On Relationship of System Testability, Reliability and Modularity

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Life-Cycle Benefits of Modularity

- Design
  - Problem Tractability
  - Evolvability/Reuse
  - Upgradability
- Implementation/Integration/Manufacturing
  - Parallel implementation
  - Testability
  - Assembility
- Use/Operation
  - Maintainability
  - Reparability
  - Extendability of operations/functions
- Retirement
  - Recyclability

What is Testability?

- Testability is commonly defined as the degree to which a component or system can be tested in isolation, or as the relative to effort required to test it.
- Design for test techniques improve quality of the product in addition to reducing the costs of testing
- Testability is commonly regarded as dependent on two other qualities :
  - Observability: is the degree to which internal state of a system can be inferred from its inputs and outputs relations.
  - Controllability: is the degree to which the internal state of a system is determined by the inputs.

Standard Definitions of Testability

- Extent to which an objective and feasible test can be designed to determine whether a requirement is met (ISO/IEC 12207).
- Degree to which a requirement is stated in terms that permit establishment of test criteria and performance of tests to determine whether those criteria have been met (IEEE 1233).
- Degree to which a system or component facilitates the establishment of test criteria and the performance of tests to determine whether those criteria have been met (ISO/IEC/IEEE 24765).
- Degree of effectiveness and efficiency with which test criteria can be established for a system, product, or component and tests can be performed to determine whether those criteria have been met (ISO/IEC 25010).

So…

- Testability can be a property of a requirement, a system, or any structural constituent of the system—that is, of any system element.
- We define one aspect of testability as the reliability of the test, or the confidence in the outcome of the test, or the probabilistic accuracy of the test in having the correct outcome.

A Model of System Integration and Testing

- Reliability of the system after integration **without** any testing:

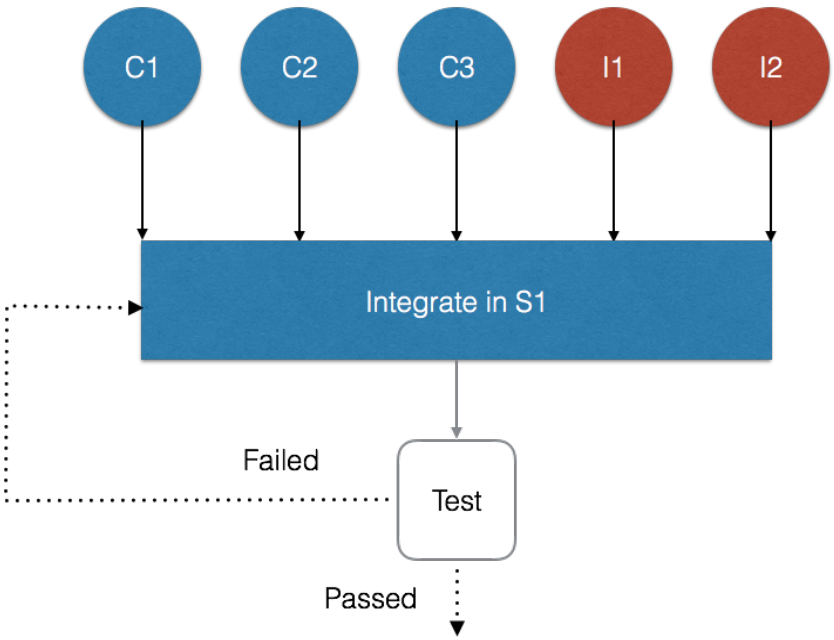
$$R_S = \prod_{i=1}^{n} R_i$$

- Reliability of the system after integration and testing:

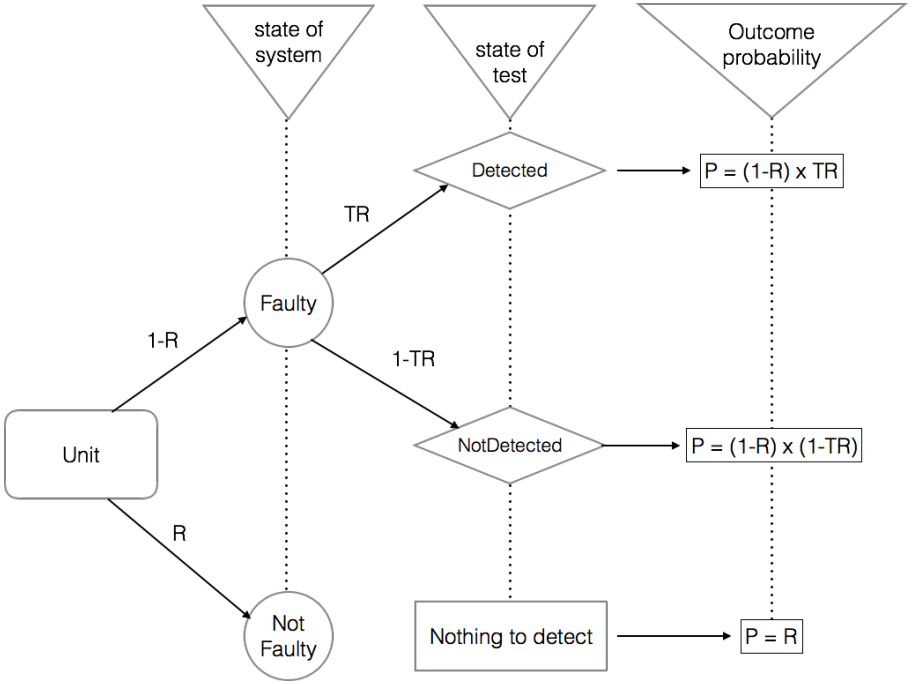
$$R_{ST} \geq \prod_{i=1}^{n} R_i$$

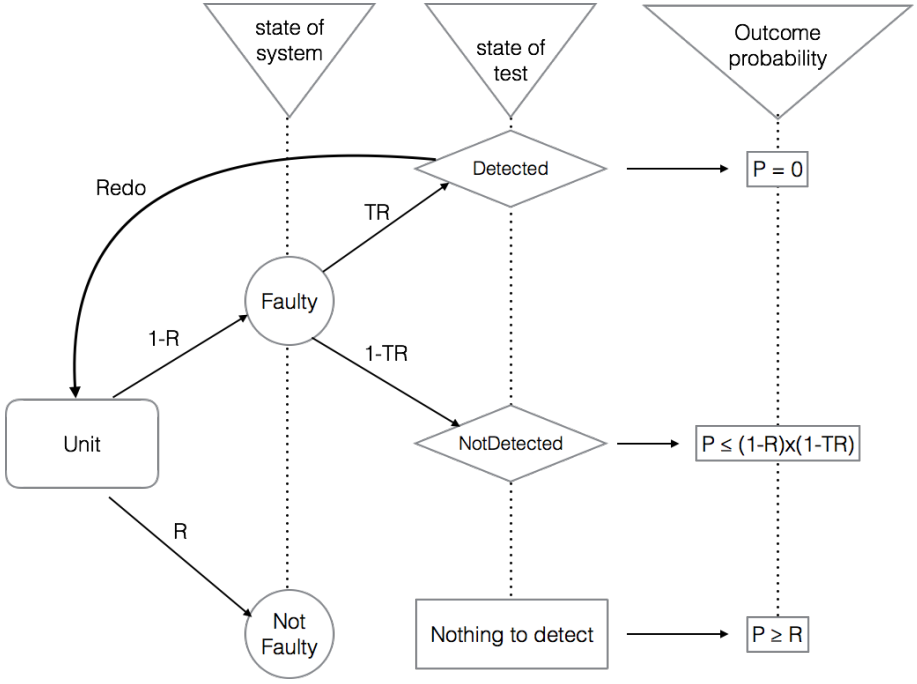
- **Latent Defect** Probability:

P_{LD} = (1-R)×(1-TR)



