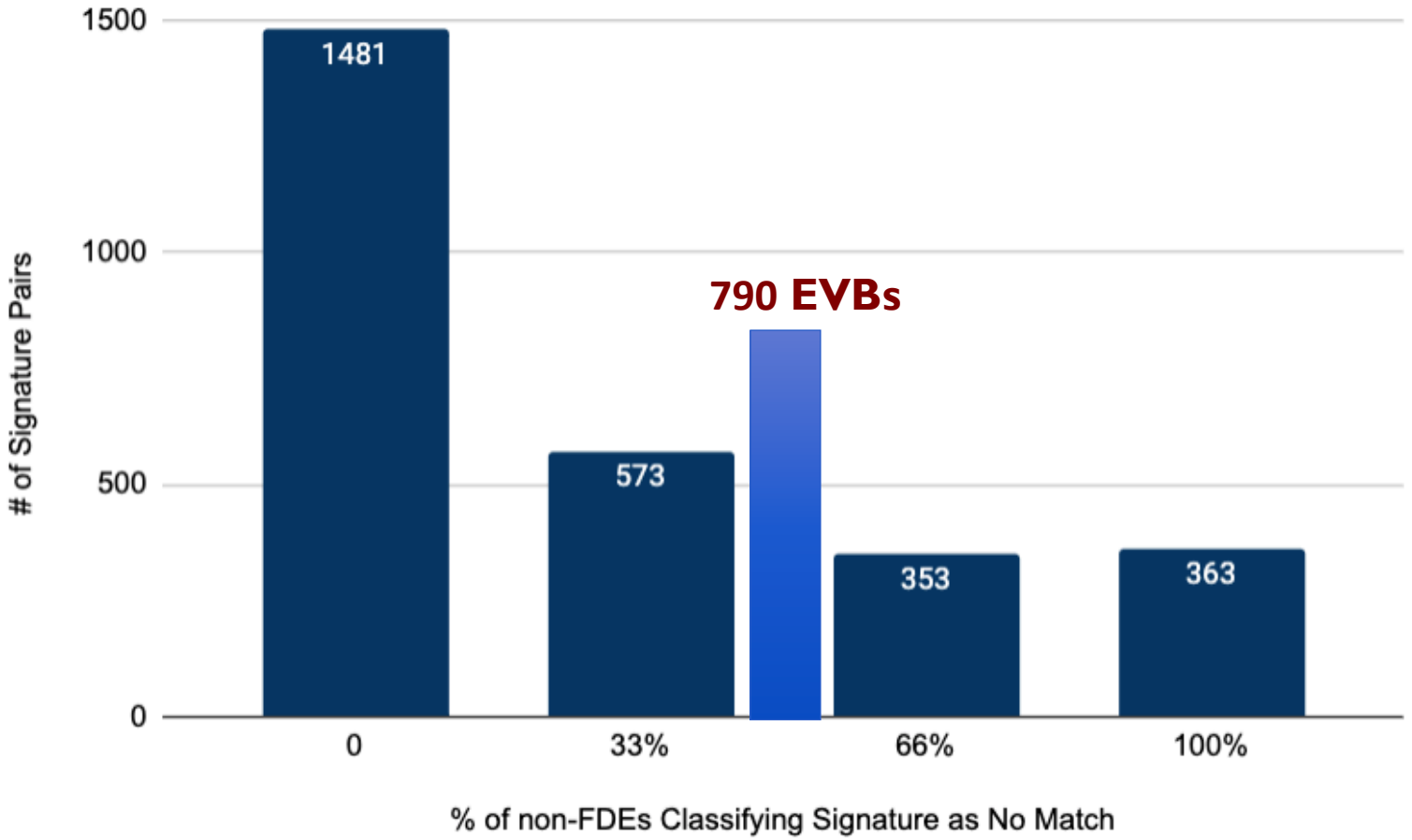
**[β]** is a vector of the pooled consensus mismatch rates $\beta_i$ for each $EVB_i$ for *i* = 1 to 2,770

**[ϒ]** is vector of joint probabilities **[α]x[β]** such that $\Upsilon_i$ is the joint probability that for $EVB_i$ the pooled consensus of FDEs classified it as ***No Match*** after pooled consensus non-FDEs classified as ***No Match***.

**[E]•[ϒ]** is the number of EVBs that the pooled consensus of FDEs classified as ***No Match*** after the pooled consensus of non-FDEs classified as ***No Match.***

# Calculation of EVBs Determined by non-FDEs to be No Match

## [E]•[α]




**[E]·[α]= 790 EVBs**

790 EVBs flagged as No Match by non-FDEs.





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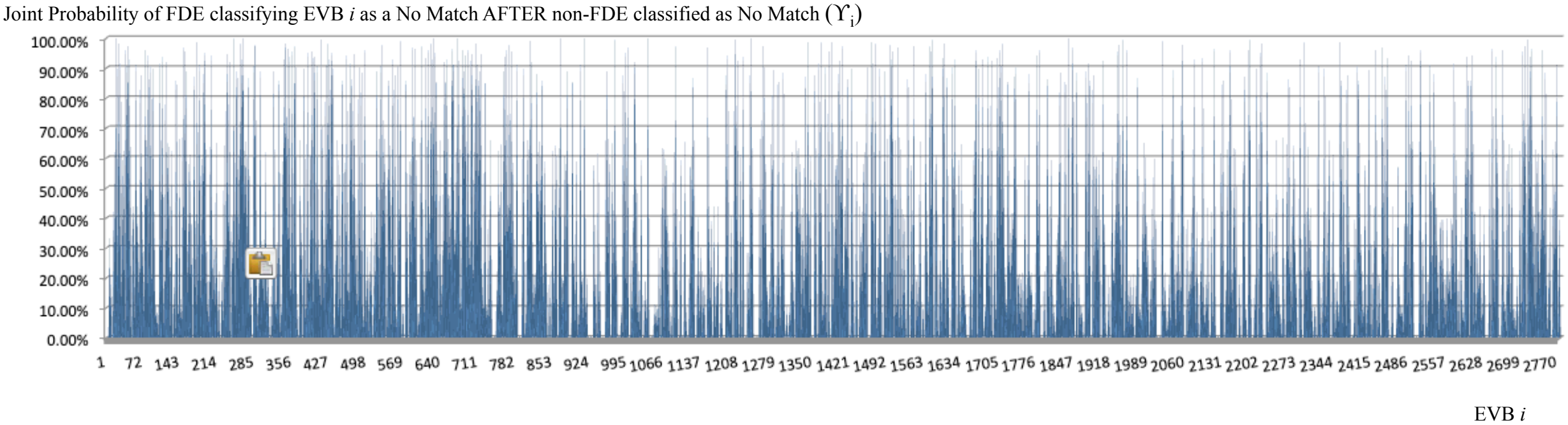
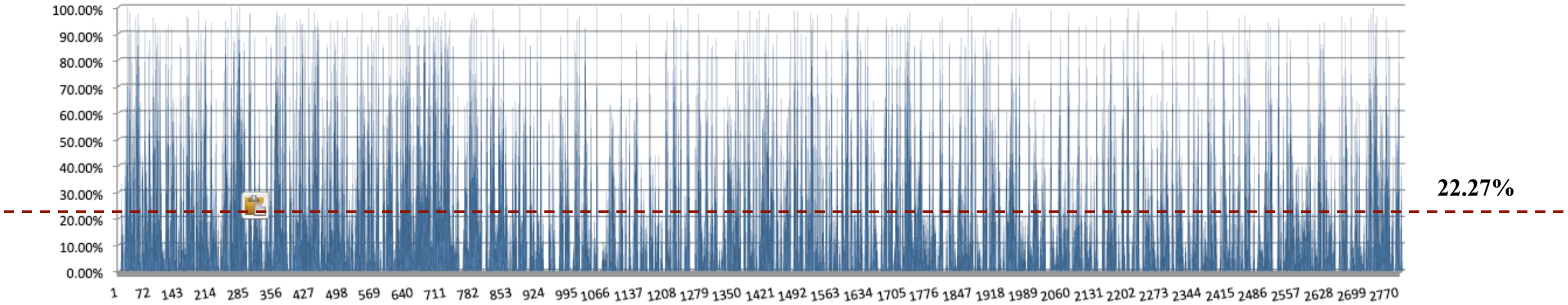
# Calculation of [ϒ] = [α] x [β], the Joint Probability
## Two-Step Review Signature Mismatch Rate



# Calculation of [ϒ] = [α] x [β], the Joint Probability

## Two-Step Review Signature Mismatch Rate

Joint Probability of FDE classifying EVB *i* as a No Match AFTER non-FDE classified as No Match ($\Upsilon_i$)

