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Requirements and Recommendations for STEP Conformance Testing

NATIONAL PDES TESTBED™

Sharon J. Kemmerer, editor

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Requirements and Recommendations for STEP Conformance Testing

Sharon J. Kemmerer, editor

U.S. Department of Commerce
Robert A. Mosbacher, Secretary

Technology Administration
Robert M. White,
Undersecretary for Technology

National Institute of Standards and Technology
John W. Lyons, Director

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Foreword

This report was developed by Shantu Dhar and Robert S. Matthews of the Industrial Technology Institute (ITI) under a National Institute of Standards and Technology (NIST) task order contract number 43NANB020484. ITI is a not-for-profit research and development organization located in Michigan, whose mission is to advance the competitiveness of American manufacturing organizations. ITI technical staff is experienced and educated in manufacturing-related technologies and organizational, economic, and business issues. One area (of many) where ITI and NIST interests coincide is in the development and conformance testing of STEP. NIST published the National PDES Testbed Development Plan for a STEP Conformance Testing Service (NISTIR 4641), which defines an important need for the conformance testing (CT) of STEP products.

The work described in this document was funded by the U.S. Government's Department of Defense Computer-aided Acquisition and Logistic Support (CALS) initiative. Although the CALS Evaluation and Integration Office and NIST do not necessarily endorse the recommendations found here, it is important to make public such recommendations for discussion. This report focuses on important issues that will arise during an effort to offer a full-scale STEP conformance testing service to U.S. industry. The content presented here draws from ITI's past conformance testing experience in order to provide a perspective of the real-life problems associated with developing and offering testing services. Thus, to the decision-maker and funding agency considering active participation in STEP CT, this report identifies major issues confronting CT in general, and STEP CT in the United States in particular. It also offers insight into the direction that U.S. activity should proceed.

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Executive Summary

The Standard for the Exchange of Product Model Data (STEP) is an emerging set of standards that will revolutionize the use and exchange of product information by manufacturing organizations. In order for STEP to achieve this objective of free exchange and use of product data, STEP-conformant products based on standardized application protocols have to be available to users. Moreover, since such products will interact and transmit information among each other, it is imperative that they "interoperate" (work together or share data appropriately).

The National Institute of Standards and Technology (NIST) actively participates in the STEP development effort to support U.S. industry. NIST and other U.S. activities contributing to STEP are known as PDES (Product Data Exchange using STEP). NIST is developing a nation-wide Product Data Exchange Network,[1] along with associated long-range strategic development plans. The objective of this activity is to enable the broad-based adoption of STEP-conformant products.

The objective of this report is to evaluate the need for a conformance testing (CT) service for STEP implementations, and identify the steps that should be taken to develop an appropriate CT service. Two important assumptions underlie the conclusions presented in this report. First, experiences gained from CT services of other standards implementations can be adapted to STEP. Second, STEP is not a single standard but a collection of standards. Among this collection are application protocol (AP) standards, on which conformance testing of implementations will be based. An application protocol defines the context for the use of product data and specifies the use of the standard in that context to satisfy an industrial need.

This report is deliberately freestanding and fairly generic. Many of the issues raised here have been or are being considered by ISO TC184/SC4,[2] the international organization responsible for STEP standardization.

Conformance testing for standards such as STEP is a means of increasing the likelihood that two different systems operating under the same standard will work together. It is based on the concept that evaluating implementations of an AP against the standard itself, then giving the vendor time to make any corrections, will eliminate most obstacles to successful interoperability.

When implementations of standards for information representation and exchange were few in number, the evaluation of products required only the straightforward operation of determining whether they interoperated. Testing every product with every other through interoperability explodes to a complex task as more products exist. This is why conformance testing (CT) is the most important method of evaluating a product's adherence to a standard. Conformance testing does not remove the need for interoperability testing, but it can dramatically reduce the amount of effort required to get two differing systems to work together. The cost of CT is not insignificant, but if executed properly, it reduces the overall cost of getting systems to interoperate.

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[1]Simon Frechette and Kevin Jurrens, Product Data Exchange Network, NISTIR 4431, September 1990.

[2]International Organization for Standardization (ISO) Technical Committee on Industrial Automation (TC184) Sub-Committee on Industrial Data and Global Manufacturing Programming Languages (SC4).

The four main participants concerned with CT are the standard bodies that develop the standards, the vendors who build standard-conformant products, the users who require these products and need the assurance the products will interoperate, and the testing community which includes: testing laboratories, accreditation authorities, and certification bodies. To be successful, CT needs to satisfy the needs of all these entities. It must reflect the true intent of the standard in question, be inexpensive in the long run, and build the users' confidence in the value CT provides.

There are some strategic issues to consider when planning for STEP CT. The involvement of U.S. bodies, particularly the Department of Defense (DoD), is critical. Since DoD and its suppliers will be major users of STEP, the indigenous development of CT capabilities is essential. Another strategic issue is that of CT system openness. Once developed, STEP CT systems should be publicly available to vendors and users to perform in-house testing to help in product and application development.

A large number of procedural and administrative issues are associated with offering STEP CT. To begin with, a single or small number of STEP APs should be used to evaluate CT services. Then the experience gained in this preliminary exercise should be applied toward additional APs. Since funding is an important factor, major beneficiaries of these services would be expected to fund a CT development activity.

A number of recommendations are made as a result of this study. Among the most important are:

- The United States should create its own STEP CT system and not rely on other countries.
- The CT system itself should be made widely available, and in-house testing should be encouraged prior to formally-supervised CT.
- CT system development should start small, both in number of application protocols addressed, and in the facility established (resources and equipment) to undertake development.
- CT systems should be made highly automated for low-cost operation and high accuracy.

1. *Introduction*

The Standard for the Exchange of Product Model Data (STEP) is an emerging set of standards that will revolutionize the use and exchange of product information by manufacturing organizations. In order for STEP to achieve this objective of free exchange and use of product data, STEP-conformant products based on standardized application protocols have to be available to users. Moreover, since such products will interact and transmit information between each other, it is imperative that they "interoperate" (work together or share data appropriately).