Repeated Testing



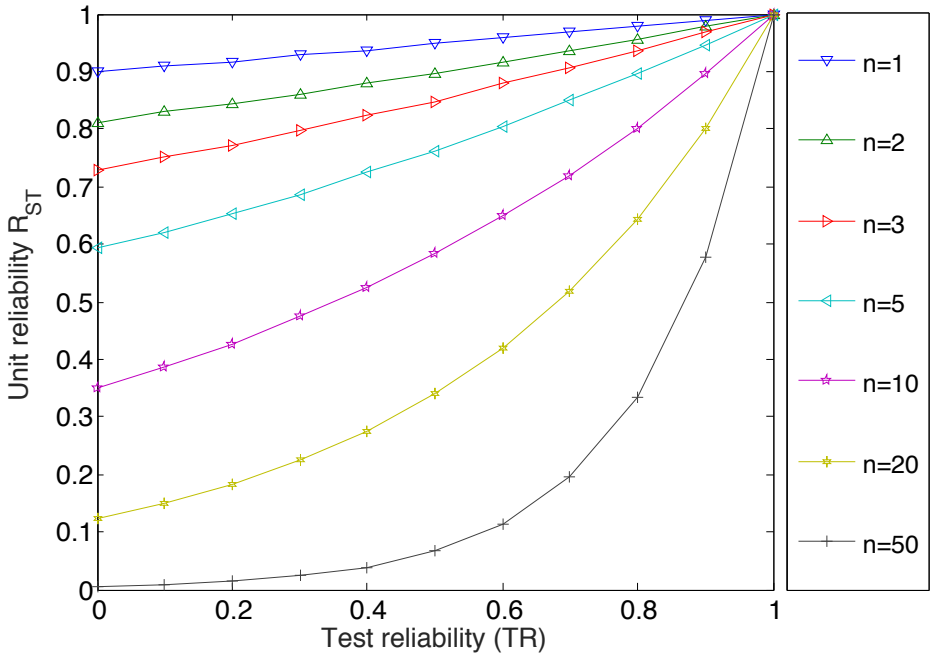


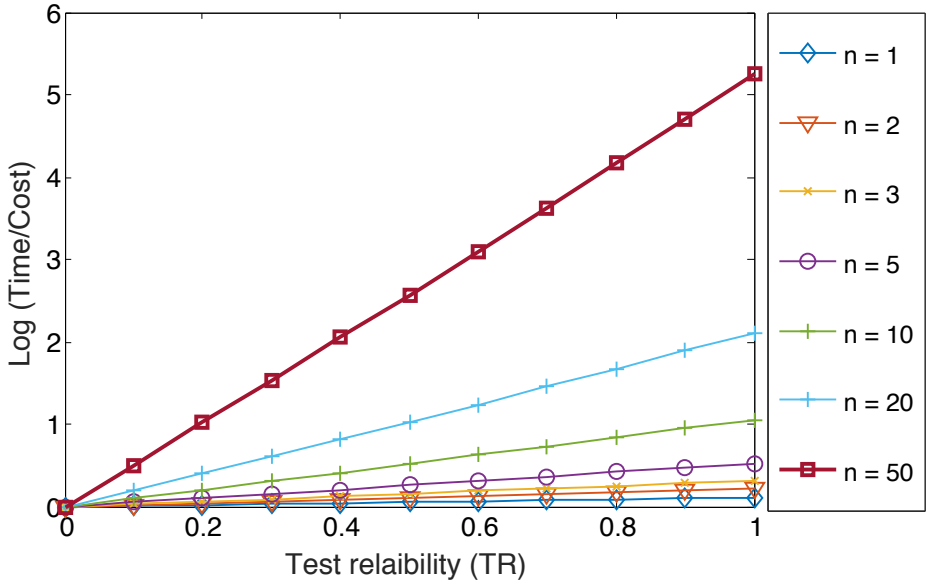
Solving for R_{ST} and Test time/cost

- Monte Carlo Simulation:
  - R_{ST} is system reliability after repeated testing.
  - The expected number of tests are indicators of the total test cost/time.

```
k= 1000000;
test_time = 0;
latent = 0;
for i = 1:k
    f = rand(1,n) > R;%a one means a fault
      test_time= test_time + 1;
       while any(f)
         m = nnz(f);%no of actual defects
          d = rand(1,m) < TR; %detected defects
            if any(d)
                 j = find(d);
                    f = rand(1,n) > R;
                 test_time=  test_time + 1;
            else
               f = 0;
               latent = latent + 1;
            end
    end
end
RST = 1 – (latent/k);
TST = n * test_time / k;%for the unit
```