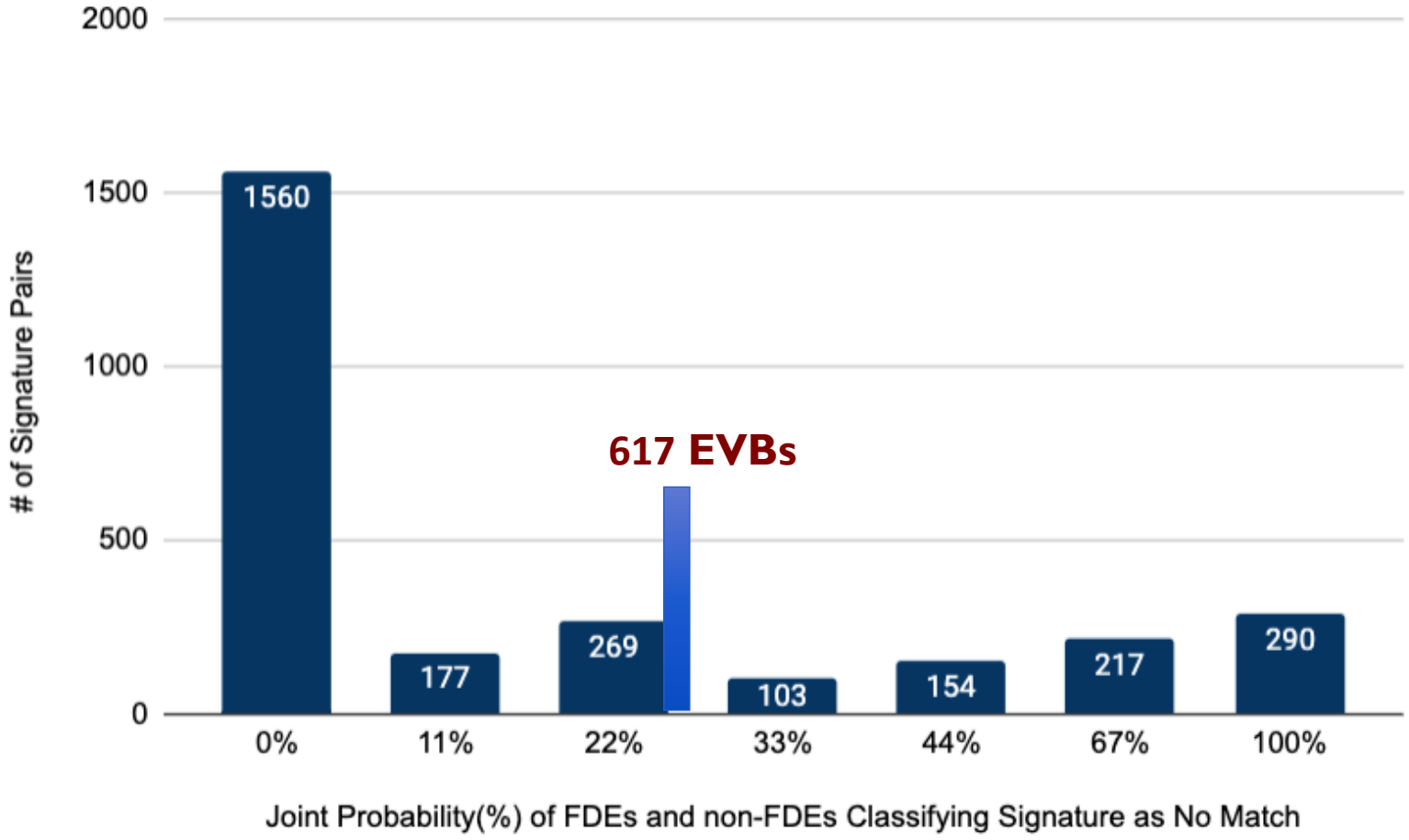



$$\gamma_i = \alpha_i * \beta_i$$

$$\gamma = \frac{1}{2770} \sum_{i=1}^{2770} \gamma_i \quad = 22.27\%$$

# Calculation of EVBs To Be Cured: [E]•[ϒ]

Use of Calculated Joint Probability ϒ to Determine Number of EVBs to Be Cured = 617 EVBs




**[E]·[ϒ]= 617 EVBs**

617 EVBs would be flagged for curing. These are the EVBs determined as as NO MATCH following FDE review of EVBs flagged by non-FDEs as NO MATCH.





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# Two-Step Review Signature Mismatch Rate

Result: non-FDEs Would Have Flagged 544,897 EVBs for Curing

| | |
|---|---|
| **Total Number of Voters Submitting EVBs** | **1,911,918** |
| **Maricopa Mismatch Rate Before Curing** | **1.31%** |
| Maximum Number of EVBs Actually Cured | 25,000 |
| | |
| **Two-Step Review Signature Mismatch Rate** | **22.27%** |
| Number of EVBs That Should Have Been Cured | 425,784 |

# Analysis A Summary

| Measures | Mismatch Rate (%) | EVBs to be Cured | Maximum Cured by Maricopa | EVBs to be Disallowed Post-Curing | Maricopa Disallowed Post-Curing |
|---|---|---|---|---|---|
| **Non-FDEs Pooled Consensus** Analysis A – Expt I | 28.50% | 544,897 | 25,000 | 12,533 | 587 |
| **FDEs Pooled Consensus** Analysis A - Expt II | 48.98% | 936,457 | 25,000 | 21,547 | 587 |
| **2-Step Pooled Consensus** Analysis A | 22.27% | 425,784 | 25,000 | 9,793 | 587 |

# Analysis A Summary

- If Experts - Forensic Document Examiners (FDEs) – alone were used to review the EVBs, then 936,457 EVBs should have been cured.
- If Trained Novices – non-FDEs – alone were used to review the EVBs, then 544,897 EVBs should have been cured.
- If non-FDEs and FDEs BOTH were used to review the EVB signatures in a two-step process (non-FDEs reviewing first, then FDEs), then 425,784 EVBs should have been cured.
- The original data for Analysis A including images is found in PDF:
  - Analysis-A-Extended-Study.pdf
- The original date for Analysis A not including images is found in the XLS file:
  - Analysis-A-Extended-Study.xls

# Additional Constraints for Updated Analysis

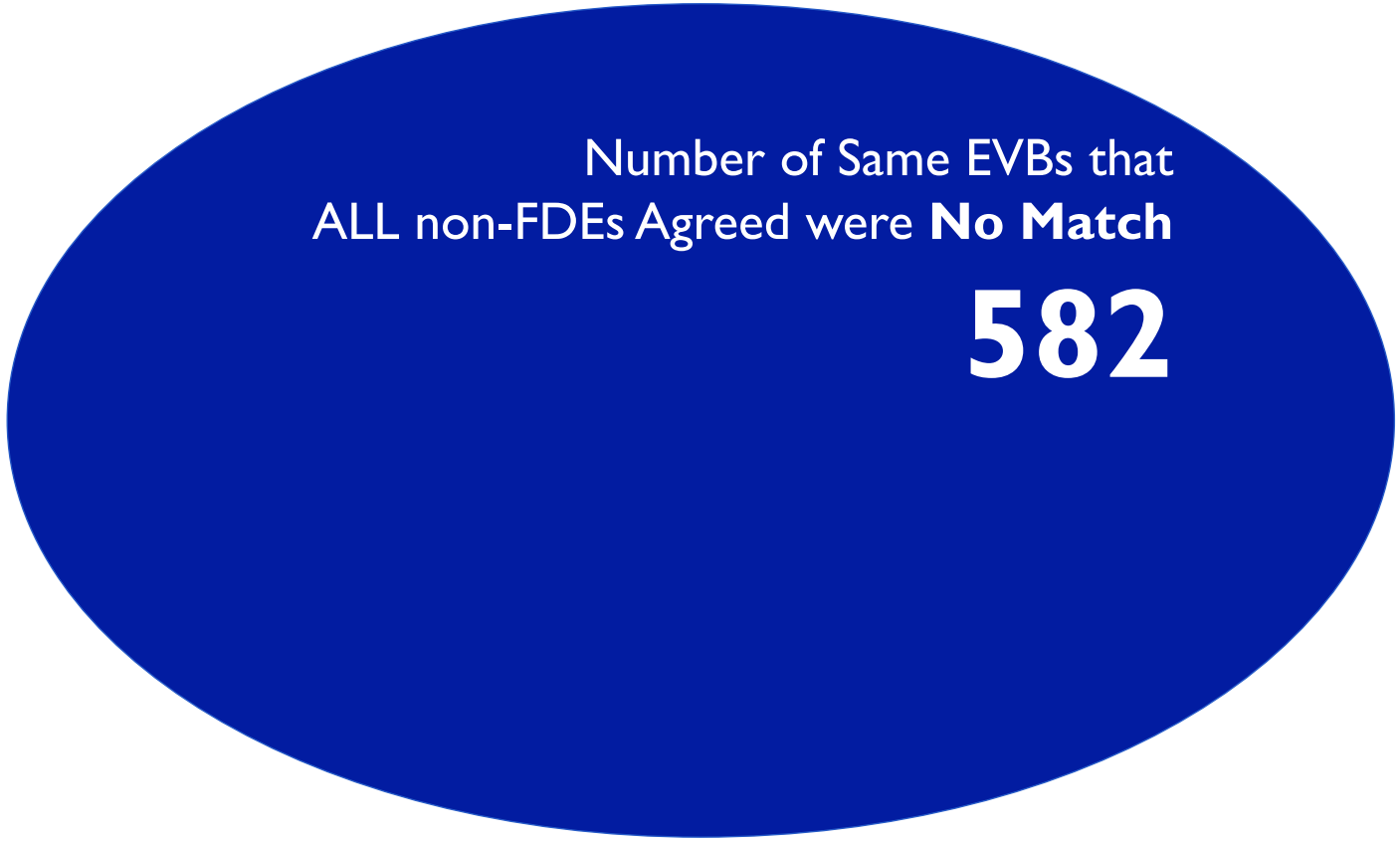
## Application of Constraints to Remove Pairwise Signatures That May Have Non-genuine Signatures from Deeds' Repository

# Updated Analysis With Additional Constraints

- Specifically, in this update:
  1) Additional constraints are applied to the original 2,770 data set with greater restrictions on the name matching of signatures acquired from the Deeds repository. **This removed 101 more pairwise signatures.**