Conformance testing is the evaluation of a product to see whether it meets a particular standard. Conformance testing (CT) for the products based on technologies like STEP (Standard for the Exchange of Product Model Data), where many suppliers and products must interoperate, is critical to STEP's rapid adoption by implementors and users. CT increases the user's confidence that the products will work. The initial planning, organizational interfacing, and prototyping of a CT system will be most effective if coordinated with STEP standards development activities. These activities include those associated with application protocol prototyping and validation, STEP standardization activities, and early commercial product development. In particular, AP validation activities can contribute test data and software to the development of CT.

The objective of this report is to evaluate the need for a conformance testing (CT) service for STEP implementations, and identify the steps that should be taken to develop an appropriate CT service. Two important assumptions underlie the conclusions presented in this report. First, experiences gained from CT services of other standards' implementations can be adapted to STEP. Second, STEP is not a single standard but a collection of standards. Among this collection are application protocol (AP) standards, on which conformance testing of implementations will be based. An application protocol defines the context for the use of product data and specifies the use of the standard in that context to satisfy an industrial need.

The following philosophy should guide CT development efforts. Foremost, CT and associated tools must help, not hinder, market adoption of conformance-tested products. CT development efforts can lose sight of this objective if the developers are not careful. Tools or services which perform to CT specifications could still be technically cumbersome, too expensive, or politically unacceptable because of a lack of consensus. To overcome such pitfalls, it is key for CT developers to regularly check decisions from the perspective of how will this help market adoption and stimulate the availability of useful products. By bearing this in mind, CT will stimulate increasing buyer confidence in STEP standards and STEP-based products.

1.1 *Organization of this Report*

In addition to this introduction, this report has four major sections. Recommendations on a specific issue are made, as appropriate, in the subsection dealing with that issue.

- Section 2 identifies CT issues and makes recommendations for dealing with such issues for STEP.

- Section 3 discusses evaluation procedures which include issues relating to the abstract and executable test suites (ATSs and ETSs) and tools, and evaluation of CT systems and testing laboratories.

- Section 4 proposes a set of milestones for the realization of STEP CT services in the United States.

- Section 5 concludes the report with a summary of the recommendations.

1.2 Definitions and References

Those terms most frequently used in this report are defined in Section 6. Unless otherwise noted, the definitions are extracted from ISO CD 10303-31, "Conformance Testing Methodology and Framework, General Concepts," of 15 November 1990.

In addition to ISO CD 10303-31, the following documents have been used in the preparation of this report:

ISO DIS 9646, OSI Conformance Testing Methodology and Framework, Parts 1,2, 4, and 5. [Available through the ISO Secretariat: 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland.]

ISO/IEC Guide 25, General Requirements for the Technical Competence of Testing Laboratories. [Available through the ISO Secretariat: 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland.]

ISO WD 10303-1, "STEP Overview and Fundamental Principles," August 1990. [Available through ISO TC184/SC4 Secretariat: NIST, 220, A127, Gaithersburg, MD 20899, USA.]

ITI Technical Report 87-14.1, Test Coverage Analysis and Measurement (TCAM) - A Practical Approach to Determining Coverage. [Available through ITI: P.O. Box 1485, Ann Arbor, MI 48106, USA.]

2. Conformance Testing Issues and Recommendations

This section discusses various issues relevant to STEP CT. The approach and structure of this report have been determined through discussions between NIST's contract representatives and ITI about the issues that need to be addressed. These discussions have led to the following major areas of concern:

- High-Level Issues
- Strategic Issues
- Development Issues

This section is an examination of the nature of CT and its characteristics and how they affect the task of developing and offering CT services. Section 2.1 presents these ideas for CT in general, and STEP CT in particular.

In any standard-related activity, be it standard development, implementation, or CT, there are four main participants that are primarily involved. These are the standards bodies which develop the standards, the developers who will build standard-conformant products, the users who will use these products, and, last but not least, the testing community. Of these four main participants each has its own concerns and needs and has to position itself strategically in order to fill these needs. Section 2.2 discusses these strategic issues.

Developmental concerns are an important component for the task of developing, offering, and arbitrating CT. Standards bodies and user groups (who are interested in seeing the standard get widespread acceptance) are concerned with the availability of high-quality standards, CT facilities, and competent CT staff. Developers want to ensure CT costs are reasonable, and CT is conducted fairly and without prejudice. Past experience has shown that an efficient and cost-effective way to conduct CT for networking protocols is with a set of tools that are modular, configurable, extendable, and automated. For STEP this is particularly significant. The right tools that can be configured to a given ATS, will automate the development of executable test cases (ETCs) and save on resources that would have been expended in developing them manually. Section 2.3 deals with these issues and lists brief descriptions of paper-and-pencil tools, software, and hardware that could be used to automate the CT process.

2.1 High-Level Issues

Conformance testing often means different things to different people. Because of this confusion there is a need to define CT, discuss its limitations, and describe measures of success. On some occasions CT has been promoted as the cure for incompatibility, which it is not. On the other hand, developers may see it as an extra hurdle in the path to commercialization. The following subsections identify some important issues in STEP CT and provide the basis for the discussions on strategic, developmental, and procedural issues that follow.

2.1.1 Scope of Conformance Testing

Successfully completing the conformance assessment process is not a guarantee of interoperability. CT may discover errors in an implementation; it cannot however demonstrate the implementation is error free. For a moment, let us assume that all conformance faults have been eliminated for a particular implementation. This would mean that an implementation would faithfully follow its specified behavior and that behavior required by the standard. But standards have their own inherent (and sometimes unavoidable) weaknesses. Validation and verification of STEP APs will hopefully eliminate the most serious problems of this nature prior to standardization, and thus prior to CT. Remaining subtleties, faults, ambiguities, or omissions in a standard can lead to two conformant implementations failing to interoperate in executing a desired function. Thus, demonstration of conformance does not unequivocally translate to a guarantee of interoperability. The standards development process must balance two diametrically opposed concepts: (1) over-specifying requirements to guarantee interoperability; or (2) under-specifying requirements to provide maximum latitude to implementors to optimize performance with respect to cost.

Conformance testing can be used to help in debugging implementations. ETSs and testing tools developed for testing laboratories could be offered to help developers in such debugging. Also, CT system openness (see Section 2.2.2) can allow developers to debug implementations at their premises without using accredited CT facilities.