Reliability and Cost of Repeated Testing





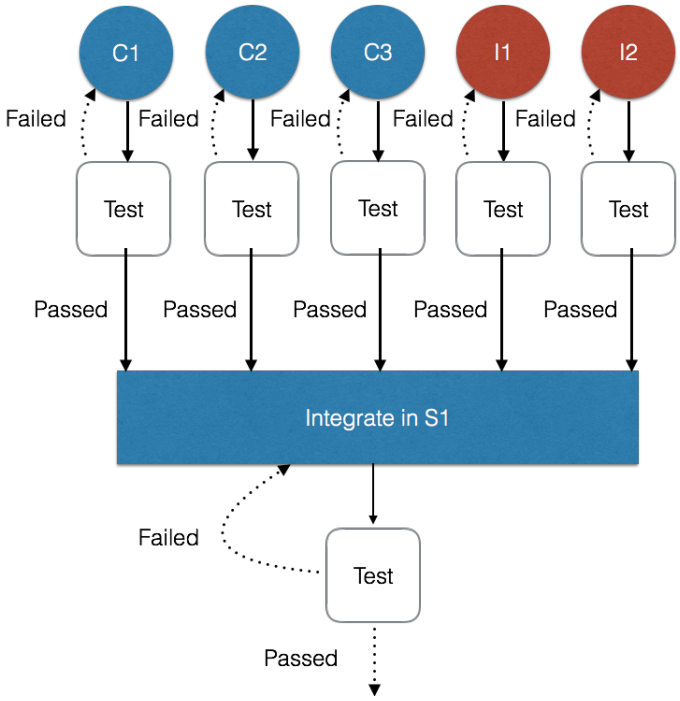
n is system size, number of components and interfaces.

R = 0.9 for all components/ interfaces.

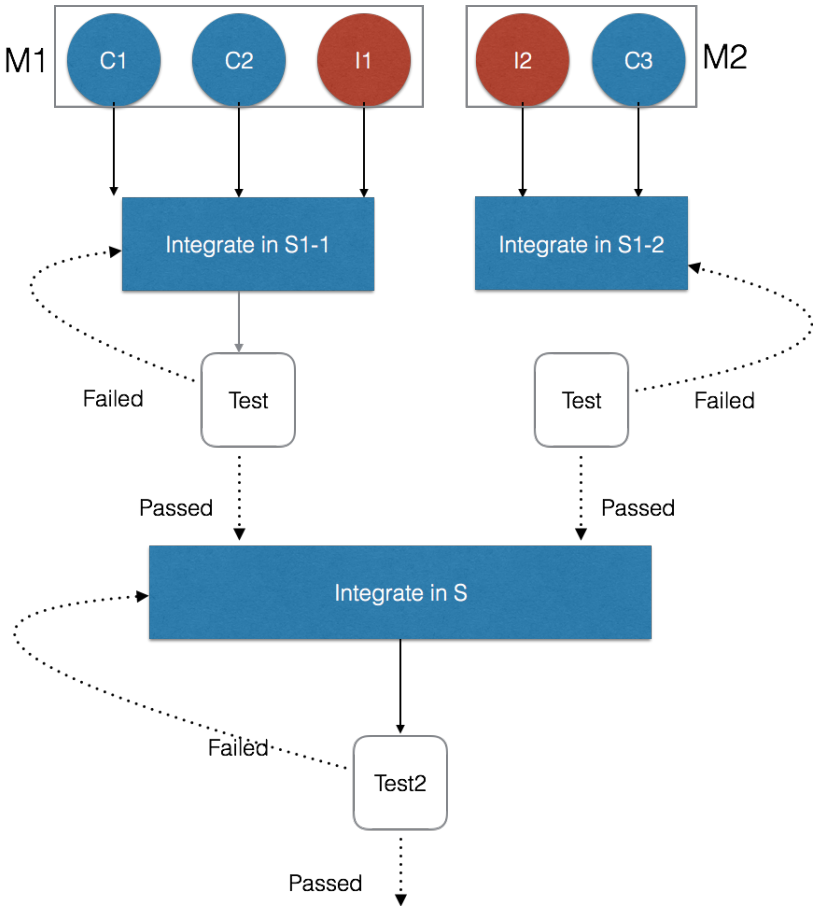
Modular Testing

- Grouping of components into modules for test.
- Each module then requires creation of separate test plans.
- We ignore the cost of creating separate test plans for modules.

Testing Architecture



or



A two level testing architecture with no modularization.