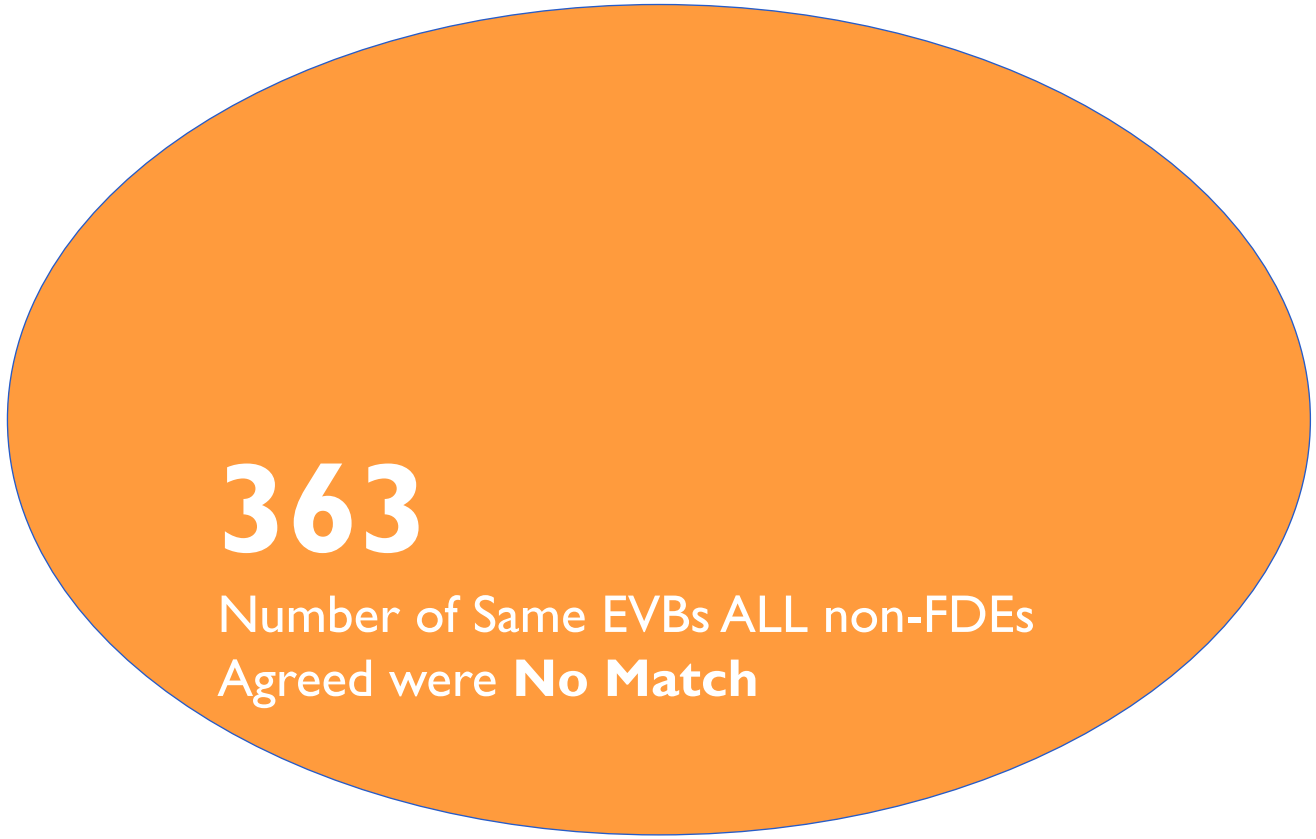
# Updated Analysis With Additional Constraints

## Determination of Number of EVBs ALL 6 Reviewers Flagged as NO MATCH



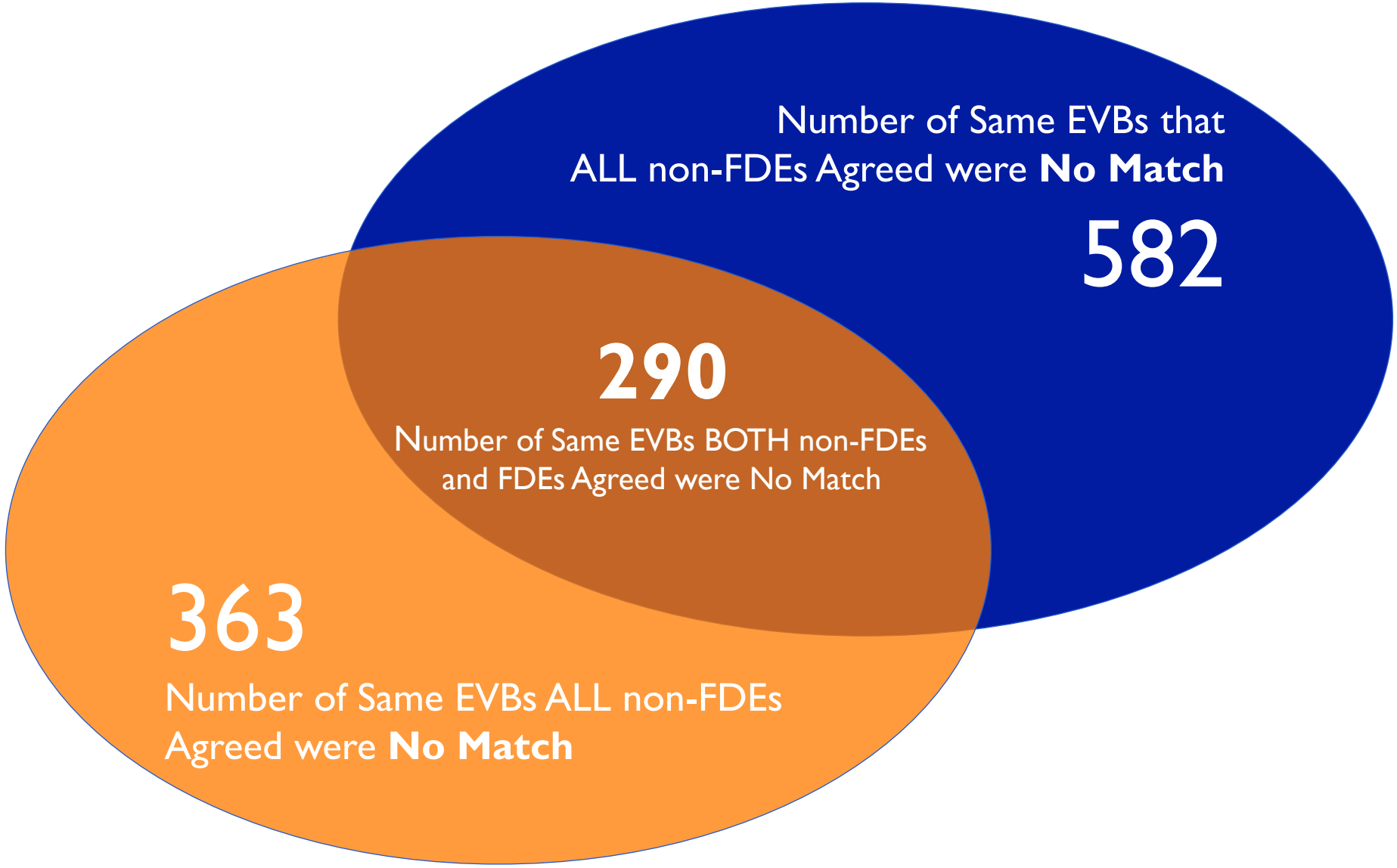
# Updated Analysis With Additional Constraints

## Determination of Number of EVBs ALL 6 Reviewers Flagged as NO MATCH



# Updated Analysis With Additional Constraints

## Determination of Number of EVBs ALL 6 Reviewers Flagged as NO MATCH





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# Updated Analysis With Additional Constraints

- Specifically, in this update:
  1) Additional constraints are applied to the original 2,770 data set with greater restrictions on the name matching of signatures acquired from the Deeds repository. This removed 101 more pairwise signatures
  2) ALL pairwise signatures (290) wherein ALL six reviewers classified them to be No Match are removed. When ALL six reviewers believe a set of pairwise signatures are NO MATCH, it could be one of two possibilities: the pair are indeed a NO MATCH or the genuine signature being used is not genuine. Herein, the latter possibility is applied across all the 290. This choice may lead to false negatives – pairwise sets with genuine signature being removed; however, it significantly reduces likely error i.e. the probability of this Study having signatures which are not genuine.
  3) After (1) & (2)**, 391 pairwise signatures were removed** from the original data set of 2,770 to create a new data set of 2,379.
  4) Relative to point (2), some examples of pairwise signatures that are false negatives, which were removed with a highly likely genuine signature from the 290 set are displayed in the next section.

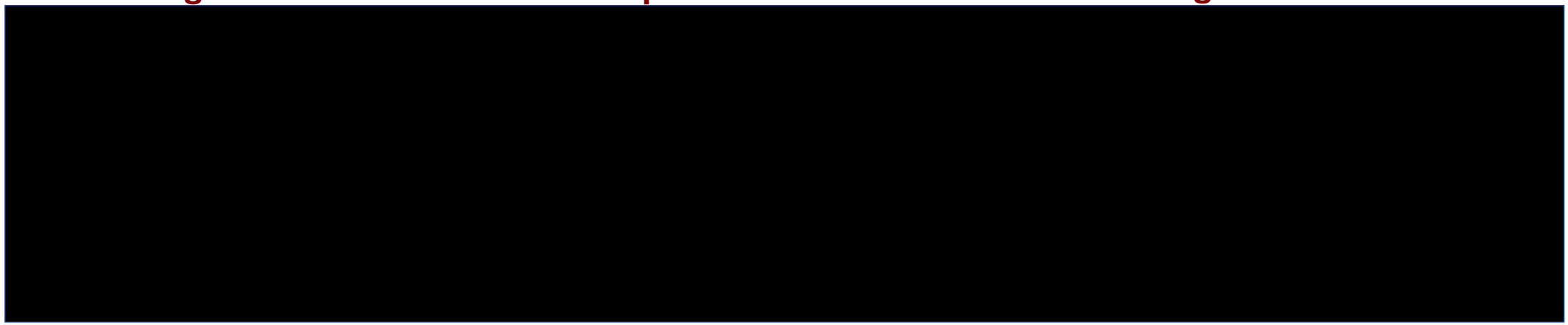
# Examples of False Negatives from 290 Set*

*The full set of 290 is in a PDF file named: No-Match-Set-of-290.pdf

# Example of False Negative

Pairwise Signature Removed from Set of 290 Where All 6 Reviewers Said No Match But the Genuine Signature appears to be genuine give first name, middle initial, last name, and address match

**Signature on Mail Ballot Envelope** | **Genuine Signature***

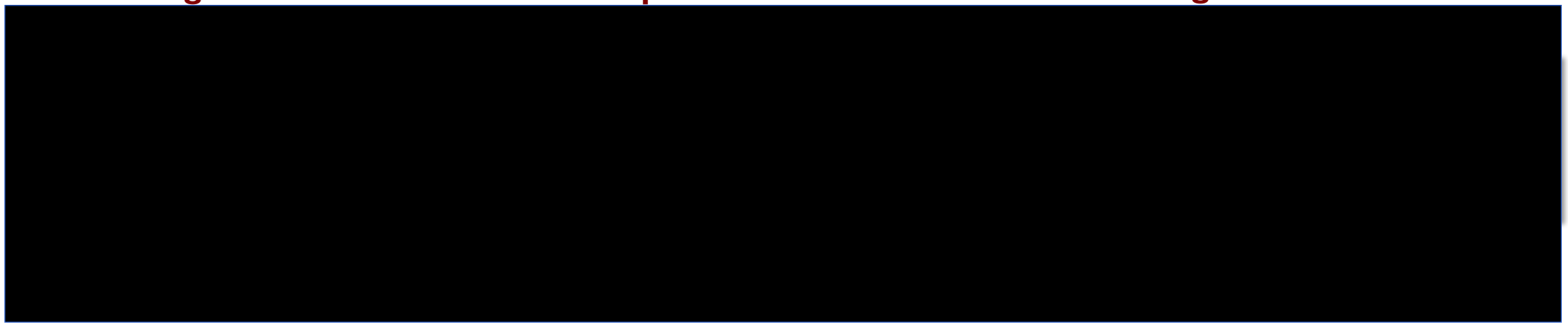


***For the genuine signature the first name, middle initial, last and address match.**

# Example of False Negative

Pairwise Signature Removed from Set of 290 Where All 6 Reviewers Said No Match But the Genuine Signature appears to be genuine give first name, middle initial, last name, and address match