2.1.2 Why Conformance Testing is Useful

The four main participants concerned with CT have different views of, and expectations from, CT. From the perspective of the standards bodies, CT is key to facilitating the acceptance and adoption of standards. Without CT a standard exists only on paper, and vendors' claims of conformance cannot be validated. In a sense, the conformance test is the standard. Further, CT can provide additional validation of the standard itself. Even though an AP was tested before being established as a standard, CT may yet expose parts of a standard that are difficult to implement, contradictory in nature, or too complex. Thus CT can provide valuable feedback to standards bodies to help them modify standards appropriately and thereby facilitate acceptance and adoption among vendors and users.

From the users' point of view, CT gives them confidence in a product in much the same way as products tested and marked by the Underwriters Laboratory--the product does what it is intended to do. In the long run, CT aims directly at reducing costs associated with product acquisition, operation, and maintenance.

In order to build conformance products, developers must invest in detailed and careful design, test thoroughly, and subject the product to CT. Thus, developers often see CT as an impediment in their ability to quickly respond to market needs, and as a factor that raises product prices. However, more and more developers agree that if done right, an early start in CT makes the task of developing standard-conformant products easier, less expensive in the long run, provides a marketing advantage, and gives users confidence in these products.

CT services and tools should be ready when STEP is accepted as an international standard. The Initial Graphics Exchange Specification (IGES) is an example where formal conformance testing requirements, tools, and procedures do not exist today for a standard against which there are many implementations. Having no conformance requirements against which to gauge developmental requirements has proven costly to the vendor, and therefore costly to the user. In addition, users are often reluctant to accept vendor claims of product conformance and therefore marketing of the product is delayed.

2.1.3 Conformance Versus Interoperability Testing

Traditionally, for standards involving the interaction of different companies' products, pairs of vendors' implementations were tested to see if they interoperated. This process is known as interoperability testing. To correct problems with the two systems' interactions, modifications were then made to either product (or both) based on what was convenient. Thus, a de facto standard evolved as a few key developers iteratively developed, tried to interoperate, went back to the drawing board to modify their implementation, and documented the assumptions based on their interactions. This approach was acceptable for three reasons: there were relatively few standards, few interested developers, and no better method was known.

Today, standards exist or are under active development in many areas of computing and information technology. Also, the number of developers and users has increased. But most important, the benefits of systematic development and standardization of CT have been recognized.

CT for STEP is intended to determine the degree to which a developer has correctly implemented a standard AP. CT determines whether or not an implementation operates correctly both in normal operation and under error conditions. While CT evaluates a single implementation against a reference system, interoperability testing uses two real systems to see if they interoperate. Since candidate systems test against a single reference system (or exact copies thereof), CT is a parallel process; whereas interoperability testing requires interoperation between all systems, thereby having a sequential nature. Doing interoperability testing alone quickly loses its attractiveness as the number of systems increases. In general, the cost of interoperability testing grows exponentially. On the other hand CT, while starting with a higher fixed cost (because of the need to build the reference system), grows approximately in a linear fashion with N. This relationship is shown in Figure 1. Interoperability testing is not without its benefits, however. Often, interoperability testing uncovers problems that went undetected during CT.

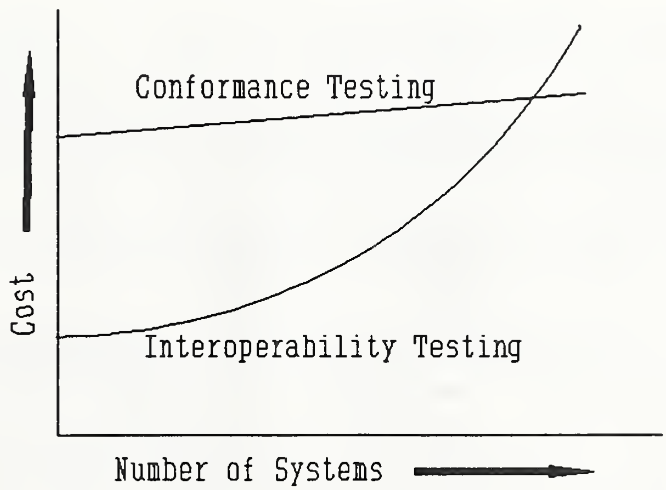

Figure 1: Conformance Testing versus Interoperability Testing

It should be mentioned that neither conformance nor interoperability testing is transitive in nature; i.e., if systems A and B pass CT with reference system R, there is no guarantee that they will interoperate. Similarly, if A interoperates with B, and B interoperates with C, there is no guarantee that A and C will interoperate. However, CT puts individual systems through the same transitions, helping to take care of nonconformant problems before the vendor participates in interoperability testing. Therefore, doing thorough CT before attempting interoperability testing makes sense.

A positive aspect of CT is that once it is done on an implementation, it need not be repeated until the implementation or abstract test suite is modified. The intent is to exercise as much of the logic inherent in the implementation as is practical. The implementation's responses to both correct and incorrect application protocol sequences are evaluated. Due to the complexity of the application protocols, it may not be realistic to try to be exhaustive during CT but to use a representative sample of operational sequences. There needs to be a strong agreement among standards bodies, users, and developers as to what this sample for a particular application protocol should be. These operational requirements should be specified in the standardized abstract test suites (ATSs).

An early start in STEP CT activity will likely lead to economy and timely realization of the benefits of product data standardization. This early start should be applied to writing standardized CT procedures, developing conformance requirements and test purposes, and producing supporting ATSs for APs. Interoperability testing will have to be done later, when independently developed systems start interacting. With strong CT activity already in progress, interoperability testing will be a task of lesser complexity and smaller magnitude; a lesson learned from the IGES user community. If no conformance testing is available, IGES users are forced to depend solely on interoperability testing each and every time they acquire a new system. With no frame of reference for determining how well a product conforms to a standard, the user is dependent on trial-and-error to obtain a level of confidence.

2.1.4 The Cost of Conformance Testing Versus the Cost of Not Doing Conformance Testing

There are a number of costs associated with CT:

- Building the organizational infrastructure for doing CT. This involves acquiring a site, equipping it, and maintaining administrative support for abstract and executable test suite development and later CT.

