Comparison of Testing Costs between
Paper Ballot Optically Scanned (PBOS) systems and Direct Recording Electronic (DRE) Systems

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Performing the Logic and Accuracy (L&A) testing of the software on a Direct Recording Electronic (DRE) voting system is between 2 and 3 times more costly than the L&A testing of a paper ballot – optically scanned (PBOS) voting system for the same election.

Description of Costs

Every voting system (Paper ballots counted by hand, PBOS, DRE, lever machines, punch cards, etc.) has costs associated with it. The hard costs can be categorized as falling into 3 areas:

1. Acquisition
2. Training
3. Election-specific Programming
4. Election-specific Administration.

Soft costs are those costs which are hard to quantify in dollars and cents. These soft costs include:

5. Electoral trust
6. System Reliability
7. Exposure to Litigation for contested results

Election-specific administration costs include:

8. Election-specific training of poll inspectors
9. Payment of poll inspectors and other election-day workers.
10. Printing any required paper ballots for a specific election
11. Printing any required information or instructions for electors
12. Printing and verifying polling lists of registered voters
13. Testing the software or mechanism of any voting machinery used
14. Collecting, auditing and storing election materials and records at the close of a specific election.

This paper deals **only** with the cost of performing the logic and accuracy testing the software of any particular software machinery used to aid in the administration of an election. This is item 13 in the lists above. Lever machines and punch card system are unlikely to be used in the United States after January 1, 2006 due to the acceptance of federal HAVA money by the several states. Paper ballots which are hand counted have no software testing costs. Because of these technological constraints, this paper focuses on comparing the costs of performing Logic and Accuracy tests between paper ballots – optically scanned (PBOS) systems and direct recording electronic (DRE) systems.

Logic and Accuracy Testing

Logic and Accuracy (L&A) testing is a term unique to voting machinery software and is foreign to every software test professional known to this author. Functional (or black box) testing is the common term used by software test professionals for the testing described by voting machine vendors and election statutes as logic and accuracy testing. Functional (L&A) testing is testing which answers the question: *"Does the software provide the functionality required by the software specification (state election laws)?"* Given the prevalence of the term logic and accuracy testing (LAT) for election machinery, this unusual term is what will be used through out this paper.

Most states have requirements dictating logic and accuracy testing of the voting machinery software be performed prior to each election. This L&A testing is usually performed by the municipal clerk or other official administering the election at hand. This L&A testing for each election is distinct from any L&A testing which may have been performed by any state or national organizations in order to become certified. Because either prudence or statutes requires L&A testing for each election, L&A testing represents a persistent and on-going expense of using software-based voting machinery.

Regardless, of the software-based system used, a deck of test ballots must be defined. Defining a test ballot has 3 elements:

1. Describe the construction of each test ballots.
2. Describe if the ballot, as constructed, is well formed. A well formed ballot should be accepted by the software and ill formed ballots should be rejected by the software.
3. If the ballot is well formed, describe which vote tallies for which candidates are affected. If the ballot is ill-formed, state no vote tally for any candidate should be affected by the ill-formed ballot.

Regardless, of the software-based system used, the L&A testing must be executed. Executing a single round of L&A testing has 6 elements.

4. Constructing and/or entering each ballot defined above.
5. Observing the actual behavior of the software (accepted/rejected as expected)
6. Observing the vote tallies
7. Recording the results of the L&A testing
8. Reporting to the vendor any defects found so the vendor may repair them.
9. Repeat until all known defects are corrected

Comparison of L&A Testing Costs

The costs for defining a deck of test ballots (items 1, 2, and 3 above) are the same whether the software is for a DRE or a PBOS system. The cost of defining a test ballot is driven solely by ballot structure (number of races, number of candidates for each race, partisan/non-partisan, etc.) and the governing bodies of election law, election regulation and election case law. Since proper L&A testing depends on the structure of a particular ballot and the particular jurisdiction of the polling place, the author has used the ballot from District #1 of Germantown, Wisconsin for the November 2, 2004 general partisan election for the particular example for this paper. This election had 10 partisan races (US President down to Washington County Registrar of Deeds) and 4 school board referenda questions.

Using the test guidelines of the author, a minimum of 207 test ballots are required to perform the L&A testing of the voting machinery software. These 207 ballots are divided into 93 well formed ballots for which vote tallies will be incremented and 114 ill-formed ballots. It is expected the software will reject each of the ill-formed ballots. For example, one of the test ballots in the test deck is a ballot with a party preference of Republican Party and a second vote recorded for Michael Badnarik for US President. Under Wisconsin election law, chapter 5.91(2), this ballot is well-formed and should be accepted by the voting machinery software. By the same statute the software should tally a vote for every candidate fielded by the Republican Party except for George Bush/Richard Chaney. This is 9 votes; 1 each in the races from US Senate to Washington County Registrar of Deeds. For US President the software shall tally 1 vote for the ticket of Michael Badnarik / Richard V. Campagna. There should be no vote cast for any of the 4 school board referenda on the ballot.