**Signature on Mail Ballot Envelope** | **Genuine Signature***

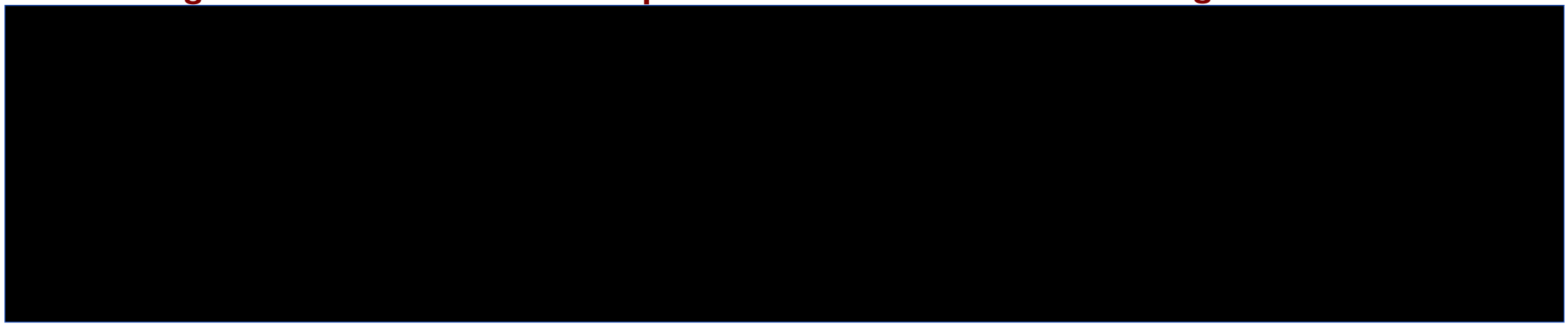


***For the genuine signature the first name, middle initial, last and address match.**

# Example of False Negative

Pairwise Signature Removed from Set of 290 Where All 6 Reviewers Said No Match But the Genuine Signature appears to be genuine give first name, middle initial, last name, and address match

**Signature on Mail Ballot Envelope** | **Genuine Signature***



***For the genuine signature the first name, middle initial, last and address match.**

# Summary of Updated Analysis Constraints

After application of the constraints 101 were removed for name matching exceptions and an additional 290 were removed for being flagged as NO MATCH by all six reviewers.

A total of 391 was removed from the 2,770 set reducing the sample size to 2,379.

This reduced sample size of 2,379 has a 99% Confidence Level so the real value would be within ±2.7% Margin of Error of the measured value.

The full set of 290 that were removed is in a PDF file named: No-Match-Set-of-290.pdf

# Analysis B: Reduce Set of 2,379 Samples

# Experiment I

## Determination of Signature Mismatching Rates of EVBs Using Experts - Forensic Document Examiners (FDEs)

# Experiment I

## Experts: Forensic Document Examiners (FDEs)

- Three FDEs were recruited and asked to apply their training
- Presented 2,379 pairwise images to review for no more than 30 sec
- Recorded each FDEs **Match** and **No Match** selections
- Calculate **FDEs Pooled Consensus Signature Mismatch** rate

# Experiment I

## Experts: Forensic Document Examiners (FDEs)

"Pooled Consensus" means the probability out of how many times among ALL three FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.

# Experiment I

## Experts: Forensic Document Examiners (FDEs)

- Three FDEs were recruited and asked to apply their training
- Presented 2,379 pairwise images to review for no more than 30 sec
- Step 1: Record each FDEs **Match** and **No Match** selections
- Step 2: Calculate **FDEs Pooled Consensus Signature Mismatch** rate
  - For each pairwise signature set, across the 2,379 pairwise images, calculate the probability that a FDE concludes it is a mismatch
  - Determine the distribution of probabilities
  - Determine the mean of the probabilities across the 2,379 to determine the FDEs pooled consensus signature mismatch rate

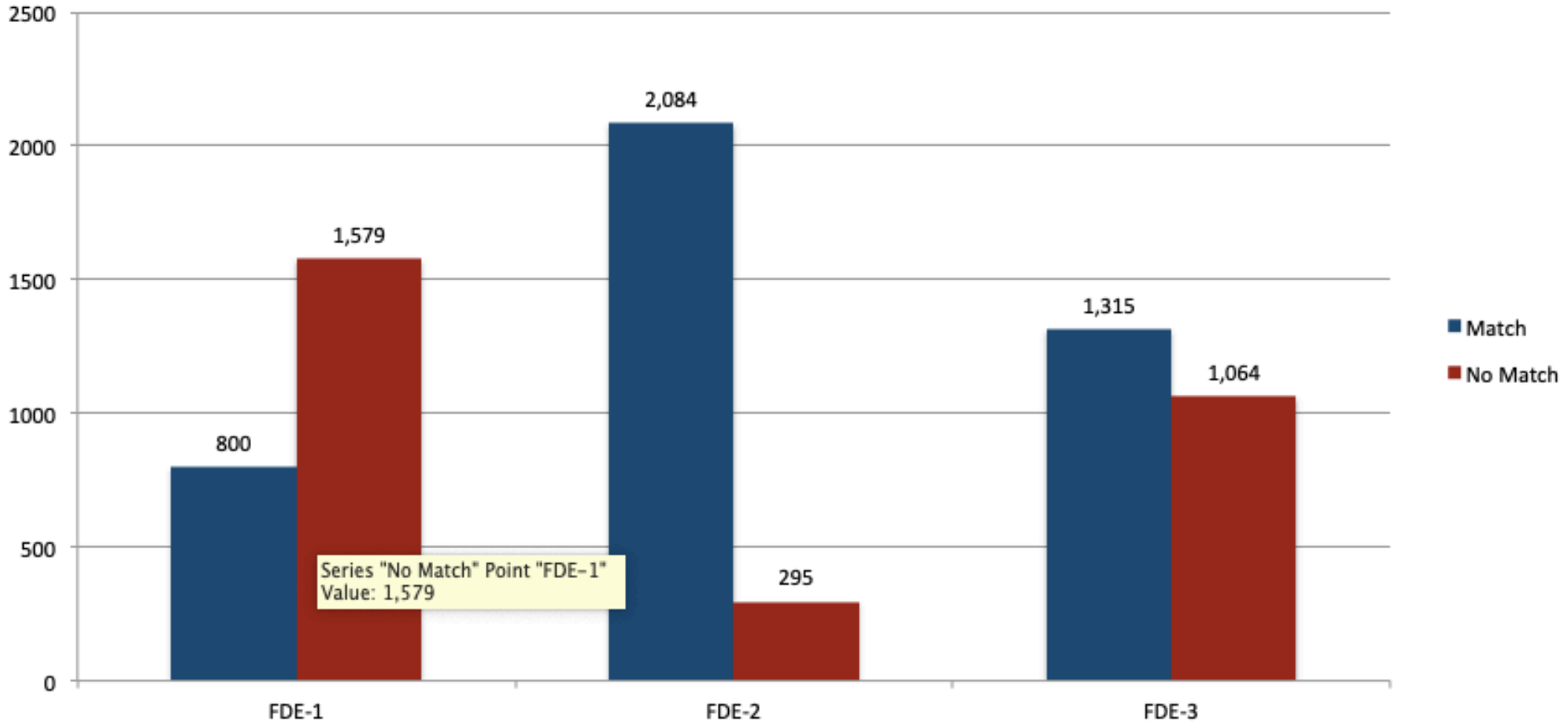
# Experiment I

## Step 1 Results: Match and No Match Counts for FDEs

| FDEs | Match | No Match | Signature Mismatch Rate (%) |
|---|---|---|---|
| FDE-1 | 800 | 1,579 | 66.4% |
| FDE-2 | 2,084 | 295 | 12.4% |
| FDE-3 | 1,315 | 1,064 | 44.7% |

# Experiment I

## Step 1 Results: Match and No Match Counts for FDEs





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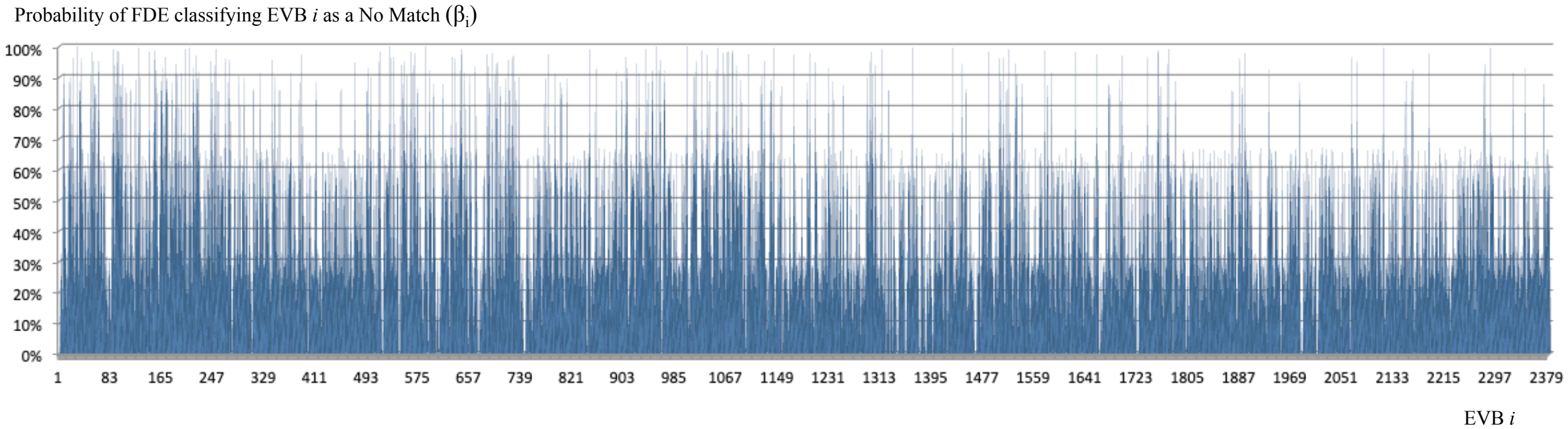
# Experiment I

