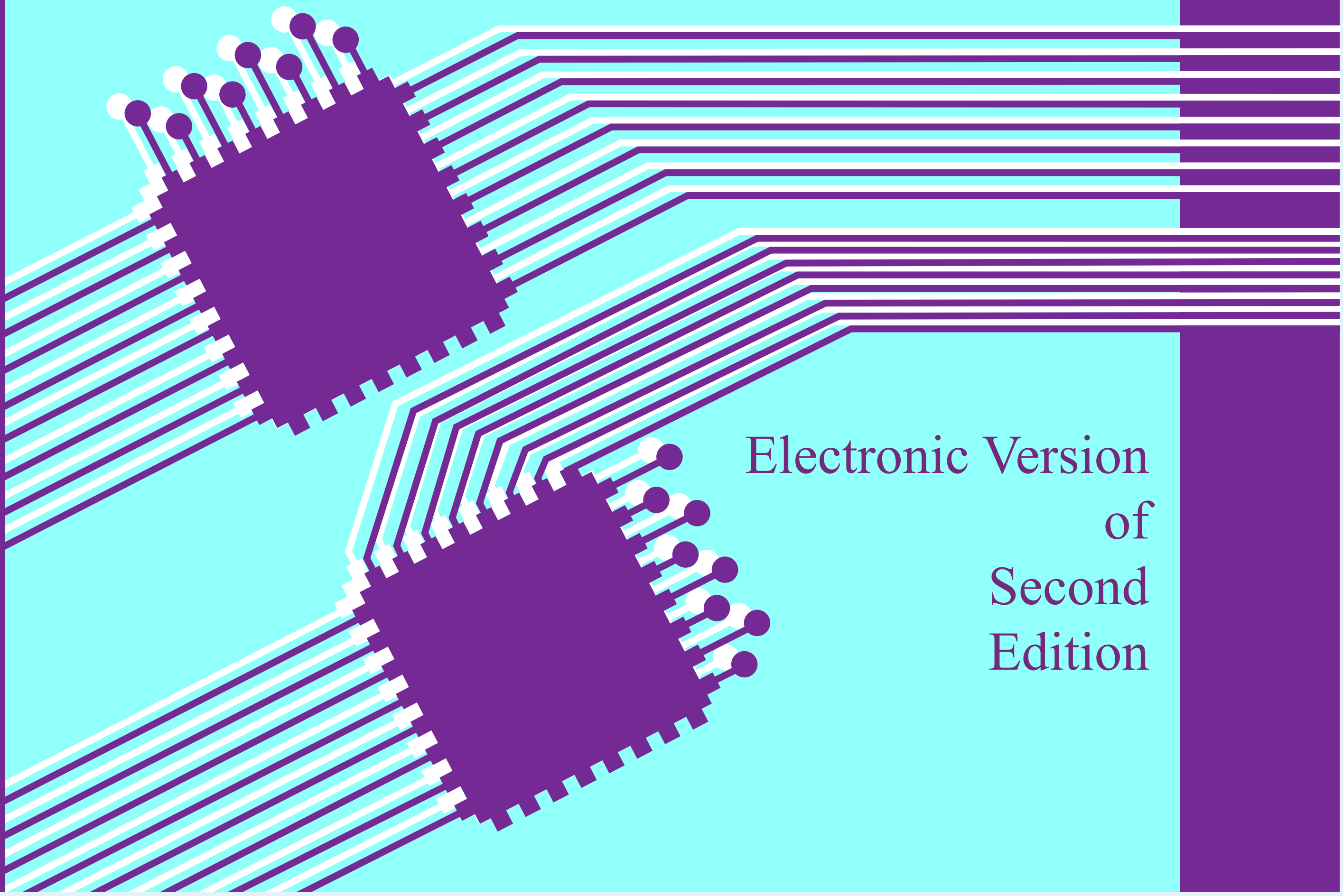
Sample pages from...

The Economics of Automatic Testing

Chapter 7
Board test economics

Brendan Davis



Electronic Version
of
Second
Edition

Copyright Notice

"The Economics of Automatic Testing"

Published by
Brendan Davis, Cahir, County Tipperary, Ireland.

