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IEEE Trial-Use Standard for Testability and Diagnosability Characteristics and Metrics

IEEE Standards Coordinating Committee 20

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IEEE Standards Coordinating Committee 20 on
Test and Diagnosis for Electronic Systems



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**IEEE Standards Coordinating Committee 20 on
Test and Diagnosis for Electronic Systems**

Approved 23 September 2004

IEEE-SA Standards Board

Abstract: This standard was developed to provide standard, unambiguous definitions of testability and diagnosability metrics and characteristics. It builds on fundamental definitions derived from elements in formal information models related to test and diagnosis defined in IEEE Std 1232™-2002.

Keywords: aggregation fundamentals, cost-related fundamentals, diagnosability, diagnostic inference model, enhanced diagnostic inference model, fault tree model, metrics, testability

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Introduction

This introduction is not part of IEEE Std 1522-2004, IEEE Trial-Use Standard for Testability and Diagnosability Characteristics and Metrics.

Publication of this trial-use standard for comment and criticism has been approved by the Institute of Electrical and Electronics Engineers. Trial-use standards are effective for 24 months from the date of publication. Comments for revision will be accepted for 18 months after publication. Suggestions for revision should be directed to the Secretary, IEEE-SA Standards Board, 445 Hoes Lane, Piscataway, NJ 08855-1331, and should be received no later than 23 March 2006. It is expected that following the 24-month period, this trial-use standard, revised as necessary, shall be submitted to the IEEE-SA Standards Board for approval as a full-use standard.

As systems became more complex, costly, and difficult to diagnose and repair, initiatives were started to address these problems. The objective of one initiative, testability, was to make systems easier to test. To be useful, this commercial standard must provide specific, unambiguous definitions of criteria for assessing system testability.

Recent initiatives by the Institute of Electrical and Electronics Engineers (IEEE), Inc. on standardizing test architectures have provided an opportunity to standardize testability metrics. The IEEE 1232™ Artificial Intelligence Exchange and Service Tie to All Test Environments (AI-ESTATE) series of standards provide the foundation for precise and unambiguous testability and diagnosability metrics.

It is the objective of this standard to provide notionally correct and inherently useful but mathematically precise definitions of testability measures that may be used to either measure the testability characteristics of a system or to predict the testability of a system. Notionally correct means that the measures are not in conflict with intuitive and historical representations.

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IEEE Trial-Use Standard for Testability and Diagnosability Characteristics and Metrics

1. Overview

This standard was developed by the Diagnostic and Maintenance Control (D&MC) subcommittee of the IEEE Standards Coordinating Committee 20 (SCC20) on Test and Diagnosis for Electronic Systems to provide standard, unambiguous definitions of testability and diagnosability metrics and characteristics. This standard builds on fundamental definitions derived from elements in formal information models related to test and diagnosis defined in IEEE Std 1232TM-2002.¹

The goals of this standard are summarized as follows:

- Provide definitions of testability and diagnosability characteristics and metrics that are independent of specific test and diagnosis technologies.
- Provide definitions of testability and diagnosability characteristics and metrics that are independent of specific “system under test” technologies.
- Provide unambiguous definitions of testability and diagnosability metrics used by procurement and support organizations.

Over a century ago, Lord Kelvin commented: “When you can measure what you are speaking about and express it in numbers, you know something about it; and when you cannot measure it, you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind. It may be the beginning of knowledge, but you are scarcely in your thought advanced to the stage of a science.” To add to Lord Kelvin’s insight, when different tools measure something differently, and the basis for the measurement is not known or understood, it is neither knowledge nor science.

It is the objective of this standard to provide precise formal definitions of metrics that may be used to predict the testability of a system. Predictive metrics may be used iteratively during various phases of design and diagnostic development to map the progress toward a project’s testability goals. On the other hand, empirical metrics are derived from actual maintenance data to determine the testability achieved during the factory and field testing of a system.

¹Information for references can be found in Clause 2.

It is the intent of this standard that predictive testability and diagnosability metrics be defined based on IEEE Std 1232-2002. Where entities are required that have not been defined in these information models, this standard will provide its own information model in the form of an AI-ESTATE extension to satisfy the deficiency. It is not the intent of this standard to impose any implementation-specific requirements for actually computing the metrics; however, metrics not computed using the identified standard information models must be demonstrated to be mathematically equivalent to the definitions provided. Furthermore, metrics defined in this standard are based on the assumption that no more than a single independent fault exists at the time of diagnostics. Multiple fault metrics are outside the scope of this standard because of a lack of industry consensus as to how those metrics should be calculated.

1.1 Scope

This standard defines technology-independent testability and diagnosability characteristics and metrics, particularly those based on relevant standard information models, including standard AI-ESTATE information models.

1.2 Purpose

This standard will provide consistent, unambiguous definitions of testability and diagnosability characteristics and metrics. As a result, a common basis for system testability and diagnosability assessment will be provided.

1.3 Conventions used in this standard

The subclauses present specification formats using the EXPRESS language (ISO 10303-11:1994). All specifications in the EXPRESS language are given in the Courier type font, which includes references to entity and attribute names in the supporting text.