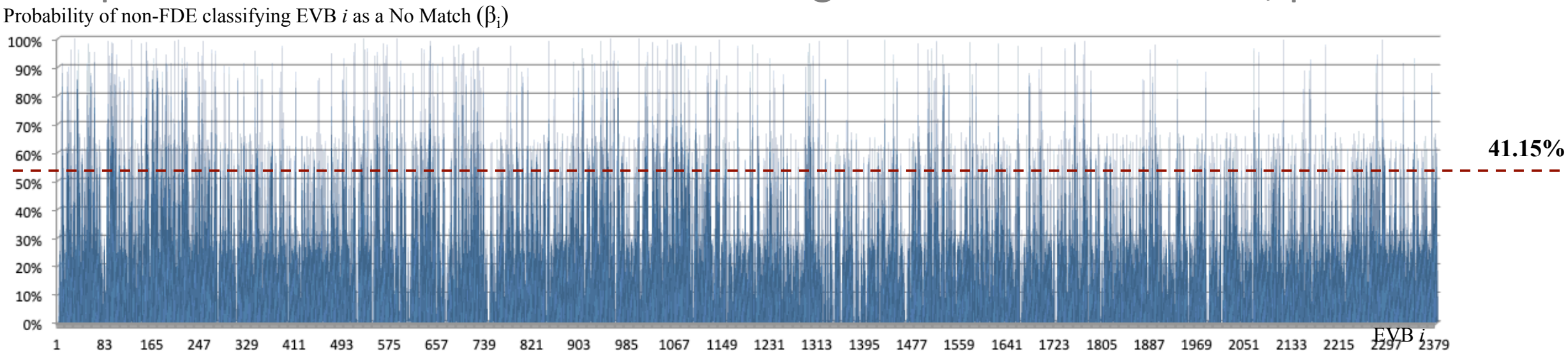
## Step 2 Results: Probability of an FDE classifying a particular EVB as mismatch*




*Each bar denotes the "pooled consensus" –the probability out of how many times among ALL three FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.

# Experiment I

## Step 2 Results: FDE Pooled Consensus Signature Mismatch Rate, β = 41.15%

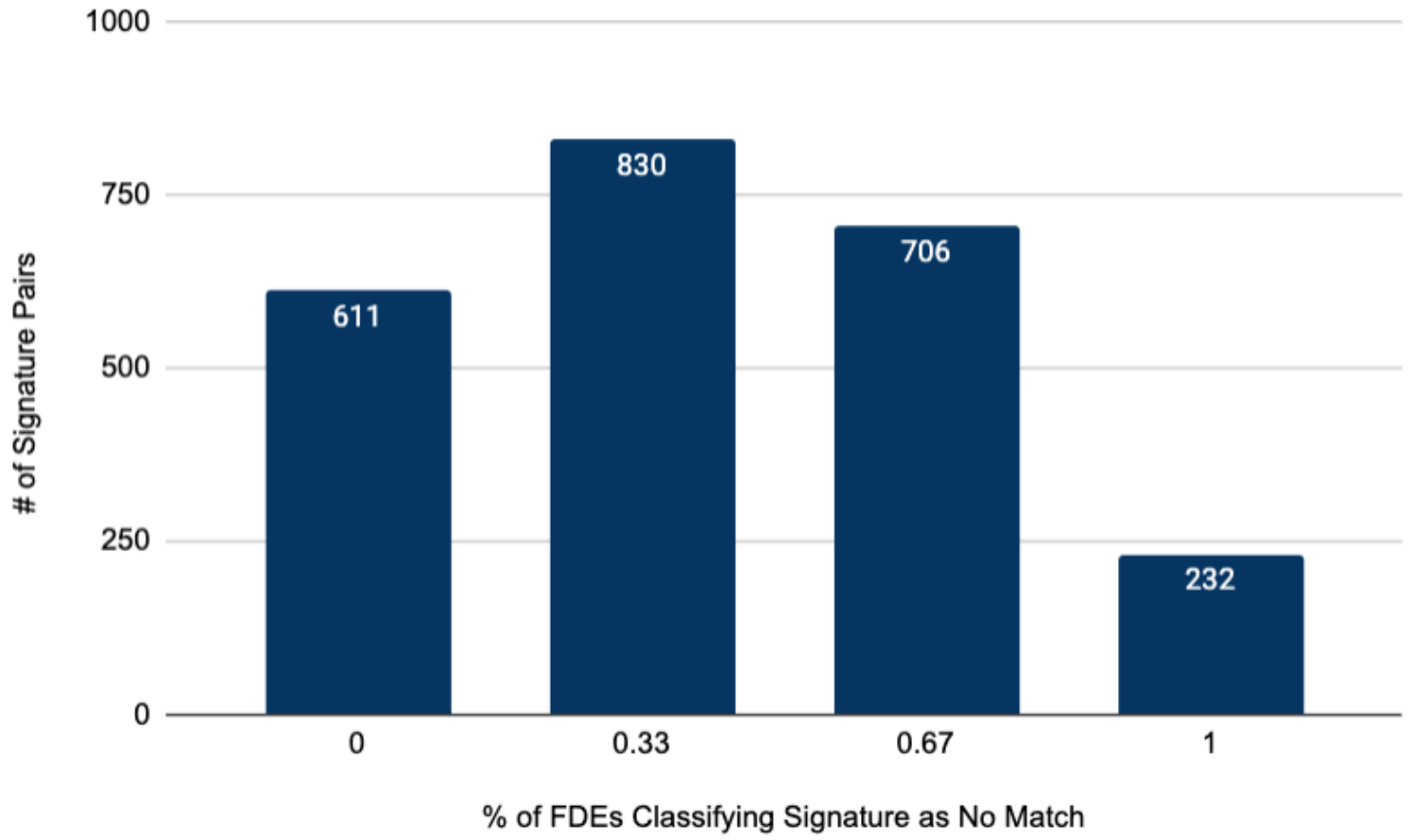



$$\beta_i = \frac{\#FDEs\ Agreeing\ pairwise\ signature\ is\ a\ mismatch}{3}$$

$$\beta = \frac{1}{2379}\sum_{i=1}^{2379}\beta_i \quad = \mathbf{41.15\%}$$

# Experiment I

Step 2 Results: Grouping of Pooled Consensus Probabilities of FDEs by Counts of Signature Pairs



# Experiment I

## Result: FDEs Would Have Flagged 786,753 EVBs for Curing

| | |
|---|---|
| **Total Number of Voters Submitting EVBs** | **1,911,918** |
| **Maricopa Mismatch Rate Before Curing** | **1.31%** |
| Maximum Number of EVBs Actually Cured | 25,000 |
| | |
| **FDEs Pooled Consensus Signature Mismatch Rate** | **41.15%** |
| Number of EVBs That Should Have Been Cured | 786,753 |

# Experiment II

## Determination of Signature Mismatching Rates of EVBs Using Trained Novices – non-Forensic Document Examiners (non-FDEs)

# Experiment II

## Trained Novices: non-FDEs (non-Forensic Document Examiners)

- Three non-FDEs were given the County's Signature Verification Guide[5]:


[5] Maricopa County Elections Department, "Signature Verification Training," Powerpoint Presentation.

# Experiment II

## Trained Novices: non-Forensic Document Examiners (non-FDEs)

- Three non-FDEs were recruited and asked to apply their training
- Presented 2,379 pairwise images to review for no more than 30 sec
- Recorded each non-FDEs **Match** and **No Match** selections
- Calculate **non-FDEs Pooled Consensus Signature Mismatch** rate

# Experiment II

## Trained Novices: non-Forensic Document Examiners (non-FDEs)

"Pooled Consensus" means the probability out of how many times among ALL three FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.

# Experiment II

## Trained Novices: non-Forensic Document Examiners (non-FDEs)

- Three non-FDEs were recruited and asked to apply their training
- Presented 2,379 pairwise images to review for no more than 30 sec
- Step 1: Record each non-FDEs **Match** and **No Match** selections
- Step 2: Calculate non-**FDEs Pooled Consensus Signature Mismatch** rate
  - For each pairwise signature set, across the 2,770 pairwise images, calculate the probability that a non-FDEs concludes it is a mismatch
  - Determine the distribution of probabilities
  - Determine the mean of the probabilities across the 2,770 to determine the non-FDEs pooled consensus signature mismatch rate