- Developing CT expertise. This involves recruiting appropriately qualified personnel and training them in the related CT technology.

- Building CT tools, ATSs, and the ETSs. This is the most important and technology-intensive part. This component will take up the largest of the fixed cost and, if not controlled, may defeat the very purpose of CT by becoming very expensive. In the context of STEP, it assumes even more importance; with several APs, an economical way to generate high quality AP-specific ATSs and ETSs is needed. The way to achieve this is to build tools that will automate the process of building the ATSs and ETSs as much as possible. Since work is already underway to validate the APs prior to their standardization, tools are being built to facilitate this process. These tools should be examined for their potential use when building the CT system.

- Maintaining liaison with the rest of the world. This includes participating in standards development meetings (e.g., ISO TC184/SC4) and technology development bodies (e.g. those doing AP validation), and keeping in touch with the user and vendor communities. The CT community needs to be actively represented in standards bodies and implementation agreement bodies, as much to make its task simpler as to provide valuable input to the standard and technology development process. This participation should continue not just when the ATS and ETS are being developed, but during CT development and enhancement. Maintaining contact with the users and vendors is needed to promote CT, its value, and its availability. Constant contact with users and vendors builds confidence in the CT process. Also, the CT community can be a valuable resource to users and vendors.

- Maintaining and offering the CT service. The tools, ATSs, and ETSs have to be maintained, upgraded, and enhanced from time to time to reflect the revisions and additions to the standards. The CT service itself involves using acceptable testing facilities and maintaining a CT-proficient staff.

- Transferring CT technology. Here we assume the model of one initial CT development center, which will later transfer the technology to multiple testing laboratories (see Section 4.3). In the case of STEP, multiple testing sites will most likely be necessary given the anticipated large number of users and vendors.

The items identified above all contribute to the fixed-cost component (see Figure 1) of CT. The first three however, are the major contributors. Careful design and development of CT tools are an important means of reducing and controlling fixed costs. Also important is structuring the APs to reduce duplication of ATSs and the need to retest the common aspects of APs. This is why active representation in the standards bodies is required. It is possible to come up with some rules of thumb, based on past experience, for estimating the above costs. While a laudable goal, estimating CT costs is beyond the scope of this report.

The cost of *not* doing CT is directly associated with the consequences of being without it. First, the earlier approach of doing ad hoc interoperability testing will have to be followed in order to have the standard implemented and used. Alternatively, there is the distinct possibility of not having a standard adopted at all. For instance, the lack of any CT for IGES has been a contributing factor in making its use frustrating, its adoption slow, and its cost/benefit ratio reduced. Due to the scope of STEP and the number of APs anticipated, STEP CT will be a large venture. Conformance testing is likely to be a key issue in the success of STEP. The long-term costs of not doing CT in the United States would probably retard the adoption of STEP in the United States. This could directly hurt the U.S. economy and have a significant negative impact on U.S. international trade as well. The European Community and Japan have made a commitment to standards in general, and to STEP in particular.

2.1.5 Standards for Libraries of Data

Conformance testing evaluates implementations for conformance to standards. In the case of STEP, CT will generally use databases that contain descriptions of parts and components. These data repositories or libraries must themselves be standards-conformant. For example, the geometric information contained in a STEP data file should be accessible by a STEP-conformant CAD system. Apart from the development of data libraries to help in conducting CT, hardware vendors are likely to build data libraries as well. STEP data files must be readable by the implementation under CT. In addition to standards for STEP data files, there should be standards for libraries of such STEP data files.

2.1.6 Conformance Levels

Past experience has demonstrated that allowing levels of partial conformance will only lead to chaos and confusion in the minds of users. Partially conformant applications may be less likely to interoperate, thereby undermining the most fundamental purpose of CT. Moreover, they encourage misrepresentation and misuse. Finally, attempts to grant partial conformance will render the task of developing CT systems and doing CT much more complex.

Recommendation

- *Partial conformance must be treated carefully; full conformance must be the goal.*

  Generally, products would either be conforming or nonconforming. In other standards there have been multiple specification classes to which applications may choose to conform. In the STEP standard, current strategy seems to be to enforce total conformance to a given AP. The logic behind this is that a well-defined, stand-alone part of an AP should become a new AP. Provisional nonconformance could be considered if time limits (e.g., one year) for correcting the nonconformities were enforced. Allowing provisional nonconformance permits greater competition, results in more products in the market, and lessens the "upfront costs" burden to the implementor. Ultimately, within an AP, full conformance should be required.

2.1.7 Dependencies Between Application Protocols

The primary objective of STEP is to provide for meaningful communication of product data from one industrial application to another. In STEP, APs will be interrelated. The scopes of proposed APs should be reviewed carefully to ensure no more or less is supplied than the justified industrial need stated on the AP project approval summary sheet. This raises the issue of testing a product for conformance to referenced APs to the extent the product's conformant behavior may be affected by these references. The question of how far to test and when to stop is not directly addressed by STEP. In ITI's opinion, the standards development activities in STEP have not progressed far enough to help provide answers to this question.

Recommendations

- *Further study is needed to determine how APs are to interoperate and what the implications on CT are.*

- *The ISO TC184/SC4 working groups on CT and AP methodologies need to address in the proposed technical report for AP Development Guidelines, the issue of AP interoperability and how it relates to CT .*

2.2 Strategic Issues

An objective of the DoD's CALS (Computer-aided Acquisition and Logistic Support) initiative is to encourage the adoption and use of STEP in DoD procurements. To make this a reality, developers and users will have to have confidence in STEP and work to build skills in using it. A key objective is to protect the interests of the various participants involved in the adoption of STEP. These participants are the developers, the users, the standards bodies, and the testing agents. The following subsections discuss in detail the various issues that confront these four main participants in relation to CT in general, and STEP CT in particular.

2.2.1 U.S. Involvement in STEP Conformance Testing

There are several reasons for the United States to be involved in STEP CT. Encouraging CT activity is a way to build indigenous application protocol expertise. This will prove invaluable later in the development of conformant implementations and enable U.S. vendors to acquire and maintain a competitive advantage and encourage users to adopt STEP-based products.