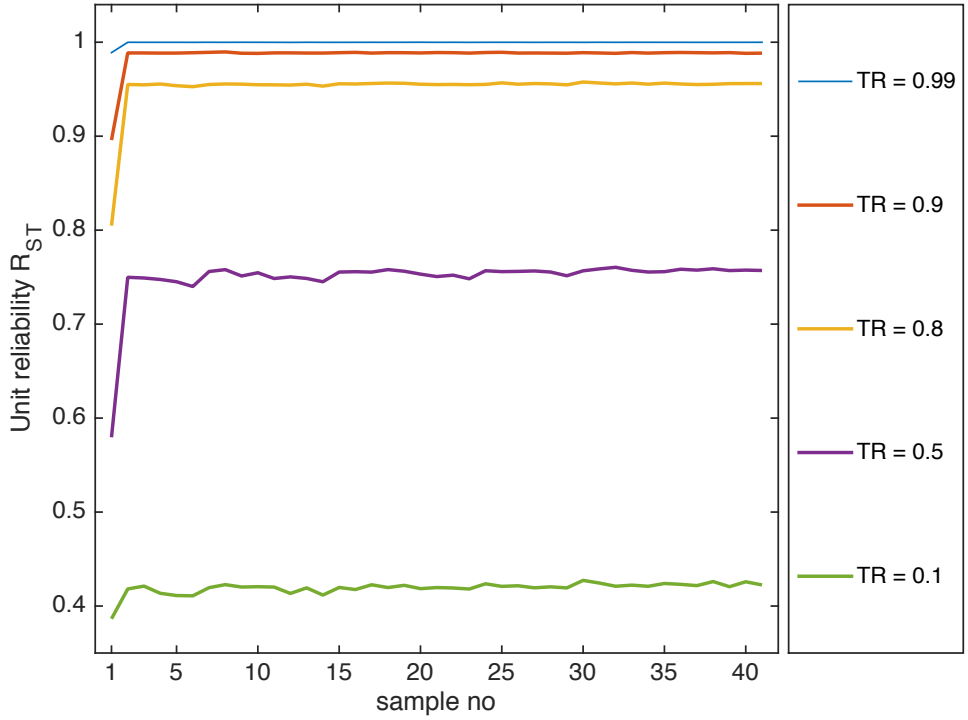
A two-level testing architecture with a two-module decomposition.

41 Sample Architectures

	no	m	no	m	no	m	no	m	no	m
Sample	**1**	1	**2**	2	**3**	2	**4**	2	**5**	2
M vector	[10]		[[5],[5]]		[[6],[4]]		[[7],[3]]		[[8],[2]]	
Sample	**6**	2	**7**	3	**8**	3	**9**	3	**10**	3
M vector	[[9],[1]]		[[4],[3],[3]]		[[4],[4],[2]]		[[5],[3],[2]]		[[5],[4],[1]]	
Sample	**11**	3	**12**	3	**13**	3	**14**	3	**15**	4
M vector	[[6],[2],[2]]		[[6],[3],[1]]		[[7],[2],[1]]		[[8],[1],[1]]		[[3],[3],[2],[2]]	
Sample	**16**	4	**17**	4	**18**	4	**19**	4	**20**	4
M vector	[[3],[3],[3],[1]]		[[4],[2],[2],[2]]		[[4],[3],[2],[1]]		[[4],[4],[1],[1]]		[[5],[3],[1],[1]]	
Sample	**21**	4	**22**	4	**23**	4	**24**	5	**25**	5
M vector	[[5],[2],[2],[1]]		[[6],[2],[1],[1]]		[[7],[1],[1],[1]]		[[2],[2],[2],[2],[2]]		[[3],[2],[2],[2],[1]]	
Sample	**26**	5	**27**	5	**28**	5	**29**	5	**30**	6
M vector	[[3],[3],[2],[1],[1]]		[[4],[3],[1],[1],[1]]		[[5],[2],[1],[1],[1]]		[[6],[1],[1],[1],[1]]		[[2],[2],[2],[2],[1],[1]]	
Sample	**31**	6	**32**	6	**33**	6	**34**	6	**35**	7
M vector	[[3],[2],[2],[1],[1],[1]]		[[3],[3],[1],[1],[1],[1]]		[[4],[2],[1],[1],[1],[1]]		[[5],[1],[1],[1],[1],[1]]		[[2],[2],[2],[1],[1],[1,[1]]	
Sample	**36**	7	**37**	7	**38**	8	**39**	8	**40**	9
M vector	[[3],[2],[1],[1],[1],[1],[1]]		[[4],[1],[1],[1],[1],[1],[1]]		[[2],[2],[1],[1],[1],[1],[1],[1]]		[[3],[1],[1],[1],[1],[1],[1],[1]]		[2],[1],[1],[1],[1],[1],[1],[1],[1]	
Sample	**41**	10								
M vector	[[1],[1],[1],[1],[1],[1],[1],[1],[1],[1]]									