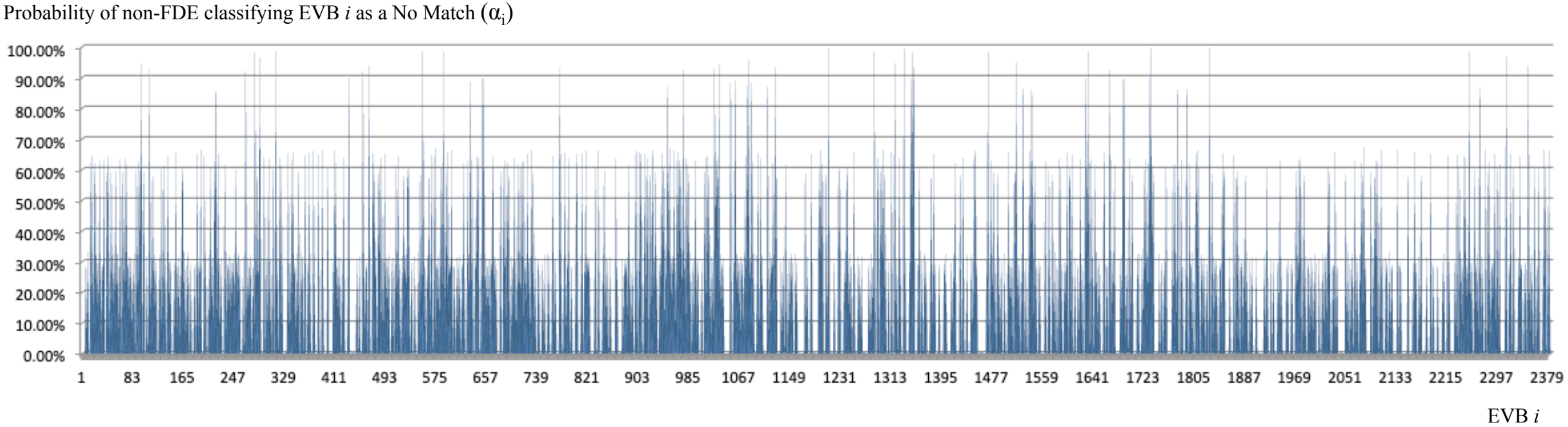
# Experiment II

## Step 1 Results: Match and No Match Counts for non-FDEs

| Non-FDEs | Match | No Match | Signature Mismatch Rate (%) |
|---|---|---|---|
| non-FDE-1 | 2,078 | 301 | 12.7% |
| non-FDE-2 | 1,899 | 480 | 20.2% |
| non-FDE-3 | 1,871 | 508 | 21.4% |

# Experiment II

## Step 2 Results: Probability of an non-FDE classifying a particular EVB as mismatch*

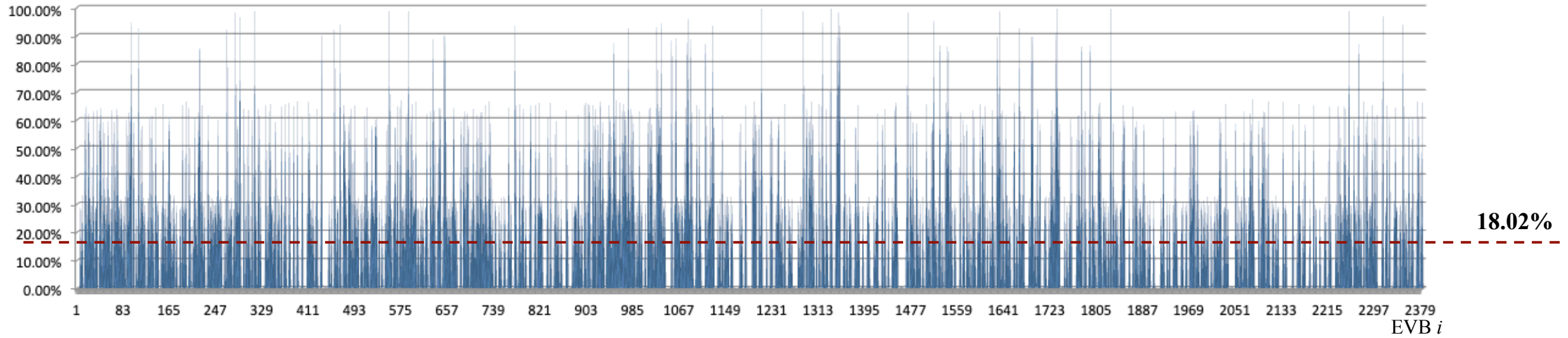



*Each bar denotes the "pooled consensus" –the probability out of how many times among ALL three FDEs that the same pair of signatures associated with an EVB is concluded to be a Match or a No Match.

# Experiment II

## Step 2 Results: non-FDE Pooled Consensus Signature Mismatch Rate, α = 18.02%

Probability of non-FDE classifying EVB *i* as a No Match ($\alpha_i$)

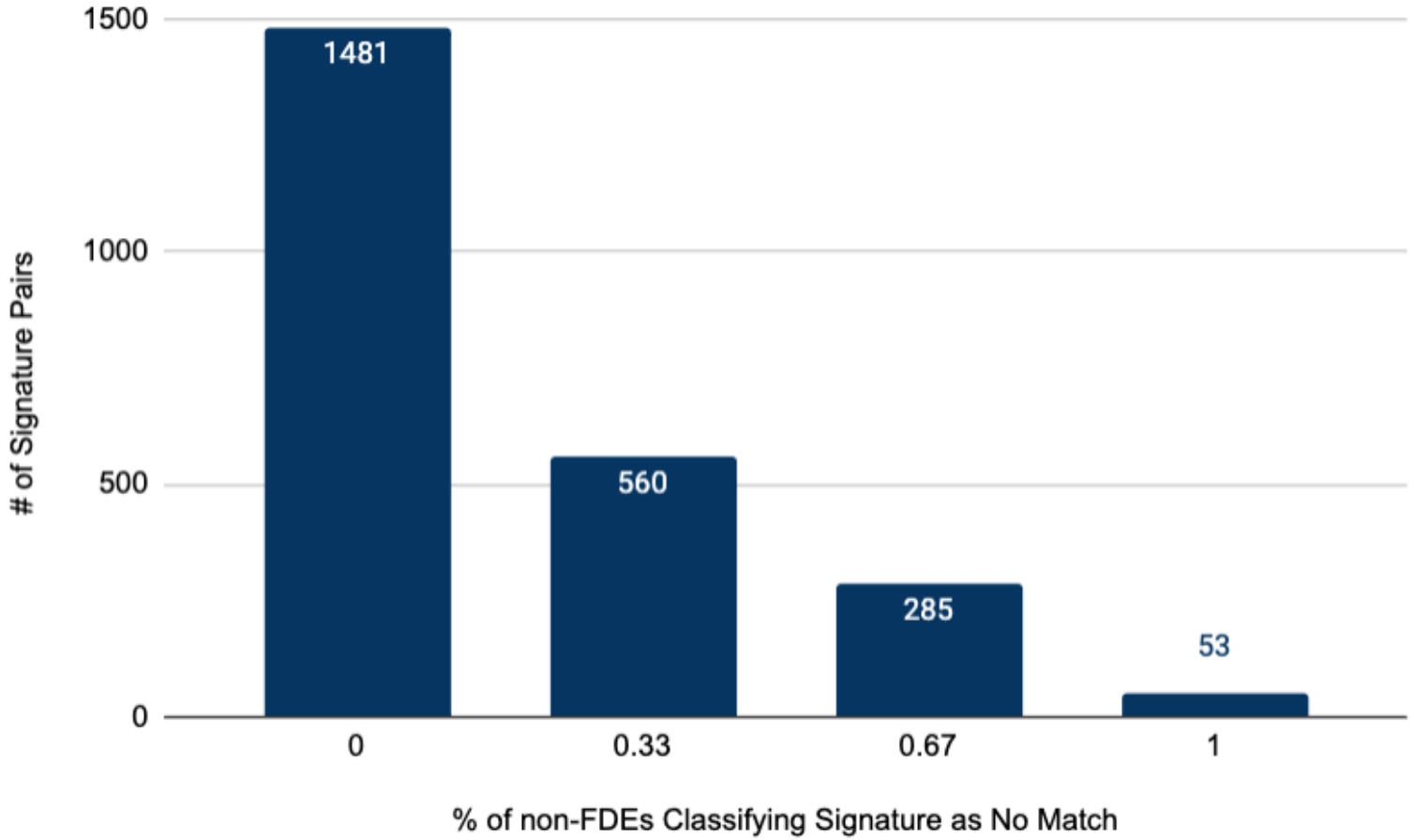



$$\alpha_i = \frac{\#nonFDEs\ Agreeing\ pairwise\ signature\ is\ a\ mismatch}{3}$$

$$\alpha = \frac{1}{2379}\sum_{i=1}^{2379}\alpha_i = \mathbf{18.02\%}$$

# Experiment II

Step 2 Results: Grouping of Pooled Consensus Probabilities of non-FDEs by Counts of Signature Pairs



# Experiment II

## Result: non-FDEs Would Have Flagged 344,528 EVBs for Curing

| | |
|---|---|
| **Total Number of Voters Submitting EVBs** | **1,911,918** |
| **Maricopa Mismatch Rate Before Curing** | **1.31%** |
| Maximum Number of EVBs Actually Cured | 25,000 |
| | |
| **non-FDE Pooled Consensus Signature Mismatch Rate** | **18.02%** |
| Number of EVBs That Should Have Been Cured | 344,528 |

# Determining Two-Step Review Signature Mismatch Rate

## First Trained Novices (non-FDEs) Review, Then Experts (FDEs)

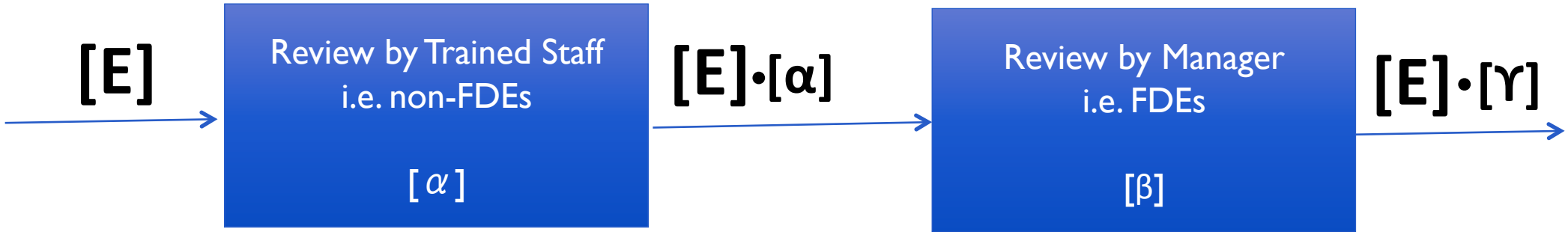
# Determining Two-Step Review Signature Mismatch Rate

- In Maricopa, the Initial Review involved Trained Staff first assessing pairwise signatures. If a ***No Match*** was detected by any one of them, the EVB was sent to a Manager with greater expertise to determine if indeed it was a ***No Match*** and needed to be cured.