Since CT inevitably raises issues about the standard itself, it becomes an important instrument in the evolution of the standard. The United States needs to play an active role in CT and the evolution of STEP.

A significant U.S. effort in development and testing activities would make clear the U.S. government's intentions and reinforce earlier policy statements in support of the standard. This, in turn, would provide the impetus needed for corporate (both user and developer) buy-in. The anticipation of future business needs and the need to be prepared for them would thus trigger a development of STEP expertise. Another important benefit of indigenous CT activity is that the organizations involved in it become a resource focused on making STEP a reality. Vendors and developers can use this resource for help in standards implementation and sorting out interoperability and acceptance issues.

Finally, developing early CT capability for an AP brings with it the opportunity of early understanding of the standard. For STEP, the ability of U.S. vendors and users to leverage this opportunity to best advantage could have significant economic implications. Conversely, if left to others, this advantage is lost, and a dependence on non-U.S. testing bodies would result.

U.S. involvement in STEP CT will benefit the entire development cycle from the development of early conformant implementations to the creation and nurturing of a vigorous and competitive market for products. Ultimately, this will lead to faster adoption of STEP by U.S. industry through the rapid appearance of more and better STEP-conformant products.

Recommendation

- *It is important that a strong participation in CT be part of U.S. STEP activities.*

2.2.2 CT System Openness

The idea that CT systems should be open has considerable merit. Openness of the CT system means CT ATSs, ETSs, associated test tools, and associated documentation are readily available to all interested parties. Developers and users could use the CT system, voice their concerns about problems and inconsistencies, report bugs, and thereby provide feedback for improvement.

Early availability of the CT system will encourage early development of STEP-conformant products. This will improve product quality and reduce developer costs. Familiarity with the CT system and use during the development process will give developers a sense of confidence in and partnership with the CT process.

Concern has been voiced that making the CT systems completely open might tempt developers to devote more of their energies to passing the CT and less to building a better product. This concern is not supported by experience in other domains. Complete CT systems are now available for many networking protocols, and commercial organizations are building their own testing laboratories for internal testing and quality assurance. Competitive pressures force vendors to produce good products.

An easily accessible CT system will expedite disseminating and popularizing the standard. It will also help users determine their own requirements.

Recommendations

- *Make CT systems available for use to interested developers at nominal cost.*
- *Create a forum for interested parties to contribute toward a better CT program. Inputs for improving the standards, the CT system, and implementation methods could be gathered through such a forum.*

2.2.3 DoD Security Concerns

Defense organizations and contractors will develop STEP-conformant software applications as a result of the CALS initiative. Often such software will work in a secure environment or access secure or classified resources (like databases). Three methods performing CT on such applications exist: (1) installing identical systems in the testing laboratory for the duration of the conformance assessment process; (2) "taking" the testing laboratory to the application; or (3) allowing vendor "self-testing" as declaration of conformity. In each of these situations the security of such applications could be compromised. Performing CT on sensitive applications and implementations, given their nature and the access restrictions they carry, is a major concern.

Recommendations

- *Two alternative recommendations to this problem are suggested:*
  - -- *DoD develops its own CT laboratory and does all classified testing in it.*

-- *DoD secures a security-cleared contractor who acquires CT capability and provides the service to DoD in a secure environment.*

It is difficult to select the best choice; the first approach may be suitable if there is sufficient software to be tested but may take some time to implement. A contracting arrangement might prove to be more economical, especially if the volume of CT does not warrant a dedicated, in-house lab.

2.2.4 DoD Adoption Concerns

The Adoption Issue: DoD is probably the largest, single stakeholder in STEP. STEP is also an important part of CALS. DoD wants to see suppliers adopt STEP so that consistent means of product information exchange can be established. Therefore, a favorable perception of STEP by DoD contractors is needed to ensure adoption. The entire CT effort is aimed at achieving this objective by expediting the adoption process and making it happen more efficiently and cost-effectively.

Recommendation

- *DoD should set realistic adoption milestones and actively support their achievement.*

DoD, as a huge buyer of information technology goods and services, wields enormous influence with its suppliers. DoD could use this influence to drive vendor agreement to build STEP application protocols and use them to meet DoD procurement requirements.

2.2.5 Vendor Community Needs

Fulfilling the needs of vendors and developers would go a long way toward encouraging widespread adoption of standards and education about CT. To many, CT represents a relatively new approach to working with standards. It is not really new. Underwriters Laboratory has been doing this kind of work for years on hardware implementations. The Federal Government has been doing CT of computer programming language software implementations for years. Even Consumers Union does CT on a targeted, ad hoc basis. It is important to promote CT and inform the broad STEP community of its benefits. This would help vendors understand the need for conformance-tested products and the competitive advantage that accrues from CT. This promotional task has to be a continuous process.

As vendors start developing STEP conformant products, there will be a need for identified personnel that will answer standard-related questions, help in application protocol implementation and CT issues, and provide a forum for discussion and problem solving.

Recommendations

- *A forum to discuss CT issues should be created. Standards bodies typically provide such a facility in some form or another (annual or semi-annual conferences, publications, newsletters, bulletin boards, etc.), but an additional forum for CT is necessary.*

Outputs from such a forum would include: regularly published news and information, workshops, education for vendors and developers, and promotion of CT. This forum would provide an opportunity to disseminate information and allow developers to report problems, request information, and seek related assistance to perform better in-house testing.

Seminars and workshops to do training on CT tools and methods should be organized through this same forum.

- *For vendors to use the open CT systems as recommended above, training to use the CT tools and methods is necessary.*

2.2.6 Accreditation

Here we assume the following model: Initially there would be one team for developing the CT system. Since a lot will depend on this, the long-term effects of choosing a particular team should be kept in mind. Once the CT system has been developed to a level where CT can begin, multiple testing laboratories would be set up and accredited.

Recommendation

- *Since one of NIST's primary functions is to promote standards for government use, it should be considered as a candidate to accept the responsibility of directing and performing the initial CT development.*

Therefore, while the funding agencies and NIST should work together to come up with a consensus approach for accrediting testing laboratories, detailed decisions could be left to NIST as an impartial agent.