This single ballot is an excellent example of the first 3 elements in the list above. The test ballot and its construction are described. The ballot is described as well-formed or ill-formed. The expected effects on candidate tallies are clearly described.

Cost of 1 round of L&A Testing on a PBOS system

For a PBOS system the time to put marks on the test ballots is assumed to be 3 seconds per ballot. The time to feed this paper ballot into the optical scanner is 1 second. The time to see if the optical scanner accepts or rejects the ballot is 2 seconds regardless if the ballot is well- or ill- formed. Recording the acceptance or rejection of the ballot is 3 seconds. After all the well-formed ballots are accepted by the machine, it takes 10 minutes to print the election report. After that it takes 10 minutes to examine the segregation of write-in ballots. It takes 30 minutes to compare the election report generated by the PBOS system to the results expected from the test deck.

This creates a table of the following costs and times:

Number of ballots in the test deck	93	Well Formed Ballots	114	Ill Formed Ballots

Time to create a single ballot before executing a single round of L&A testing	3	Seconds / Ballot	0.173	Man Hours / Round of L&A testing

Time to enter a single, well formed test ballot into the voting machinery	2	Seconds / Ballot	0.052	Man Hours / Round of L&A testing
Time to enter a single, Ill-formed test ballot into the voting machinery	2	Seconds / Ballot	0.063	Man Hours / Round of L&A testing
Recording the results of the L&A testing	3	Seconds / Ballot	0.078	Man Hours / Round of L&A testing

Printing the report of vote tallies	10	Minutes / per Round of L&A testing	0.167	Man Hours / Round of L&A testing
Verifying the reported vote tallies are correct	30	Minutes / per Round of L& A testing	0.500	Man Hours / Round of L&A testing
Time to examine the write in ballots	10	Minutes / per Round of L& A testing	0.167	Man Hours / Round of L&A testing
Total Time per round of L&A testing			1.026	Man Hours / Round of L&A testing

Test entry error	0.00%	
Number of rounds of L&A testing performed	1	Round(s)
Total time to perform all L&A testing	1.198333	Man Hours
Pay rate of Election Official	$ 20.00	per hour
Total Cost to perform all rounds of L&A testing	$ 23.97	

Cost of 1 round of L&A Testing on a DRE system

For a DRE system it is not possible to create test ballots ahead of time. The time to touch the screen in order to enter the paper ballot is 3 seconds per election for a total of 42 seconds per ballot. The time to touch the screen until an ill-formed is rejected is assumed to be ½ of the time to enter a well formed ballot. This is 22 seconds per ballot. On half was selected because, on average, the elector must enter information for ½ of the elections in order to reach the election which causes the ballot to be ill-formed. Recording the acceptance or rejection of the ballot is 3 seconds. After all the well-formed ballots are accepted by the machine, it takes 10 minutes to print the election report. After that it takes 10 minutes to examine the information captured for write-in ballots. It takes 30 minutes to compare the election report generated by the DRE system to the results expected from the test deck.

This creates a table of the following costs and times:

Number of ballots in the test deck	93	Well Formed Ballots	114	Ill Formed Ballots

Time to create a single ballot before executing a single round of L&A testing	0	Seconds / Ballot	0.000	Man Hours / Round of L&A testing

Time to enter a single, well formed test ballot into the voting machinery	42	Seconds / Ballot	1.085	Man Hours / Round of L&A testing
Time to enter a single, Ill-formed test ballot into the voting machinery	21	Seconds / Ballot	0.665	Man Hours / Round of L&A testing
Recording the results of the L&A testing	3	Seconds / Ballot	0.078	Man Hours / Round of L&A testing

Printing the report of vote tallies	10	Minutes / per Round of L&A testing	0.167	Man Hours / Round of L&A testing
Verifying the reported vote tallies are correct	30	Minutes / per Round of L& A testing	0.500	Man Hours / Round of L&A testing
Time to examine the write in ballots	10	Minutes / per Round of L& A testing	0.167	Man Hours / Round of L&A testing
Total Time per round of L&A testing			2.661	Man Hours / Round of L&A testing

Test entry error	0.00%	
Number of rounds of L&A testing performed	1	Round(s)
Total time to perform all L&A testing	2.660833	Man Hours
Pay rate of Election Official	$ 20.00	per hour

Total Cost to perform all rounds of L&A testing	$ 53.22

Costs for Testing and Software Errors

There are 28 screen touches in order to enter a single well-formed ballot into a DRE system. This is 2 touches (the candidate and next race button) for each of the 10 races and 4 questions on the ballot. Therefore, 2604 screen touches are required in order to enter the 93 well-formed ballots defined in the test deck. Using the ½ rule again for the ill-formed ballots, this is 1596 screen touches to enter the 114 ill-formed ballots. The above analysis assumes every single one of these 4200 screen touches are entered without error in the time allotted.