- In this Study, the non-FDEs are assumed to be equivalent to the Trained Staff; and, the FDEs are assumed to be equivalent to the Manager.

# Determining Two-Step Review Signature Mismatch Rate

The goal is to determine the *two-step review signature mismatch rate, ϒ,* to determine the number of EVBs that would have been sent to curing after the two-step process.




Where: **[E]** is unit vector of size 2,379 representing the pairwise signatures reviewed by each non-FDE

**[α]** is a vector of the pooled consensus mismatch rates $\alpha_i$ for each $EVB_i$ for *i* = 1 to 2,379

**[E]•[α]** is the total number of EVBs classified as ***No Match*** by non-FDEs

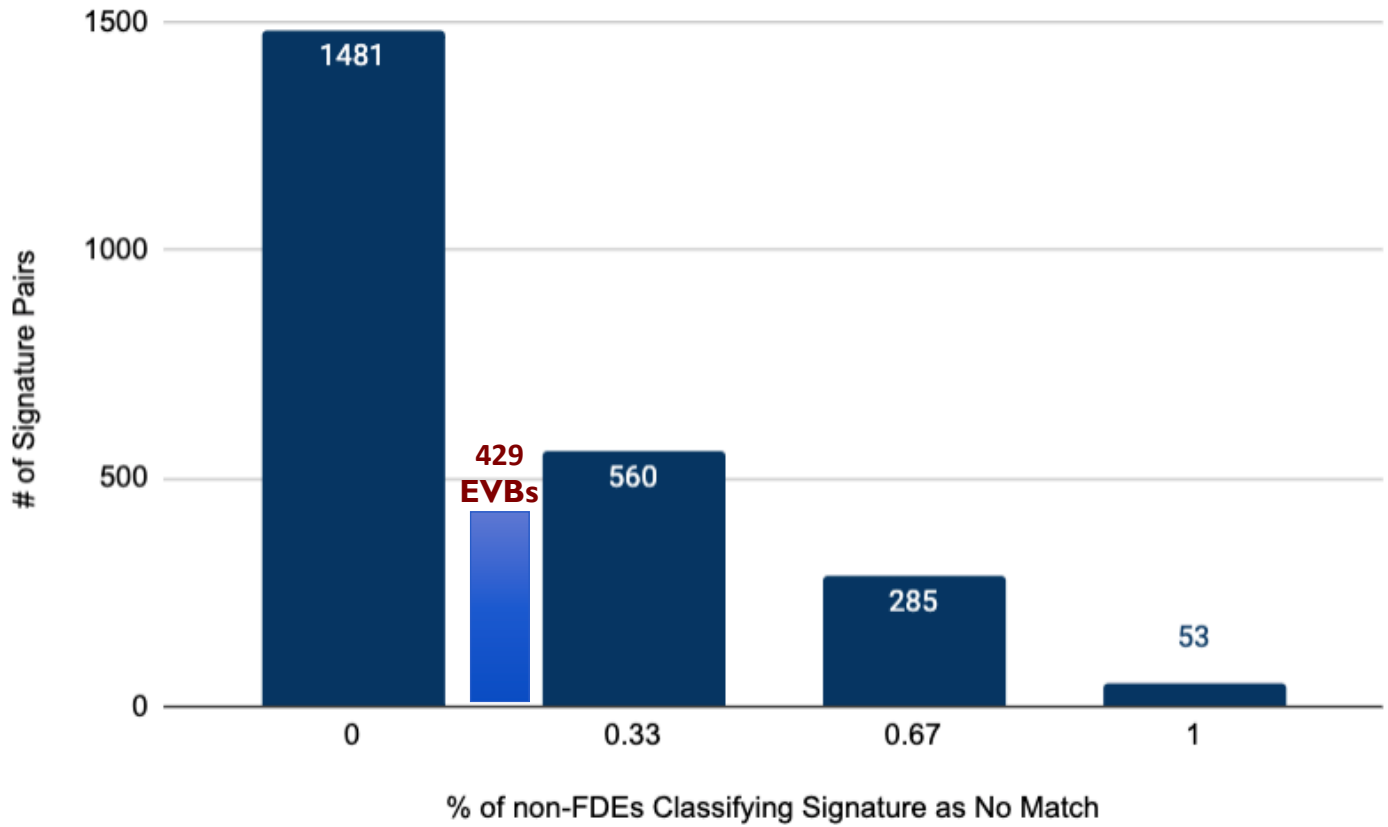
**[β]** is a vector of the pooled consensus mismatch rates $\beta_i$ for each $EVB_i$ for *i* = 1 to 2,379

**[ϒ]** is vector of joint probabilities **[α]x[β]** such that $\Upsilon_i$ is the joint probability that for $EVB_i$ the pooled consensus of FDEs classified it as ***No Match*** after pooled consensus non-FDEs classified as ***No Match***.

**[E]•[ϒ]** is the number of EVBs that the pooled consensus of FDEs classified as ***No Match*** after the pooled consensus of non-FDEs classified as ***No Match.***

# Calculation of EVBs Determined by non-FDEs to be No Match

## [E]•[α]




**[E]·[α]= 429 EVBs**

429 EVBs flagged as No Match by non-FDEs.





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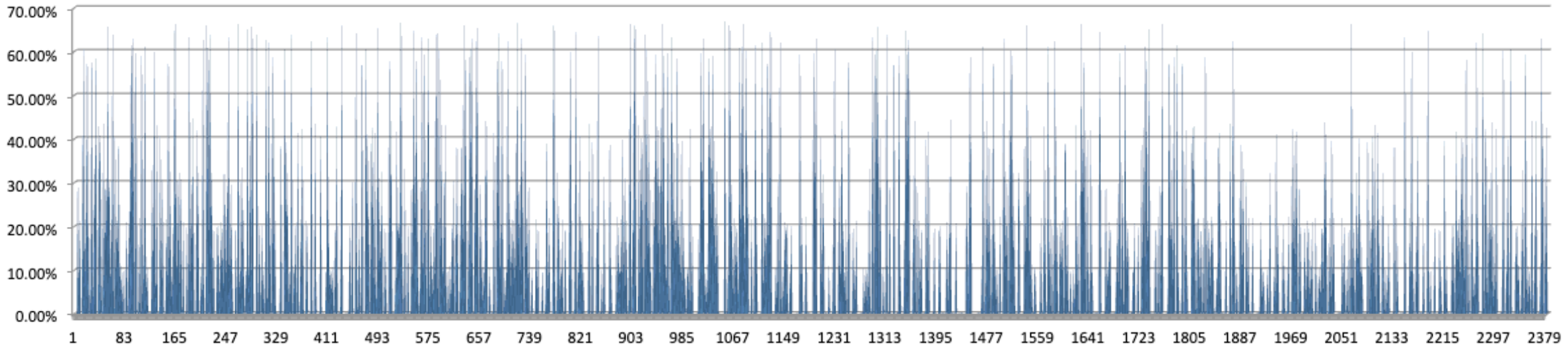
# Calculation of [ϒ] = [α] x [β], the Joint Probability
## Two-Step Review Signature Mismatch Rate

Joint Probability of FDE classifying EVB *i* as a No Match AFTER non-FDE classified as No Match ($\Upsilon_i$)*




*Mismatch rate does not exceed ~67%





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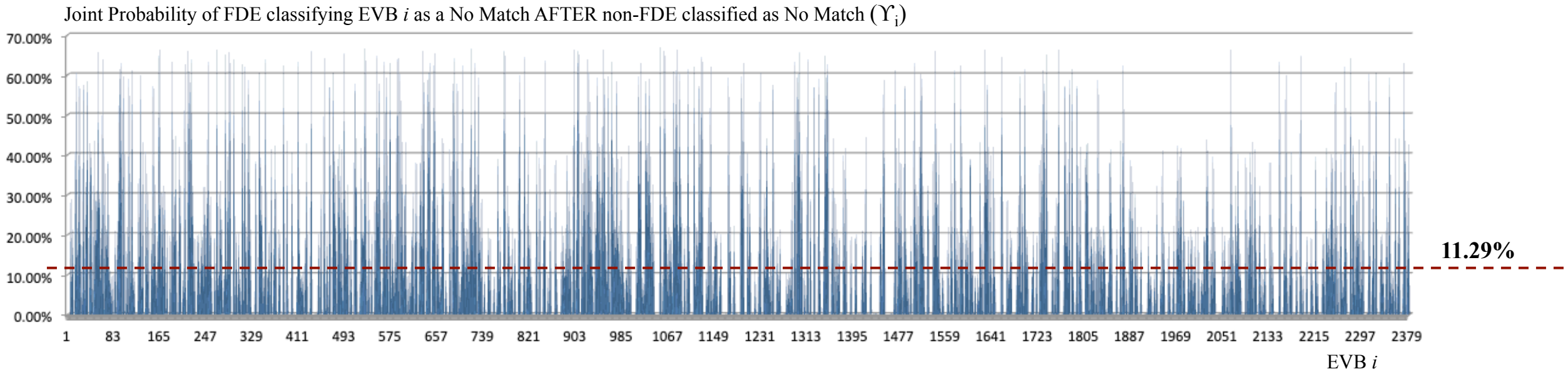
# Calculation of [ϒ] = [α] x [β], the Joint Probability

