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## **Summary of Mock Election and Risk-Limiting Audit**

On Jan 25, 2017 the Pima County Election Integrity Commission, together with the Pima County Elections Department, conducted a mock election followed by a Risk-Limiting Audit (RLA). The mock election consisted of 29699 preprinted ballots plus 265 ballots filled out by Commission members, for a total of 29,964 ballots. The preprinted ballots contained no overvotes, undervotes, or write-ins. Commission members, however, were free to include these options in their ballots. All ballots contained the same six contests (one ballot style). The RLA involved the comparison of a sample of randomly selected ballots with the election system interpretation of those ballots. The primary purpose of the exercise was to familiarize EIC members and election staff with RLA concepts and procedures and provide a basis for evaluating the RLA as a possible auditing technique for use in Pima County.

### **The Mock Election**

The mock election began with a demonstration of how to prepare, scan, and store ballots. EIC members, with guidance from the Election Department staff, operated five ES&S DS850 scanners. Upon scanning, ballots were imprinted with a unique serial number that is necessary for the particular type of RLA being conducted. The need for the serial numbers complicated scanning slightly because any ballots that needed to be rescanned (and there were quite a few) had to be rotated and/or flipped so the updated serial number did not overprint an existing serial number which would make the valid serial number difficult to read.

The 265 EIC ballots were processed first, and each member's packet of ballots was compared to their expected results. Discrepancies were noted and members determined the cause of the discrepancies for their own set of ballots. In some cases, discrepancies were caused by overvoted ballots for which the member had recorded both an overvote and (incorrectly) a vote for the candidates. In other cases, there were ballot marks that the DS850s interpreted as marginal or non-existent, so these ballots were interpreted as undervotes.

The remaining preprinted ballots were then scanned over a period of about 3 hours. Ballots were scanned in batches of about 500 ballots, but the scanners seemed to work best with smaller stacks so the 500-ballot batch was typically processed with stacks of 100 – 200 ballots on the scanner input tray. The most notable feature of this process was that 20-25% of the ballots could not be read on the first scan. These unreadable ballots appear in a separate output tray and were set to the side until the set of "fresh" ballots had been processed. The unreadable ballots were then rescanned taking care to rotate or flip the ballots. In some cases, ballots had to be read more than four times which led to overprinting a few of the serial numbers. There were also instances where the printed serial numbers overlapped with the timing marks on the edges of the ballot, but this did not prevent subsequent successful scanning of any ballots.

The ballots were stored in boxes that contained around 1000 ballots, usually two original batches. Care was taken to orient the ballots so that the valid serial number appeared in the same corner in the stack. The boxes were labeled with the range of serial numbers in each batch to support the retrieval of ballots by serial number during the RLA.

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Once all the ballots had been scanned, the staff uploaded the data from the scanners to the server and produced three files, a Ballot Table, a List of Cast Vote Records (LVR), and a Statement of Votes Cast (SOVC). The Ballot Table links a unique CVR number to the corresponding ballot serial number. The assigned CVR numbers provide a contiguous set of indices for the ballots whereas the serial numbers have many gaps caused by the rescanning of ballots (the original imprinted numbers are dropped and lose their association with ballots). Each record in the LVR spreadsheet contains a CVR number and shows how a ballot was interpreted; for each contest, the voter's selections are displayed. The SOVC shows the total votes obtained by each candidate/option for each contest and for each precinct. For the mock election, there was only one precinct. The SOVC provides all the data provided in the formal canvass except for valid write-in votes. The data in the LVR is also accessible from individual CVR files, one for each ballot. These CVR files were used during the RLA, as discussed below, because they were easily accessible and easier for human observers to read.

Table 1 shows a portion of the LVR for three of the six contests. Each record is a ballot interpretation. Best Picture was a vote-for-3 contest.