World-wide development of STEP CT does have United States representation, but in limited strength relative to the rest of the world. It is important for the United States to coordinate its position in forums such as ISO. The United States cannot ignore harmonization activities and therefore must organize itself into a position of unity, confidence, and strength with the rest of the world. Government participation, leadership, and teaming with industry, as is common within Europe and Japan, would go a long way in this area.

2.2.7 Assigning Conformance Testing Responsibilities to Testing Laboratories

Let us assume staff of the National PDES Testbed (NPT), working with others, will initially develop the CT system. They would then distribute the CT system and transfer the technology to organizations that want to be in the business of being third-party or in-house vendor test centers. once accredited, such organizations would be designated as testing laboratories.

For widespread adoption of a standard, there has to be a commitment shared by interested parties to make the standard work. A testing laboratory would have to shoulder its share of this commitment. The most fundamental role of the testing laboratory is to see that implementations work.

From the standard development point of view, a testing laboratory should also play a participatory role by providing feedback to the standard development process. Such input should reflect CT issues and closely address the problems of product developers.

Another level of responsibility of testing laboratories, though indirect, may be to ensure that STEP, as a standard, is efficiently and economically implemented. Failure to satisfy such efficiency and economy criteria often impacts how the standard itself is perceived. This aspect is beyond the scope of CT, but particularly helpful in promoting STEP's usefulness. Efficiency and economy issues of implementations are often dealt with in workshops between testing laboratory personnel and vendors.

Recommendation

- *Ensure applicant testing laboratories are both committed and skilled in conformance testing and the technical aspects of STEP.*

2.2.8 Abstract Test Suites (ATSs)

Leaving unassigned the responsibility of developing ATSs would result in different organizations (developers, testing laboratories, ad-hoc industry groups or consortia) building their own and claiming conformance to them. This would lead to inconsistencies in products and CT, cause confusion, and ultimately slow down the adoption process.

Recommendations

- *Standards bodies should be responsible for the ATSs.*
- *ATSs should be normative parts of STEP.*
- *The ATS should be a normative requirement for a given AP.*

The actual development of ATSs could be done by anyone (testing laboratories, consortia, etc.) as long as they are reviewed by the standards committees and accepted as part of the standards. Developers of such ATSs should be committed to keeping the ATSs in the public domain and internationally approved as part of STEP.

2.2.9 Executable Test Suites (ETSs)

It is possible to build multiple ETSs from the same ATS. The need for this may arise due to various platform and implementation choices made by product developers.

Recommendation

- *Despite the non-unique nature of an ETS, the development of the first ETS for an ATS should be done by those building the ATS, or in close cooperation with them.*

This would help to identify and correct any problems with future versions of the standard ATS.

2.3 Development Issues

A number of issues have to be addressed before a strong CT infrastructure is built and brought into operation. The main resource needs of CT are those of expertise, tools, a lead organization, and funds to support such activities. Building STEP CT, whether in the United States or elsewhere, will require people with the appropriate technical expertise. The first major task of this CT system development team would be to specify, design, build, and test the CT system and associated documentation. There will be a need for an organizational infrastructure to support these activities. All these tasks also require funding.

There needs to be a technical liaison between the CT system development team and ISO TC184/SC4. Contact has to be maintained through active participation in SC4 Working Groups. Contact also has to be maintained with organizations and industry groups developing ATSs. To keep abreast with vendor activities and issues of interpretation, CT system development staff should attend implementors' agreement meetings, trade shows, and symposia.

Another set of tasks includes continually assessing and controlling the quality of the CT systems being built by the CT development team. Only the initial stages of CT system and tool development will be handled by the CT development team as a single entity. Once the early versions of the transferable CT system have been developed, many organizations would have the opportunity to become testing laboratories. These organizations should be accredited and a standard procedure should be established to do this.

2.3.1 Abstract Test Suite (ATS) Development

It has been discussed earlier that standards bodies should include developing the ATSs as part of the standards-making process. ATSs could be developed by any independent organization, but responsibility for their ratification and acceptance belongs to ISO TC184/SC4.

Recommendations

- *When the CT development activity begins, some initial start-up funding may be needed to pay for the development of ATSs for those APs released without an ATS.*

- *Once the CT activity stabilizes, the cost of developing ATSs for new (and changing) APs should be borne by the users of the APs. For example, ATSs for APs supporting the automotive industry should be paid for by the auto industry.*

One approach to ATS development is that one center would develop the CT systems and tools for a small, self-contained piece of STEP (like a group of related APs). This would give the primary sponsor of the activity opportunity for input and assure interested parties the task is not getting bogged down in the complexities of very large system development. Starting small would make it possible to monitor the development activity, keep quality high, and keep costs down. As the task progresses, the scope could increase. This approach towards incremental development fits well with all the strategic issues discussed in Section 2.2.

2.3.2 Funding Conformance Testing

Conformance testing start-up costs have generally been borne by interested industry groups or consortia and applications developers. Of course, any costs faced by developers eventually filter down to the user in the form of higher prices. This effect would be more significant if developers are expected to pay for the start-up as well, since the development of the CT activity would require a significant initial investment. Ultimately, the benefits of CT to users of STEP implementations have to be seen as greater than the cost. If users fund the start-up of a CT service, the developer may incur a lower fee for such a service. Low fees will attract developers and help get the CT activity off the ground. Once stabilized, the rise in revenue from CT should make it possible to reduce the subsidy. In the long run CT should be a vendor-supported activity. Therefore, if CT costs are reasonable, it encourages more vendors to build affordable implementations while still undergoing CT.

There are other issues to consider:

- Does the complexity of the application protocol and magnitude of the ETS affect fees?
- Do all vendors pay the same or do smaller companies pay less than larger ones.

Recommendation

- *When conformance testing first begins, vendors should not be expected to pay more than nominal sums to have their products tested.*

2.3.3 Legacy Issues

Retesting may be needed when developers claim conformance with newer versions of standards, or modify their products to the existing standards. Thus, a changing standard or product drives the need for retesting. There are two issues to consider: availability and cost. If the CT systems are easily available (Section 2.2.2), vendors could do some sort of strictly controlled provisional conformance testing in-house, if their original base system was already deemed conforming. This would drive costs down. Also, the CT assessment process costs should be reasonable to encourage vendors to get CT done for upgraded products early. Moreover, if CT is carefully modularized, retesting may only involve CT of those portions that have undergone changes.