## Two-Step Review Signature Mismatch Rate

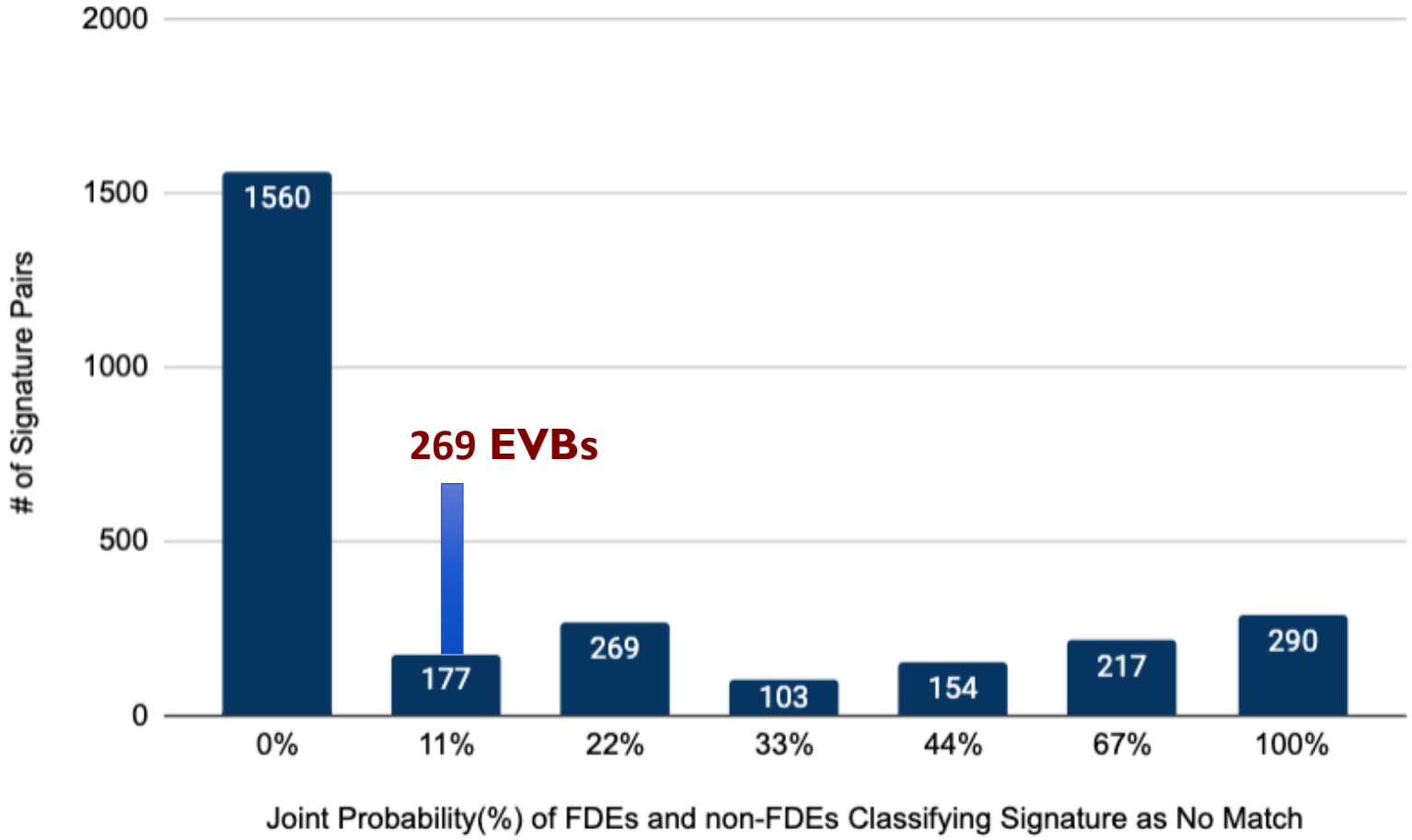



$$\gamma_i = \alpha_i * \beta_i$$

$$\gamma = \frac{1}{2379} \sum_{i=1}^{2379} \gamma_i \qquad = \mathbf{11.29\%}$$

# Calculation of EVBs To Be Cured: [E]•[ϒ]

Use of Calculated Joint Probability ϒ to Determine Number of EVBs to Be Cured = 269 EVBs




**[E]·[ϒ]= 269 EVBs**

269 EVBs would be flagged for curing. These are the EVBs determined as as NO MATCH following FDE review of EVBs flagged by non-FDEs as NO MATCH.





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# Two-Step Review Signature Mismatch Rate

## Result: non-FDEs Would Have Flagged 215,856 EVBs for Curing

| | |
|---|---|
| **Total Number of Voters Submitting EVBs** | **1,911,918** |
| **Maricopa Mismatch Rate Before Curing** | **1.31%** |
| Maximum Number of EVBs Actually Cured | 25,000 |
| | |
| **Two-Step Review Signature Mismatch Rate** | **11.29%** |
| Number of EVBs That Should Have Been Cured | 215,856 |

# Analysis B Summary

| Measures | Mismatch Rate (%) | EVBs to be Cured | Maximum Cured by Maricopa | EVBs to be Disallowed Post-Curing | Maricopa Disallowed Post-Curing |
|---|---|---|---|---|---|
| **Non-FDEs Pooled Consensus** Analysis B – Expt I | 18.02% | 344,528 | 25,000 | 18,025 | 587 |
| **FDEs Pooled Consensus** Analysis B – Expt II | 41.15% | 786,754 | 25,000 | 7,924 | 587 |
| **2-Step Pooled Consensus** Analysis B | 11.29% | 215,856 | 25,000 | 4,965 | 587 |

# Analysis B Summary

- If Experts - Forensic Document Examiners (FDEs) – alone were used to review the EVBs, then 786,753 EVBs should have been cured.
- If Trained Novices – non-FDEs – alone were used to review the EVBs, then 344,528 EVBs should have been cured.
- If non-FDEs and FDEs BOTH were used to review the EVB signatures in a two-step process (non-FDEs reviewing first, then FDEs), then 215,856 EVBs should have been cured.
- The original data for Analysis B including images is found in PDF:
  - Analysis-B-Extended-Study.pdf
- The original date for Analysis A not including images is found in the XLS file:
  - Analysis-B-Extended-Study.xls

# Discussion

# Discussion

## Summary Analysis

- In Maricopa County, 1,911,918 early voting mail ballots (EVBs) were received and counted
- The County reported 1.31% of all EVBs or 25,000 EVBs had signature mismatches requiring curing
- The County reported that 0.031% of all EVBs or 587 EVBs were confirmed mismatches post-curing

# Discussion

## Potential Scenarios of Signature Mismatch Rates

| Measures | Mismatch Rate (%) | EVBs to be Cured | Maximum Cured by Maricopa | EVBs to be Disallowed Post-Curing | Maricopa Disallowed Post-Curing |
|---|---|---|---|---|---|
| **Non-FDEs Pooled Consensus** Analysis A – Expt I | 28.50% | 544,897 | 25,000 | 12,533 | 587 |
| **FDEs Pooled Consensus** Analysis A - Expt II | 48.98% | 936,457 | 25,000 | 21,547 | 587 |
| **2-Step Pooled Consensus** Analysis A | 22.27% | 425,784 | 25,000 | 9,793 | 587 |
| **Non-FDEs Pooled Consensus** Analysis B – Expt I | 18.02% | 344,528 | 25,000 | 18,025 | 587 |
| **FDEs Pooled Consensus** Analysis B – Expt II | 41.15% | 786,754 | 25,000 | 7,924 | 587 |
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# Discussion

## Potential Scenarios of Signature Mismatch Rates

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# Discussion

## Summary Analysis

- In Maricopa County, 1,911,918 early voting mail ballots (EVBs) were received and counted
- The County reported 1.31% of all EVBs or 25,000 EVBs had signature mismatches requiring curing
- The County reported that 0.031% of all EVBs or 587 EVBs were confirmed mismatches post-curing
- As the results show, a minimum of 215,856 ±2.7% EVBs should have been cured
- Based on this Extended Study that yields a minimum signature mismatching rate of 11.29% and the County's post-curing rate of 2.3%, 4,965 EVBs at minimum would have been disallowed
- In this Extended Study, genuine signatures were acquired from a Maricopa Deeds' repository. Given signatures do change over time, this Study could be updated using the County's genuine signatures used during their signature verification in the 2020 General Election.
- The results herein are based on **using the minimum signature mismatch rate** AND **assumes that the County's 2.3% post-curing numbers are accurate**.

# Conclusion

# Conclusion

- Maricopa County Election Dept. states it has a “rigorous signature verification process.”
- Of the 1,911,918 EVB signatures verified, the County reported only 25,000 were flagged as signature mismatches requiring review – “curing;” and after curing, the County concluded only 587 of the 25,000 (2.3%) to be “Bad Signatures.”
- This Extended Study confirms the findings of the earlier Pilot Study and concludes that the process used for signature verification in Maricopa is a **flawed signature verification process.**

# Conclusion

- The Extended Study found if FDEs alone were used to review the EVB signatures, then at a minimum 786,754 EVBs would have found to have mismatched signatures and sent to curing.
- If non-FDEs alone were used to review the EVB signatures, then at a minimum 344,528 would have found to have mismatched signatures and sent to curing.
- If non-FDEs and FDEs BOTH were used to review the EVB signatures in a two-step process (non-FDEs reviewing first, then FDEs), then at a minimum 215,856 EVBs would have found to have mismatched signatures and sent to curing.
- One constraint of this Study in not having access to the signature files from the County.
- Given the nearly 10x difference in EVBs to be cured between this Study and the County's actually number cured, if the County were to provide their signature files, an update to this Study can be performed.

# Future Research and Questions

# Future Research and Questions

- Why did Maricopa County report “up to 25,000” were cured? What is the exact number of cured EVBs?
- There should be at least two (2) EVB envelope images for each EVB that was cured. According to Maricopa when an EVB is cured, a copy of the original EVB envelope is copied, stamped “MCTEC VERIFIED & APPROVED,” and an image is made.
- EchoMail found from its original September 2021 research, presented to the AZ Senate, that 17,126 unique voters had at least two (2) EVB envelope images. This means only 17,126 not “up to 25,000” were cured. Further research is needed is required to resolve this matter.
- One area of Future Research is to review ALL EVB envelope images that contain a “MCTEC VERIFIED & APPROVED” stamp and validate if the number containing those stamps match the total count cured
- Why does the County in its Signature Verification Guide train reviewers to allow any EVB envelope that has “MCTEC VERIFIED & APPROVED” stamp? How can a EVB envelope have such a stamp BEFORE curing?
- There are many questions on how signature matching rates are affected by training and context, which should be actively explored.
- A future study is planned providing an economic analysis of signature verification and review.

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**AN EXTENDED STUDY - Redacted**

# Extended Study Confirms At Minimum Over 200,000 Mail Ballots With Mismatched Signatures Counted Without Review ("Curing") in Maricopa County, Arizona 2020 General Election


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**Study Completed:** February 23, 2022
**Reviewed with AZ Senate Liaison:** March 1, 2022
**Delivered to AZ Senate:** March 2, 2022
**Delivered to AZ Attorney General**: March 2, 2022
**Updated & Re-Delivered:** March 7, 2022


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