Conversion to electronic formats by…

Suirvale Design & Print, Cahir, County Tipperary, Ireland

7.12 The cost of the following test stages

Each of the test stages that follow the board test stage will have the same set of four cost areas that we have just looked at. There will be some equipment cost, some maintenance cost, some programming cost and some operational costs. These will need to be considered and determined in much the same way as the costs for the board test stage.

7.13 Field-service costs

The last cost area when looking at the life cycle costs related to the choice of tester or test strategy is the cost of field service. As stated earlier, these costs will be a function of the yield out of manufacturing and the overall combined fault coverage of all of the test stages. There is a discussion of these costs in the previous chapter.

7.14 A simple example

Although it is necessary to perform a detailed economic comparison of test strategies and test tactics in the manner described in the next chapter, there are times when a quick and dirty analysis is needed just to get a feel for the situation. This can be done on paper or by developing a simple spreadsheet model. The following example shows how this might be done for two alternative functional board testers. The evaluation team at XYZ Electronics has narrowed down the field to two testers, A and B. Tester A has marginally better performance in terms of program preparation, fault coverage and operational costs, but it is 50 per cent more expensive at $300,000 as opposed to only $200,000 for tester B. At first sight it does not appear that the performance differences justify the additional $100,000, but they decide to perform a simple analysis anyway. The new tester is required for a new product range that is forecasted to sell about 7,500 units per year, with each unit containing four boards of low to medium complexity. The annual board volume will therefore be 30,000 boards per year. The yield from manufacturing is expected to be 70 per cent, which equates to an average of 0.357 faults per board…

$$(FPB = ABS[LN(yield/100)])$$

i.e. the average number of faults per board (FPB) is equal to the absolute value (ABS) of the natural logarithm (LN) of the yield, when yield is expressed as a proportion rather than a percentage. For their expected fault spectrum they have determined that the fault coverage will be 95 per cent for tester A and 90 per cent for tester B. Tester A is likely to have fewer problems with mis-diagnosis than system B so a correction factor, known as the ***'diagnosis/repair loop number',*** of 1.1 is applied to system A and of 1.15 for system B. This implies that system A would have 10 per cent more diagnosis and repair actions than the true yield of 70 per cent would indicate. System B would have 15 per cent additional, unnecessary diagnosis and repair actions. This figure is also applied to any diagnoses and repairs that result from defects detected at the final test stage.

The test strategy opted for is to follow the board tester with a single final system test stage since there are no 'sub-assemblies' in the product. Table 7.1 tabulates the above information along with calculations of the number of ***'detected faults per board'*** (DFPB), the number of ***'escaping faults per board'*** (EFPB), the ***'apparent yield'*** (Ya) and the number of ***diagnosis and repair actions.***

As you will see from the table, the assumption is that 90 per cent of the defects escaping from the board test stage will be detected at the system test stage. Table 7.2 lists the main

	Board Test A	Board Test B	Final System Test With A	Final System Test With B
Average faults per board	0.357	0.357	0.018	0.036
Fault coverage	95%	90%	90%	90%
DFPB	0.339	0.321	0.0162	0.0324
EFPB	0.018	0.036	0.0018	0.0036
Apparent Yield	71.2%	72.5%	98.4%	96.8%
Diagnosis/repair loop number	1.1	1.15	1.15	1.15
Number of diagnostic actions per board	0.373	0.369	0.0186	0.0373
Number of repair actions per board	0.373	0.369	0.0186	0.0375

Table 7.1 Defect detection and escaping defects for the example

	System A	System B	System Test
Average good board test time	45 s	45 s	2 hr*
Average diagnosis time	5 min	6 min	2 hr
Average repair time	10 min	12 min	15 min
Diagnosis/repair loop number	1.1	1.15	1.15
Average cost of test program	$12,000	$13,200	$5,000
Debug time on tester per test program	3 days	4 days	N/A
Labour cost of operator	$20/hr	$20/hr	$30/hr

*Time for one system (4 boards)

Table 7.2 Principal test stage performance parameters

performance parameters as determined by the evaluation team.