**Table 1. List of Cast Vote Records (LVR)**

<b>Cast Vote Record</b>	<b>Precinct</b>	<b>Ballot Style</b>	<b>Best Picture</b>			<b>Best Actor</b>	<b>Best Actress</b>
138900	001	001	The Big Short	Mad Max Fury Road	The Martian	Michael Fassbender	Charlotte Rampling
138901	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138902	001	001	Bridge of Spies	The Brooklyn	The Revenant	Matt Damon	Brie Larson
138903	001	001	Bridge of Spies	Mad Max Fury Road	The Room	Eddie Redmayne	Jennifer Lawrence
138904	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138905	001	001	Bridge of Spies	Mad Max Fury Road	The Room	Eddie Redmayne	Jennifer Lawrence
138906	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138907	001	001	Bridge of Spies	The Brooklyn	The Revenant	Matt Damon	Brie Larson
138908	001	001	Bridge of Spies	The Brooklyn	The Revenant	Matt Damon	Brie Larson
138909	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138910	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138911	001	001	Bridge of Spies	Mad Max Fury Road	The Room	Eddie Redmayne	Jennifer Lawrence
138912	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138913	001	001	The Big Short	Mad Max Fury Road	The Martian	Michael Fassbender	Charlotte Rampling
138914	001	001	Bridge of Spies	Mad Max Fury Road	The Room	Eddie Redmayne	Jennifer Lawrence
138915	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138916	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138917	001	001	Bridge of Spies	Mad Max Fury Road	The Room	Eddie Redmayne	Jennifer Lawrence
138918	001	001	The Big Short	The Martian	The Revenant	Matt Damon	Saoirse Ronan
138919	001	001	The Big Short	Mad Max Fury Road	The Martian	Michael Fassbender	Charlotte Rampling
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Table 2 shows the (transposed) SOVC. In a real election the SOVC would show vote tallies for each precinct as well as total vote counts.

**Table 2. Statement of Votes Cast (SOVC)**

COUNTY NUMBER	""	1
PRECINCT CODE		1
PRECINCT NAME		1
REGISTERED VOTERS - TOTAL	VOTERS	0
BALLOTS CAST - TOTAL	BALLOTS CAST	29964
BALLOTS CAST - BLANK	BALLOTS CAST	0
Best Picture	The Big Short	16569
Best Picture	Bridge of Spies	15575
Best Picture	The Brooklyn	8277
Best Picture	Mad Max Fury Road	17761
Best Picture	The Martian	13487
Best Picture	The Revenant	12078
Best Picture	The Room	5099
Best Picture	The Spotlight	890
Best Picture	WRITE-IN	14
Best Picture	OVER VOTES	12
Best Picture	UNDER VOTES	130
Best Actor in a Leading Role	Bryan Cranston	68
Best Actor in a Leading Role	Matt Damon	12076
Best Actor in a Leading Role	Leonardo DiCaprio	838
Best Actor in a Leading Role	Michael Fassbender	11945
Best Actor in a Leading Role	Eddie Redmayne	5023
Best Actor in a Leading Role	WRITE-IN	4
Best Actor in a Leading Role	OVER VOTES	6
Best Actor in a Leading Role	UNDER VOTES	4
Best Actress in a Leading Role	Cate Blanchett	5048
Best Actress in a Leading Role	Brie Larson	5554
Best Actress in a Leading Role	Jennifer Lawrence	5864
Best Actress in a Leading Role	Charlotte Rampling	6944
Best Actress in a Leading Role	Saoirse Ronan	6533
Best Actress in a Leading Role	WRITE-IN	5
Best Actress in a Leading Role	OVER VOTES	10
Best Actress in a Leading Role	UNDER VOTES	6
Best Actor in a Supporting Role	Christian Bale	16976
Best Actor in a Supporting Role	Tom Hardy	14315
Best Actor in a Supporting Role	Mark Ruffalo	10598
Best Actor in a Supporting Role	Mark Rylance	10579
Best Actor in a Supporting Role	Sylverster Stallone	7371
Best Actor in a Supporting Role	WRITE-IN	13