This standard uses the vocabulary and definitions of relevant IEEE standards. In case of conflict of definitions, except for those portions quoted from standards, the following precedence shall be observed: (1) Clause 3; (2) SCC20 documentation and standards; and 3) *The Authoritative Dictionary of IEEE Standards Terms*, seventh edition [B4]. For clarity, portions of IEEE Std 1232-2002 are repeated in this standard. In the event of revision to AI-ESTATE, the current, approved version of IEEE Std 1232-2002 takes precedence.

2. References

This standard shall be used in conjunction with the following publications.

IEEE Std 1232-2002, IEEE Standard for Artificial Intelligence Exchange and Service Tie to All Test Environments (AI-ESTATE).²

ISO 10303-11:1994, Industrial Automation Systems and Integration—Product Data Representation and Exchange—Part 11: Description Methods: The EXPRESS Language Reference Manual.³

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

³ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembe, CH-1211, Genève 20, Switzerland/ Suisse (<http://www.iso.ch/>). ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards and Terms*, Seventh edition [B4] should be referenced for terms not defined in this clause.⁴

3.1 characteristic: With respect to testability and diagnosability, this property or indicator of a system describes its behavior under test. It may or may not be measurable during actual system operation or maintenance.

3.2 diagnostic strategy: An approach taken to combine factors, including constraints, goals, and other considerations to be applied to localizing faults in a system.

3.3 diagnosability: The degree to which faults within a system can be *confidently* and *efficiently* identified. Confidently means frequently and unambiguously detecting and isolating faults when they occur. Efficiently means optimizing the resources required to achieve fault isolation.

3.4 fault detection: The process of identifying and reporting the presence of one or more faults within a system.

3.5 metric: With respect to testability and diagnosability, this characteristic can be evaluated by analysis or measured during system operation and maintenance.

3.6 testability: A system design characteristic that allows its operational status to be determined and the isolation of faults to be performed efficiently.

4. Context

As systems became more complex, costly, and difficult to diagnose and repair, initiatives were started to address these problems. Early on, these initiatives focused on having enough test points in the right places. As systems evolved, it was recognized that the system design had to include characteristics to make the system easier to test. This recognition was the start of considering testability as a design characteristic. As defined in MIL-STD-2165, testability is “a *design characteristic* which allows the status (operable, inoperable, or degraded) of an item to be determined and the isolation of faults within the item to be performed in a timely manner” ([B1], emphasis added). The purpose of MIL-STD-2165 was to provide uniform procedures and methods to control planning, implementation, and verification of testability during the system acquisition process. This standard, although deficient in some areas, provided useful guidance to government suppliers. Furthermore, lacking any equivalent industry standard, many commercial system developers have used it to guide their activities, although it was not imposed as a requirement.

Today, the discipline of testability is made up of two related practices. The first of these, design for test (DFT), facilitates the testing process by encouraging good design practices. The second testability practice, the one that is addressed within this standard, evaluates *diagnosability*. Thus far, formal, unambiguous definitions of testability and diagnosability metrics and characteristics have been unavailable. This standard addresses this issue by building on the fundamental definitions in the information models of AI-ESTATE. Specifically, this standard defines metrics related to fault detection and isolation.

Traditionally, fault detection metrics are represented as a ratio of detected or detectable faults to the full set of possible faults under consideration (often called a fault universe). Frequently, this ratio is weighted using the failure rates of the faults within the fault universe so that it expresses the likelihood of a fault being detected.

⁴The numbers in brackets correspond to those of the bibliography in Annex A.

Traditionally, fault isolation metrics are based on a ratio of the number of faults in ambiguity groups of a specified size (or less) to the total number of faults that can be isolated for a given system. As with detection, isolation calculations are frequently weighted using failure rates so that they express the likelihood of isolating a fault within an ambiguity group of a given size.

In addition to fault detection and fault isolation, testability has been concerned with, among other things, attempting to predict and measure the incidence of false indication (i.e., frequency of false alarm and nondetection). False indication issues are complex, and no consensus exists in the test industry for predicting and measuring the incidence of false indication. Given this lack of consensus, this standard will defer specification of metrics for false indication until such time as consensus is reached.

4.1 Predictive and empirical metrics

This standard distinguishes between two classes of metrics—predictive and empirical. Predictive metrics include all testability and diagnosability metrics that can be derived from a static AI-ESTATE-compliant model (i.e., the fault tree model [FTM], diagnostic inference model [DIM], or enhanced diagnostic inference model [EDIM]) and thus provide a quantitative evaluation of how well the system can be diagnosed using that diagnostic model. These metrics will be calculated differently depending on whether the diagnostic model is developed in the form of a fault tree (FTM) or test-to-diagnosis inference relationships (DIM or EDIM). Empirical metrics, as previously discussed, are derived from collected maintenance data and are beyond the scope of this standard.