The labour cost of the repair technicians is also $20 per hour. Table 7.3 now shows the calculation of the operational costs.

Table 7.3 provides the cost data for the operation of the board testers, the following test stages and the field. The program preparation costs are $144,000 (12 x 12,000) for system A and $158,400 (12 x 13,200) for system B.

The annual cost difference of $105,335 represents the cost savings of system A relative to system B. These savings would be generated by the incremental $100,000 invested in system A, so when viewed over several years this would be a cheaper alternative. See the example in Fig. 4.1 and the accompanying text for a discussion about 'incremental investment'. The numbers down the left-hand side of Table 7.4 refer to the six main cost areas outlined in Section 7.7 earlier in this chapter.

The next thing that the evaluation team look at is the capacity situation for the, two alternatives. XYZ Electronics want to avoid buying two testers or operating more than one shift, so the capacity calculations are important. They estimate that they will have 1680 operational hours available each year. This is based on there being 7 usable hours each day, 20 working days each month and 12 months in a year. They calculate the amount of

	Board Test		System Test	
	A	B	A	B
Good board testing costs				
30,000 x (45s/60) x ($20/60)	7,500	7,500		
2hr x $30 x 30,000/4			225,000	225,000
Diagnosis costs				
30,000 x 0.373 x 5min/60 x $20	18,650			
30,000 x 0.369 x 6min/60 x $20		22,140		
30,000 x 0.0186 x 2hr x $30			33,480	
30,000 x 0.0373 x 2hr x $30				67,140
Repair costs				
30,000 x 0.373 x 10min/60 x $20	37,300			
30,000 x 0.369 x 12min/60 x $20		44,280		
30,000 x 0.0186 x 15min/60 x $20			2,790	
30,000 x 0.0373 x 15min/60 x $20				5,595
Field costs				
30,000 x 0.0018 x $1,000	54,000			
30,000 x 0.0036 x $1,000		108,000		

Table 7.3 Operational cost calculations

		System A	System B
Non-recurring costs			
1	Purchase price	$300,000	$200,000
Annually recurring costs			
2	Maintenance costs	30,000	20,000
3	Test programming costs	144,000	158,400
4	Operational costs		
	Testing	7,500	7,500
	Diagnosis	18,650	22,140
	Repair	37,300	44,280
5	The cost of following test stages	261,270	297,735
6	Field service costs	54,000	108,000
Total annual recurring costs		552,720	658,055

Table 7.4 Summary of cost calculations

time required on each tester in the manner shown in Table 7.5.

The results in Table 7.5 tend to settle the issue. With only 1680 hours available system B does not have the capacity to get the job done without some overtime, a second shift or a second tester.

	System A	System B
Time needed for test and diagnosis		
30,000 tests x 45s/3600	375hr	375hr
11,190 diagnoses x 5min/60	932.5hr	
11,070 diagnoses x 6min/60		1,107hr
Totals	1,307.5hr	1,482hr
Tester time needed for program debug		
12 x programs x 3days x 7hr	252hr	
12 programs x 4days x 7hr		336hr
Total tester time required	1,559.5hr	1,818hr

Table 7.5 System time required for the expected workload

This example illustrates a number of things. It shows how a rough analysis can be performed quite quickly with just a paper, pencil and a calculator. It also shows how first impressions can be very misleading. The apparently small advantages that system A had over system B did not appear to be enough to justify an extra 50 per cent on the capital investment. It also shows the importance of performing a 'life cycle cost analysis' rather than simply looking at the direct costs associated with the testers. The bulk of the savings are made in the stages that follow the board tester. System A does a much better job of helping the company to meet its four main objectives. The operational ***cost*** is lower, the ***quality*** of the shipped product is higher, the ***time to market*** is faster and the more powerful system will cope with new ***technologies*** more easily. It should be stressed that this is a very simple approach and a number of things are not included in the analysis. However, this kind of analysis can quickly weed out the nonstarters and so reduce the effort required for the more detailed study of the alternatives.