Recommendation

- *As mentioned earlier, if CT is done right (open, modular, reasonably priced), retesting should not be an insurmountable problem. Also, as APs stabilize, retesting would cease to be an important issue.*

2.3.4 Tools

One point this report has emphasized is the need for automating the conformance assessment process and the ETS development process. The way to achieve this is through software tools. CT tools reduce dependence on the expertise of the CT system operator and also reduce the chances of CT system operator error. CT development tools help build new CT system components, thus reducing costs.

The following is a list of the tools needed for conformance testing. They can be classified into three types: CT System Tools, Client Support Tools, and CT Service Tools. Some of the tools listed below will become a part of any CT system for virtually any application protocol. Others are less common, but valuable, nonetheless.

2.3.4.1 CT System Tools

Test Engines - These are the generally invariant core drivers of test execution that probe and detect the behavior of the System Under Test (SUT). They perform common activities required by the abstract and executable test cases (ATCs and ETCs).

Executable Test Cases - These are the data sets or instructions that when coupled with a test engine, control a test engine into stimulating particular sets of behaviors from an Implementation Under Test (IUT).

Test Session Controllers - These tools sequence and orchestrate the execution of other CT tools, with the objective to see the procedural requirements of conformance test sessions are properly carried out, or if not, duly noted.

Loggers - These tools record the most basic activities of CT system execution for consumption by other tools, or for an occasional detailed audit of test execution events.

Monitors - These are the real-time sensors and formatters which observe and report on SUT behavior.

Analyzers - These are tools which substitute for both tedious clerical editing and insightful expert interpretation.

Report Generators - These tools collect the important outputs of the other CT system tools into a report format suitable for external distribution.

Preparation Tools - These tools collect information about an SUT, and record it for use by other CT system components.

Data Management Tools - These tools enable organized archival storage and examination of test data.

Debuggers - These tools are a required by-product of CT system development in that they can be used to evaluate and possibly correct CT system operation.

Build Tools – These tools extract appropriate information about the tests to be performed, and configure and activate the CT system accordingly.

Clean-Up Tools - These tools de-activate and de-configure the CT system, along with safely archiving captured test results.

Training Tools - These tools can be used to educate the testing laboratory staff on the use of the CT system.

2.3.4.2 Client Support Tools

CT System Interfaces – These are the necessary hooks that a client must provide to the CT system in order for the SUT to be examined.

Test Support Tools – These may be required of a client, executable in the SUT, so that the SUT is testable.

Test Responders – These are tools and functions sometimes required by vendors to test their implementations. These could be sample code that is portable or a detailed specification.

Test Procedures – These are established to help clients get their products tested easily. These procedures should be precise, simple, and easy to carry out.

Report Generators – These are tools to format the CT results for easy perusal by vendors and users.

Training Tools – These tools can simplify the client's efforts in the CT operation activities by providing key information about such aspects as the CT process and requirements of an SUT.

2.3.4.3 Testing Laboratory Service Tools

Test Engine – As described above, it is the automated apparatus which can stimulate and observe an SUT's behavior in a controlled manner.

System Diagnostics – These tools can be engaged to validate proper operation of the CT system, the client system, or the CT environment.

Remote Testing - These tools can be used to execute tests over telecommunication facilities if required by special client needs.

Remote Control – These tools further enhance remote CT by providing clients with the capability to control the CT environment for either preconformance testing preparation or debugging.

Scheduling – These tools are the classic software packages which are quite valuable in moderate-to-high activity operations.

Logistics Coordination – These tools help in facilitating coordinated interactions between CT service parties.

Accounting - These tools assist in tracking the costs of both client and testing laboratory operations.

Forms Management - These tools assist in the generation, preparation, and organization of blank and completed reports, forms, and data sets.

Report Production - These tools help with the collection, organization, and preparation of reports for "official" results reporting, CT plan generation, and other external document publication.

Recommendation

- ***The specific set of tools needed for STEP CT needs to be determined as part of the CT system development.***

A full set of CT tools is probably too much to develop as part of the initial CT work. As an initial set of specific tools is developed, they will help in further CT and product development. The earlier tools become available, the quicker CT of standard-conformant products will occur. The lists presented above are an initial suggestion of tools likely to be useful.

3. Evaluation Procedures for STEP Conformance Testing

The success of STEP-based application systems will depend on the representation of product data in a form completely independent of any particular computer-aided software system. This basic requirement brings with it the need for file exchange capabilities, sharing of product databases, and device-independent archiving and de-archiving capabilities.

To have confidence in the verdict of a CT system, the system itself needs to be evaluated as do the ATSs for the various application protocols that will be used to generate the ETS run on the CT system. Thus, evaluation applies suitably defined criteria to candidate CT systems and offers authoritative approval or disapproval. In this section we focus on the evaluation of CT systems, ATSs, and ETSs for CT and offer some recommendations for evaluation procedures.

One important caveat needs to be raised in regard to CT system approval. The evaluation process must not fall into a gatekeeper mentality. The processes need to be designed to encourage CT and the operation of testing laboratories. If the attitude becomes one of keeping testing laboratories out rather than helping them become operational, then the CT system will be inadequate, if not counterproductive. Likewise, the testing laboratories will need to take the approach of helping their customers create high-quality, standards-conformant products.

3.1 CT System Evaluation

Criteria are needed for the process of evaluation of CT systems. The following subsections introduce some important criteria and related recommendations.

3.1.1 CT System Environment

The hardware and software environments in which the CT system exists will have to be evaluated. Since multiple CT environments could be built to meet the criteria for acceptance, any such CT system must not give commercial advantage to any particular candidate product during CT.

Recommendations

- *The CT environment specifications should be easily available to all interested parties who would have the opportunity to voice their concerns, if any, and request reasonable modifications in the early stages of CT system development.*

- *The acceptance of a CT environment should not favor some product vendors over others.*

- *The CT environment must be an "open" platform to and from which the porting of CT-related software will be easily accomplished.*

- *The CT environment should not impose architectural requirements on SUTs for their successful CT; i.e., the cause for failure of a test or the inability to perform it should not be architectural incompatibility between the CT system and the SUT.*

3.1.2 CT System Availability

Product vendors need easy access to CT systems to be used as development and debugging tools throughout the process of product development. Thus CT systems should be reasonably priced.