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Best Actor in a Supporting Role	OVER VOTES	8
Best Actor in a Supporting Role	UNDER VOTES	68
Best Actress in a Supporting Role	Rachel McAdams	11384
Best Actress in a Supporting Role	Alicia Viander	14285
Best Actress in a Supporting Role	Kate Winslet	6614
Best Actress in a Supporting Role	Jennifer Jason Leigh	12788
Best Actress in a Supporting Role	Rooney Mara	14777
Best Actress in a Supporting Role	WRITE-IN	9
Best Actress in a Supporting Role	OVER VOTES	4
Best Actress in a Supporting Role	UNDER VOTES	67
Oscars be Funded by the US Government?	Yes	14788
Oscars be Funded by the US Government?	No	15158
Oscars be Funded by the US Government?	OVER VOTES	5
Oscars be Funded by the US Government?	UNDER VOTES	13

## The Risk-Limiting Audit

The “Comparison” RLA involves the comparison of randomly selected paper ballots with the voting system interpretation of the ballot as represented in the corresponding CVR. The risk limit (we used 10%) is the maximum probability that the audit will not correct an erroneously reported election outcome. In other words, if the reported outcome is incorrect, there is at least a 90% chance that the audit will sample enough comparison discrepancies to cause an expansion of the sample set to all ballots, thereby correcting the erroneous outcome. If the reported outcome is correct, as we expect, then the audit will discover few, if any, discrepancies and will terminate.

To be sure that the LVR (and its component CVRs) is an accurate representation of the results as reported in the SOVC, an independently developed program<sup>1</sup>, called “countvote” was used to count all the choice entries in the LVR to produce results that were compared visually to the results presented in the SOVC. These results agreed, so the LVR and the CVR records could confidently be used to represent election results.

The next step was to select a random sample of ballots for the RLA. The size of the sample in an RLA depends on the risk limit and the “diluted margin” of victory for the contests on the ballot. The margin is given for each contest by the vote difference between the winner with the smallest vote count and the loser with the largest vote count divided by the number of ballots cast in that contest. For this mock election, all contests had the same number of cast ballots. The margins

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<sup>1</sup> Thanks to Steve Pothier for developing this program.

<sup>2</sup> <http://www.stat.berkeley.edu/~stark/Vote/auditTools.htm>

<sup>3</sup> An overstatement is a discrepancy that, if corrected, would narrow the margin between any pair of winners and losers. An understatement is a discrepancy that, if corrected, would widen the margin for all winner-loser pairs.

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and corresponding sample sizes calculated using Dr. Philip Stark's Audit Tools website<sup>2</sup> and a 10% risk limit are given in Table 3:

**Table 3. Contests and Initial RLA Sample Sizes**  
**10% Risk Limit**

Contest	Margin	Sample Size
Best Picture (vote for 3)	6.97%	69
Best Actor (vote for 1)	0.44%	1095
Best Actress (vote for 1)	1.37%	349
Best Supporting Actor (vote for 2)	12.4%	39
Best Supporting Actress (vote for 2)	5.0%	96
Oscar Funding (yes/no) (vote for 1)	1.23%	388

The RLA requires a larger sample size for smaller margins of victory and lower risk limits. To do a complete audit for all the races in this election would require 1095 sample ballots with the possibility of requiring more or fewer if discrepancies (overstatements or understatements, respectively) are found.<sup>3</sup> The sample size is determined by the contest with the smallest margin. Since we were conducting a mock election with time constraints and our objective was to understand the process, not fully complete the audit, we chose an initial sample size of 300.

The random ballot set was selected using a random number generator from Stark's website. We used twenty 10-sided dice to generate a random number seed. The website tool produced 300 random integers in the range 1 to 29964. To convert these random numbers to CVR numbers, we added a fixed integer one less than the smallest CVR number. The set of random CVR numbers were then associated with the corresponding ballot serial numbers from the Ballot Table. The serial numbers could then be associated with individual boxes of ballots to create a sample ballot manifest as shown in Table 4.

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<sup>2</sup> <http://www.stat.berkeley.edu/~stark/Vote/auditTools.htm>

<sup>3</sup> An overstatement is a discrepancy that, if corrected, would narrow the margin between any pair of winners and losers. An understatement is a discrepancy that, if corrected, would widen the margin for all winner-loser pairs.