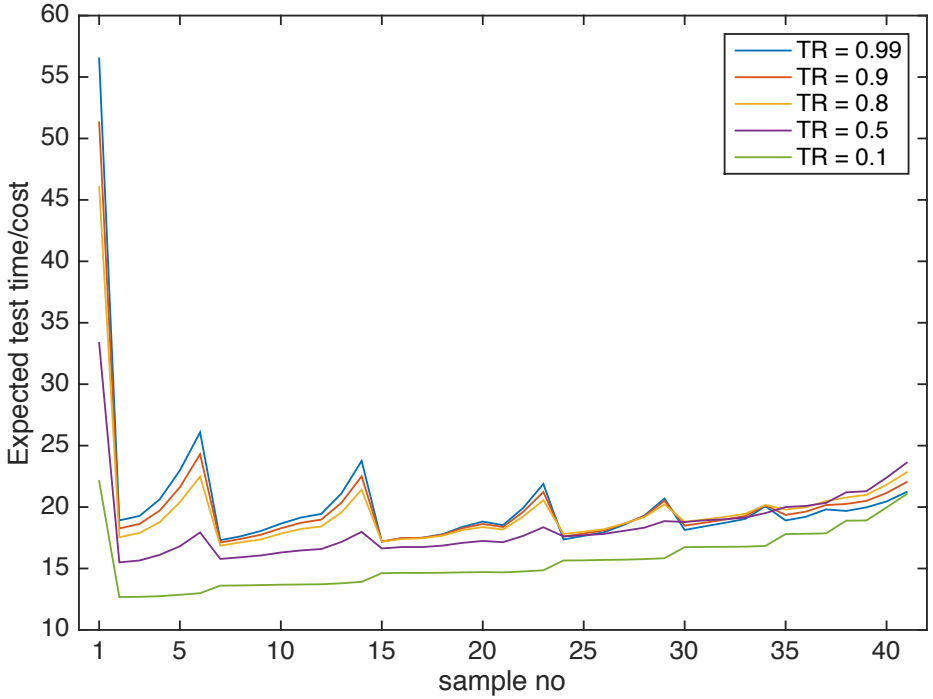
N = 10 (system size)

Reliability after Testing



For all two-layer testing architectures (sample no≥2), the achievable unit reliabilities are mostly identical for any given test reliability value.

Testing Cost



- The expected time/costs of the two-layer architectures vary greatly with architecture.
- Modularization reduces the cost of testing more than 50% relative to non-modular (one-layer) architecture.
- The time/cost is sensitive to the topology of the testing.
- Samples no 2, 7, 15, 24, 30, and 35 show a consistent pattern of local cost minimization; thus they are a more efficient architecture for testing; because the same unit reliability results at the lowest cost.
- These sample numbers have the minimum standard deviation of the number of modules for their modularization number.

Conclusion

- Modularity facilitates testability: any modular testing architecture reduces the number of latent defects.
- Although the expected time/costs vary greatly with architecture, modularization into a two-level architecture reduces the cost of testing more than 50% relative to a non-modular (one-layer) architecture.
- Additionally, the time/cost is much more sensitive to the topology of the testing than it is to the unit reliability.
- Balanced modularization leads to lowest testing cost.
  - For example when creating two modules, a modularization vector of MV = [5,5] has a variance of zero, and for three modules MV=[3, 2, 2] has the lowest variance amongst all three-module architectures.

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- Extent to which an objective and feasible test can be designed to determine whether a requirement is met (ISO/IEC 12207:2008 Systems and software engineering--Software life cycle processes, 4.52).
- Degree to which a requirement is stated in terms that permit establishment of test criteria and performance of tests to determine whether those criteria have been met (IEEE 1233-1998 (R2002) IEEE Guide for Developing System Requirements Specifications, 3.18).
- Degree to which a system or component facilitates the establishment of test criteria and the performance of tests to determine whether those criteria have been met (ISO/IEC/IEEE 24765:2010 Systems and software engineering--Vocabulary).
- Degree of effectiveness and efficiency with which test criteria can be established for a system, product, or component and tests can be performed to determine whether those criteria have been met (ISO/IEC 25010:2011 Systems and software engineering--Systems and software Quality Requirements and Evaluation (SQuaRE)--System and software quality models, 4.2.7.5).