Depending on the DRE software involved, an entry error on the 10th race may require the current test ballot be voided and the whole test ballot be re-entering the whole test ballot again. Other DRE systems provide a mechanism to return to the prior race and re-enter the correct data for the single race. This variation and its effect on entering the test data cannot be well quantified. For the purposes of this paper this variation due to test data entry errors has been ignored in this initial estimate of L&A testing costs. If the paper ballot is properly marked, there is no possibility of human error while entering the ballot into the optical scanning tabulator.

This initial analysis also assumes the L&A testing found no defects. If a defect was discovered during the L&A software then the software defect must be reported to the vendor for repair. When the defect is repaired by the vendor, the repaired software must be re-tested with the same test deck to insure the defect is indeed repaired. The whole deck of test ballots must repeated to insure the programming changes which fixed the defect did not also introduce a new defect.

Here are the tables of the time and costs if 2 rounds of L&A testing are required and there is a 4% error rate entering the test ballots into the DRE.

For the PBOS system:

Number of ballots in the test deck	93	Well Formed Ballots	114	Ill Formed Ballots

Time to create a single ballot before executing a single round of L&A testing	3	Seconds / Ballot	0.173	Man Hours / Round of L&A testing

Time to enter a single, well formed test ballot into the voting machinery	2	Seconds / Ballot	0.052	Man Hours / Round of L&A testing
Time to enter a single, Ill-formed test ballot into the voting machinery	2	Seconds / Ballot	0.063	Man Hours / Round of L&A testing
Recording the results of the L&A testing	3	Seconds / Ballot	0.078	Man Hours / Round of L&A testing

Printing the report of vote tallies	10	Minutes / per Round of L&A testing	0.167	Man Hours / Round of L&A testing
Verifying the reported vote tallies are correct	30	Minutes / per Round of L& A testing	0.500	Man Hours / Round of L&A testing
Time to examine the write in ballots	10	Minutes / per Round of L& A testing	0.167	Man Hours / Round of L&A testing
Total Time per round of L&A testing			1.026	Man Hours / Round of L&A testing

Test entry error	0.00%	
Number of rounds of L&A testing performed	2	Round(s)
Total time to perform all L&A testing	2.224167	Man Hours
Pay rate of Election Official	$ 20.00	per hour
Total Cost to perform all rounds of L&A testing	$ 44.48	

For the DRE system:

Number of ballots in the test deck	93	Well Formed Ballots	114	Ill Formed Ballots

Time to create a single ballot before executing a single round of L&A testing	0	Seconds / Ballot	0.000	Man Hours / Round of L&A testing

Time to enter a single, well formed test ballot into the voting machinery	42	Seconds / Ballot	1.128	Man Hours / Round of L&A testing
Time to enter a single, Ill-formed test ballot into the voting machinery	21	Seconds / Ballot	0.692	Man Hours / Round of L&A testing
Recording the results of the L&A testing	3	Seconds / Ballot	0.078	Man Hours / Round of L&A testing

Printing the report of vote tallies	10	Minutes / per Round of L&A testing	0.167	Man Hours / Round of L&A testing
Verifying the reported vote tallies are correct	30	Minutes / per Round of L& A testing	0.500	Man Hours / Round of L&A testing
Time to examine the write in ballots	10	Minutes / per Round of L& A testing	0.167	Man Hours / Round of L&A testing
Total Time per round of L&A testing			2.731	Man Hours / Round of L&A testing

Test entry error	4.00%	
Number of rounds of L&A testing performed	2	Round(s)
Total time to perform all L&A testing	5.461667	Man Hours
Pay rate of Election Official	$ 20.00	per hour
Total Cost to perform all rounds of L&A testing	$ 109.23	

Summary

Logic and Accuracy testing for a PBOS system is significantly less than the same L&A testing on a DRE system. This advantage in testing cost widens if the L&A testing must be performed a second time due to the discovery of a software defect. The advantage for multiple executions of the L&A testing is due to the fact that the paper ballots of the PBOS system are created once and re-used. On a DRE system each test ballot must be entered from scratch for each execution of the L&A tests.

More over asking a person to touch a screen ***thousands*** of times without error is unreasonable. Because of this entering test ballots on a DRE is prone to error. If the data entry error is not noticed until the election report is compared to the expected results of the test deck, it is conceivable the entire test deck would have to be re-entered on the DRE. This further increases the advantage of PBOS systems over DRE in the area of L&A testing.

Performing the Logic and Accuracy (L&A) testing of voting machinery software on a Direct Recording Electronic (DRE) voting system is no less than 2 times more costly than the L&A testing of a paper ballot – optically scanned (PBOS) voting system for the same election. The cost difference could (depending on error rates) be significantly higher than 2 times those of a PBOS system.