Notes on the example. *The above example featured a comparison between two functional testers which is probably the simplest case from a mathematical point of view. The reason is that functional testers will tend to find only one defect at a time and the diagnosis time will be fairly similar for different defect types. For these reasons we can simply determine the total number of defects detected and multiply this figure by the average diagnosis time. Since each board will receive one 'passing' test, either because it was defect-free to begin with or because it was successfully repaired, we can simply multiply the 'good board test time' by the total production volume. This calculation of the 'testing' cost part of the 'operational costs' is also true for other tester types since the board will only receive one 'passing test'. However, the diagnosis and repair costs are more difficult to calculate because ICT type systems can detect multiple defects in one operation provided that they are detected in the same part of the test program. Specifically, two or more shorts will be detected in one operation and the test would usually be suspended at the end of the shorts test part of the program. The board would then go off to be repaired. If there are* *no shorts present then the tests would progress into the 'component testing' part of the ICT test program and any defects detected here will be reported at the end of the test. The ICT's 'one component at a time' technique means that it can also detect multiple faults in this section of the program. It should be clear, however, that if there is a short and another defect present then these will not be detected simultaneously because the testing would normally terminate after the shorts test. This means that the mathematics become a bit more complicated. A full discussion of how this situation is handled appears in Chapter 4 along with an example. Failure to take this operational situation into account when performing even a simple analysis like the above example will result in some significant errors.*

The situation gets more complex yet for combinational testers or for in-circuit testers with a 'boundary scan' test capability, which are really combinational testers anyway. Now we have a situation where we have the complication mentioned above ***and*** we can have some defects detected by the 'functional' or 'boundary scan' portion of the test program. This situation becomes a bit difficult to model in a simple way and will almost certainly need the use of a more complex model such as the one described in the next chapter.

7.15 Another view of board test economics

The classical definition of quality is ***'conformance to requirements'***. If the product conforms to (or meets) all of the requirements of the customer, it is a high-quality product. This leads to the concept that the overall cost of quality is made up of two parts. The ***'cost of conformance'*** is the cost of all the things we do to ensure that the product will indeed conform to the customer's requirements and the ***'cost of nonconformance'*** is the cost incurred when the product does not conform. In general the cost of conformance is incurred before the product is shipped, and the cost of nonconformance is incurred after it ships to the customer. This concept can be adapted to compare the effectiveness of alternative board test systems. Ideally we would like the board tester to find all of the defects present on the boards regardless of the source of the defects. In practice this 100 per cent fault coverage is unlikely to be achieved and some defects will ***'escape'*** to the following test stages and even out to the field. The costs incurred in using the board tester can be regarded as the cost of conformance for the tester, and the costs generated by the escaping defects can be regarded as the cost of nonconformance for the tester. Clearly the tester with the lowest escape rate will have the lowest cost of nonconformance. In general the cost of conformance rises as you try to achieve a higher degree of test comprehensiveness, and the cost of nonconformance falls as the test comprehensiveness rises. The total cost at any point will be the sum of the two and this cost will be at a minimum somewhere near the point where the two cost lines cross each other. This is illustrated in Fig. 7.1.

Several elements of the cost of nonconformance are difficult to quantify. These are the cost of lost repeat business due to customer dissatisfaction and the cost of lost sales resulting from a poor quality reputation. Another important area is the added risk of ***'product liability'*** litigation, as referred to in Chapter 2. As a result of this the real minimum may be at a point where the measured cost of nonconformance is well below the cost of conformance.