In defining the metrics for this standard, the following approach has been taken. Clause 5 provides several fundamental measures to be used in defining testability and diagnosability metrics. First, several fundamental functions are defined in 5.2, which aggregate basic elements from the AI-ESTATE models. Next, functions are defined in 5.3 to estimate cost of tests or probability of faults based on the cost model within AI-ESTATE.⁵ Third, several functions are defined in 5.4 to assist in traversing the diagnostic models within AI-ESTATE. Although all of the fundamental measures under Clause 5 are defined using the AI-ESTATE information models, often multiple correct means compute the individual fundamentals. As it is the purpose of this standard to provide semantically rigorous definitions, not to dictate the method(s) of calculation, detailed algorithms are not provided for these fundamental measures. Finally, Clause 6 uses these fundamental measures from Clause 5 to define the standard metrics for testability and diagnosability.

4.2 Relationship to AI-ESTATE standard

IEEE Std 1232-2002 (AI-ESTATE) is an information exchange standard for test and diagnosis. The standard defines the architecture of an AI-ESTATE-conformant system, the information models for knowledge and data exchange, and a set of standard software services to be provided by a diagnostic reasoner in an open-architecture test environment. Because it provides formal definitions (via information modeling) of the information required for test and diagnosis—the same information required for determining the testability and diagnosability of a system—the AI-ESTATE standard is used as the basis for the metrics defined within this standard.

A description of how to use the fundamentals to develop metrics is contained in Clause 6.

4.3 Conformance

This subclause defines the requirements for conformance to the standard testability and diagnosability characteristics and metrics defined in this standard. Conformance demands that all metrics be computed as specified in Clause 6.

⁵Failure rate was accounted for by extending the AI-ESTATE models with the EXTEND schema in 5.3.1.

4.4 Extensibility

Although extensions are nonconformant, an extensibility mechanism is provided to facilitate future enhancement of this standard. Extensions should be submitted to the D&MC Subcommittee to be considered for inclusion in future versions of the standard. Proposed extensions to the metrics defined in this standard are ranked in order of preference as follows:

- a) Metrics derived strictly from the fundamental measures of Clause 5
- b) Metrics derived from functions and measures based strictly on the AI-ESTATE models
- c) Metrics derived from functions and measures based on the AI-ESTATE models in combination with AI-ESTATE-conformant extensions (i.e., EXTEND schemata)

Extensions cannot be used to redefine any metrics defined in this standard.

5. Fundamental measures

The fundamental measures defined in this clause are categorized as either aggregation measures, cost-related measures, or measures to support detection and isolation metrics. The specific measures defined in this clause are listed in Table 1.

5.1 Overview and assumptions

The approach being taken to define standard, unambiguous testability and diagnosability metrics is based on the assumption that standard information models provide formal semantics for information of interest to the testability and diagnosability domain. In this section, several specific, fundamental measures will be defined using terminology from EXPRESS models defined in AI-ESTATE. The approach to specifying measures will follow the conventions for defining services in AI-ESTATE (see 4.2).

The fundamental measures in this clause are based on the following propositions:

- The primary information models used to define these measures are drawn from the AI-ESTATE standard. The specific models used include the AI-ESTATE common element model, fault tree model, diagnostic inference model, and enhanced diagnostic inference model.
- All cost-related metrics shall be computed with respect to a single test or repair within the AI-ESTATE common element model as qualified by specifically identified constraints and types.
- To manage the complexity of computing isolation-related metrics and to remove dependence on diagnostic and maintenance strategies, all isolation metrics shall be computed under the assumption that no more than a single, independent fault exists at the time of diagnostics.
- When defining the measures for detection and isolation, it is clear that the type of underlying diagnostic model (i.e., fault tree model, diagnostic inference model, or enhanced diagnostic inference model) will establish detectability and isolatability differently. Consequently, these measures will be defined with an identification of which of the model types provided in AI-ESTATE is being used.
- Many measures are defined relative to a “level” defined within the AI-ESTATE model. AI-ESTATE defines the level entity to be “the level of indenture for a particular hierarchical element. This defines a common level for purposes of constraining diagnosis or analysis for testability and diagnosability assessment.”

Table 1—Defined fundamental measures

Aggregation functions action_set diagnosis_set failure_mode_set failure_set fault_set function_set repair_item_set repair_set resource_set
Cost functions probability_of_diagnosis probability_of_repair_item_set repair_context_non_time_cost repair_context_time_cost repair_level_non_time_cost repair_level_time_cost repair_non_time_cost repair_time_cost test_context_non_time_cost test_context_time_cost test_level_non_time_cost test_level_time_cost test_non_time_cost test_time_cost total_repair_non_time_cost total_repair_time_cost total_test_non_time_cost total_test_time_cost
Detection and isolation functions get_leaves get_signature get_ambig_group get_diag_ambig_group get_size_n_ambig_group get_size_n_diag_ambig_group convert_repair_to_diag_ambiguity convert_diag_to_repair_ambiguity repair_item_ambiguity diagnosis_ambiguity single_level_detection implicated_diagnosis_set detectable_failure_set detectable_fault_set isolatable_repair_item_set isolatable_diagnosis_set isolatable_failures_set isolatable_faults_set fault_ambig_set failure_ambig_set