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**Table 4. A Portion of the Sample Ballot Manifest**  
**Sample Ballot Manifest**

<b>Box #</b>	<b>Cast Vote Record</b>	<b>Serial Number</b>
1	139036	0107022494
	139071	0107022530
	139154	0107022661
	139242	0107022751
	139486	0107022998
	139547	0107023061
	139659	0107023185
	139894	0107023461
	2	139967
140008		0107023603
140025		0107023621
140063		0107023661
140251		0107023959
140312		0107024038
140418		0107024204
140500		0107024300
140517		0107024317
140721		0107024632
3	141037	0107024993
	141133	0107025089
	...	

Copies of the manifest were provided to several EIC members to retrieve sample ballots from specified boxes. Each was assigned a specific box and all of the sample ballots from that box were pulled according to their serial numbers and replaced with a sheet of colored paper to make it easier to replace the pulled ballots after comparison with the corresponding CVRs.

The Election Dept. staff provided original CVR files (one per ballot) along with the corresponding ballot images produced by the DS850 scanner, both as pdf files. An example CVR file and corresponding ballot image are shown below.

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**Cast Vote Record: 143,862**

Poll Place: **POLLS**

Precinct: **001**

Ballot Style: **001**

Party: **NONPARTISAN**

Serial Number: **0107028219**

Machine Serial: **8513090107**

Blank Ballot: **NO**

**Contests:**

**Best Picture**

Vote For: 3

The Big Short

Mad Max Fury Road

The Martian

**Best Actor in a Leading Role**

Vote For: 1

Michael Fassbender

**Best Actress in a Leading Role**

Vote For: 1

Charlotte Rampling

**Best Actor in a Supporting Role**

Vote For: 2

Christian Bale

Tom Hardy

**Best Actress in a Supporting Role**

Vote For: 2

Jennifer Jason Leigh

Rooney Mara

**Oscars be Funded by the US Government**

Vote For: 1

Yes

MOCK ELECTION

MOCK RLA ELECTION  
JUNE 2016  
PIMA COUNTY, STATE OF ARIZONA

**INSTRUCTIONS TO VOTERS:**

If you wish to vote for the adoption of a proposition or question, fill in the oval to the left of "YES". If you wish to vote against the adoption of a proposition or question, fill in the oval to the left of "NO".

To vote for the candidates, fill in the oval to the left of the name of the candidate. To vote for a person not on the ballot, write the candidate's name in the write-in space and fill in the oval to the left of the write-in space. VOTE LIKE THIS: ●

**PROPOSITIONS:**

Refer to Official and Descriptive Titles in the sample ballot and posted in the polling place.

<b>Best Picture</b>		<b>Best Actress in a Leading Role</b>	<b>Best Actress in a Supporting Role</b>
VOTE FOR NOT MORE THAN THREE		VOTE FOR NOT MORE THAN 1	VOTE FOR NOT MORE THAN TWO
<input checked="" type="radio"/> The Big Short	<input type="radio"/> Cate Blanchett	<input type="radio"/> Rachel MoAdams	<input type="radio"/> Alice Vander
<input type="radio"/> Bridge of Spies	<input type="radio"/> Brie Larson	<input type="radio"/> Alicia Vander	<input type="radio"/> Kate Winslet
<input type="radio"/> The Brooklyn	<input type="radio"/> Jennifer Lawrence	<input type="radio"/> Kate Winslet	<input checked="" type="radio"/> Jennifer Jason Leigh
<input checked="" type="radio"/> Mad Max Fury Road	<input checked="" type="radio"/> Charlotte Rampling	<input checked="" type="radio"/> Jennifer Jason Leigh	<input checked="" type="radio"/> Rooney Mara
<input checked="" type="radio"/> The Martian	<input type="radio"/> Saoirse Ronan	<input type="radio"/> _____	<input type="radio"/> _____
<input type="radio"/> The Revenant	<input type="radio"/> _____	<b>Best Actor in a Supporting Role</b>	
<input type="radio"/> The Room	VOTE FOR NOT MORE THAN TWO		
<input type="radio"/> The Spotlight	<input checked="" type="radio"/> Yes		
<input type="radio"/> _____	<input type="radio"/> No		
<b>Best Actor in a Leading Role</b>	<b>Should the Oscars Receive Government Funding</b>		
VOTE FOR NOT MORE THAN 1	<input checked="" type="radio"/> Christian Bale		
<input type="radio"/> Bryan Cranston	<input checked="" type="radio"/> Tom Hardy		
<input type="radio"/> Matt Damon	<input type="radio"/> Mark Ruffalo		
<input type="radio"/> Leonardo DiCaprio	<input type="radio"/> Mark Rylance		
<input checked="" type="radio"/> Michael Fassbender	<input type="radio"/> Sylvester Stallone		
<input type="radio"/> Eddie Redmayne	<input type="radio"/> _____		
<input type="radio"/> _____			