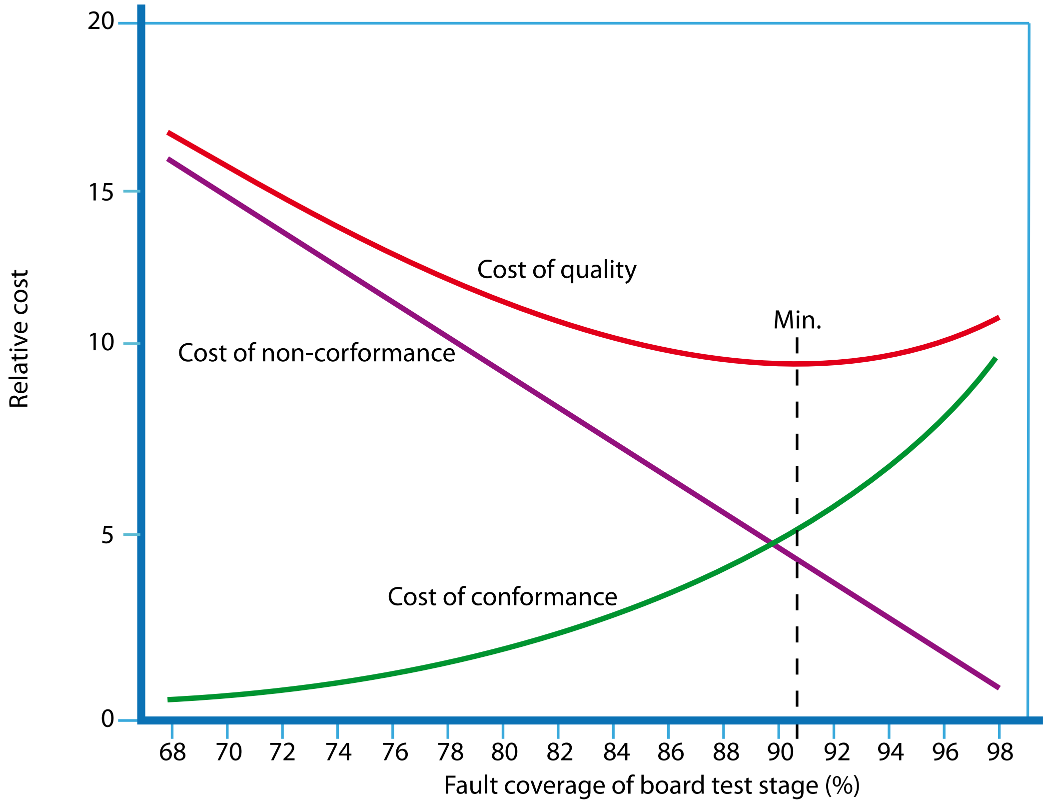


Figure 7.1 The total cost of quality consists of two elements, the cost of conformance and the cost of non-conformance. The cost of non-conformance will fall as the the test comprehensiveness increases, but the cost of achieving this test comprehensiveness will usually rise in a non-linear manner. In this example the cost of conformance rises exponentially by an order of magnitude as the fault coverage of the board test stage increases from 69% to 98%. The cost of non-conformance is made up of additional system test and field test costs. The minimum cost of quality is achieved, for this case, when the board test fault coverage is a little over 90%.

7.16 The search for cheaper board testing

The test engineering manager is under pressure to reduce the cost of test. At the same time he or she is told that 'testing adds no value'. The only ray of sunshine that can be seen is the increased yields that the quality improvement process has generated. Unfortunately the search for cheaper testing and the high manufacturing yields have occasionally resulted in some less than optimal decisions being made. Cheaper testing does not necessarily come from cheaper testers unless those testers still have good fault coverage, and higher yields do not mean that you can get by with a lower level of fault coverage. In fact the reverse is true. The fault coverage capabilities of a tester are dependent on the fault spectrum that it sees. If all of the faults are simple ones then the coverage can be very high. However, as the fault spectrum moves towards defects that are more difficult to detect the fault coverage will fall. Most quality improvement processes are based upon the Pareto method of eliminating the biggest causes of defects first so there is a tendency for the fault spectrum to become biased towards the most problematic defects as the yield improves. The laws of mathematics cannot be bent. If you attack a 90 per cent yield with a 70 per cent fault cover the escape rate will be the same as attacking a 70 per cent yield with a 90 per cent fault cover. The net result will be no improvement in the shipped quality of the product. All the effort taken to improve the yield will have been wasted. The cheapest testing will