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The names of the CVR and ballot image files contain the cast vote record number so the directory containing these files could be easily searched. When retrieved ballots were provided, the CVR number was used to search the directory and isolate the CVR and image files corresponding to each ballot. These were opened and displayed by projector on a screen for everyone to see. The entries in the CVR, including the serial number, were compared visually to the ballot. The physical ballot was also compared to the ballot image (unnecessary for the RLA but added additional certainty).

At this point of the exercise we were nearing the end of the working day and we decided to terminate the RLA after retrieving, processing, and replacing 78 ballots. This took about 71 minutes. Continuation of the process the next day was unnecessary for our purposes because it would simply be more of the same retrieval-comparison-replacement. The comparison process produced no discrepancies. This was anticipated because the vast majority of ballots were preprinted. It was clear that the bottleneck was the comparison process that required checking every contest for each ballot. In a real election, this comparison process could be done in parallel with several computers to make the RLA more efficient. Ballot retrieval was straightforward but the sample ballot set included no write-ins (see comment below).

This exercise provided useful experience with ballot processing, data organization, ballot retrieval, ballot comparisons, and the RLA concept and procedures. A review of the RLA and the implications for use in Pima County in future elections will be produced at a later date.

## **Comment on Write-In Ballots and Mock Election Ballot Design**

Prior to this exercise, there was discussion about how we might emulate write-ins using the preprinted mock election ballots. There is good reason to do so because write-in ballots are counted but sent to a special output tray so that a panel can evaluate each write-in to see if it contains a valid write-in candidate. Thus these ballots (with valid serial numbers) get separated from the general ballot population, are handled by humans, and are therefore more likely to get out of numerical sequence and harder to retrieve by serial number during the RLA. Approximately 10% of ballots in a typical election contain write-in votes, so approximately one in ten RLA sample ballots would have to be found in the write-in set.

One suggestion was to randomly select a fraction of the ballots from the processed output tray (say 10%) and set them aside as if they were write-ins. Given a ballot number, the CVR would normally provide an indication that the desired ballot is in the write-in set, but in the proposed approach, no such indicator would exist. Thus retrieval of these “write-ins” would require searching for their serial numbers in the general population and failing their discovery, looking again in the write-in set. This was considered to be not sufficiently realistic.

A second suggestion was to add write-in votes to the preprinted ballots. Unfortunately, the preprinted ballots had no undervotes, so any added write-in would create an overvoted ballot. All overvoted ballots are shuttled to a special output tray and reviewed for possible duplication if clearly indicated by voter intent. The originally assigned serial number is therefore disregarded. These overvoted ballots are only known to the election system when they are rescanned at a later

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time. During rescanning, the equipment is set to read all non-overvoted contests instead of diverting the ballot to the overvote output tray. If these overvoted write-ins are set aside as if they were write-ins (and not rescanned), there would be no cast vote records for them and they would therefore never be selected by the RLA. If they are rescanned, they would simply appear as ballots with overvotes in the general population, not as write-ins. This approach was also considered to be unrealistic.

The design of the ballots for the mock election was thus not optimal in terms of simulating a real election. Had the ballot set included a substantial number of undervoted ballots, the write-ins could have been easily added.