Recommendation

- *The cost of acquiring (buying, leasing, or sharing) a CT system should not be such that it would prohibit widespread use.*

Since the cost of purchasing some CT systems may preclude their in-house use by some vendors, arrangements to make them available at reduced costs or for cost sharing should be put in place.

3.1.3 CT System Characteristics

CT systems need to possess some basic characteristics which assure their integrity, exhibit their independence of the CT environment, and provide evidence of their usability:

- Repeatability of CT results
- Reporting and easy comparability of CT results
- Auditability of CT results
- Usability (ease of installation and use) of the CT system

3.1.3.1 Repeatability of Conformance Testing Results

To assure a high level of confidence in the results of any conformance assessment process and the credibility of the testing laboratory, CT results must be repeatable. A combination of the same ETS, CT system, and the IUT must produce identical results over multiple runs.

Recommendations

- *A candidate CT system should be subjected to a calibration process to evaluate its repeatability. This evaluation should include the CT system's responses to both error-free and erroneous implementations of STEP products.*

To maintain a high degree of confidence in the performance of this calibration, the implementation(s) to be used should be selected from a known, fairly large list. The results of this exercise will form the basis for the judgement of whether repeatable results can be expected.

- *Because repeatability of test results may be affected by CT system operator error and result generation error, a high degree of automation is recommended.*

3.1.3.2 Reporting and Easy Comparability of Conformance Testing Results

A CT system must report information that will allow the production of a Conformance Test Report (CTR) for each implementation tested against each relevant AP. The CTR shall specify for every test run one of three outcomes: pass, fail, or inconclusive. No other verdicts are allowed. The CT system should thus allow logging of each test outcome during the testing process.

Moreover, the CTR generated should be independent of the CT environment. Thus for the same SUT, the CTR generated at different test sites, whether in-house or in a testing laboratory, should be comparable.

Recommendations

- *The CT system should possess the capability of using its logs to automatically generate a CTR.*
- *Formats and procedures as defined in ISO WD 10303-32*[3] *for generating CTRs should be adhered to.*
- *Procedures in ISO WD 10303-34*[4] *for executing test cases should be followed.*

These procedures should be built with flexibility in mind and should consider situations in which repetitions of specific test case executions may be warranted.

3.1.3.3 Auditability of Conformance Testing Results

A CT process usually includes an arbitration subprocess. To effectively arbitrate a dispute between product vendor and testing laboratory, detailed information on the inputs and outputs for the execution of a test suite is required.

Recommendation

- *The ability to document the actual procedure of a test campaign and log its details should be built into the CT system. These logs should then be used as the basis of the arbitration process.*

3.1.3.4 Usability of the Conformance Testing System

The CT system builder should not assume that the CT system operator will be STEP-knowledgeable or conversant with CT technology. It should be possible to quickly train a lay computer user to be a CT system operator. Also, the purposes for building and using a CT system is defeated if many parts of the conformance assessment process are left non-

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[3]ISO WD 10303-32, "The Requirements on Testing Laboratories and Clients."

[4]ISO WD 10303-34, "Abstract Test Methods."

automated. The CT system should be straightforward to install, configure, and operate. CTRs should be clear, concise, and should contain all required information.

Recommendations

- *The CT system should be easy to use and learn. At the time of building the CT system, minimal assumptions about the CT system operator's skills should be made. The CT system operator command set should be compact and relatively simple to master and use. Information, error messages, and prompts should be clear and easily interpretable.*

- *The CT system should incorporate tools to automate, as far as possible, the entire CT process thereby minimizing the room for human error.*

- *Comprehensive documentation should be available for installation, configuration and use of the CT system. The CTR generators should follow the format requirements of ISO WD 10303-32 for CTRs.*

3.1.4 Equivalence of CT Systems

The issue of CT-system equivalence assumes importance when multiple CT systems for the same set of application protocols have to be evaluated. The primary criterion is to show comparability of conformance test results between CT systems. The first step towards achieving this is to use a common ATS.

While it is not possible to formally prove the equivalence of two CT systems, multiple ETSs with identical SUTs provide a reasonable level of confidence that future IUT CT results would be comparable. At least one of the SUTs has to be non-conforming to ensure the system can detect problems properly.

Demonstrating the equivalence of CT systems with a high degree of confidence is technically challenging and demands rigorous examination of conformance test suite logs and results. Identical circumstances have to be maintained on each CT system throughout the evaluation process and the maximum possible amount of data logged for post-completion evaluation.

Recommendations

- *Where a reference implementation capable of generating known errors in a controlled manner exists, it should be used in the equivalence evaluation process.*

- *The ETCs should be carefully planned, run in identical sequences, and the results and logs subjected to meticulous examination.*

- *If a CT system is modified (in any manner) by its developer, it should again be subjected to the same process.*

3.2 Executable Test Suite Generation

It is a matter of general agreement that the standards committee that develops a particular AP will also oversee the development of the ATS for that AP. Once officially accepted, the ATS will then be used by testing laboratories to develop ETSs. These tasks will be performed in accordance with the ISO TC184/SC4 10303-30 class of standards which specify different abstract test methods, development of ATSs, and the policies and procedures for the development of ETSs for STEP. That an ETS correctly implements its parent ATS is a matter important enough to warrant attention by the Certification Body.

3.2.1 Policy Issues

The need for openness in STEP CT systems requires the availability of detailed information on the CT system, ATSs, and ETS tools. Also, the need for strictly adhering to standards requires documents and forms be filled out before, during, and after the test campaign. It is the mandate of the CT system builder to provide sufficient assurance of quality and coverage in areas which the standard specifies as required.

Recommendations

- *The CT system builder must provide all documentation for the implementation of the AP to be tested. Such documentation should provide all information necessary to prepare the SUT for conformance testing and include a description of the conformance assessment process, a definition of the CT system configuration, and a description of any special requirements placed on the SUT by the CT system.*

- *The ETS should test IUT response to both valid and invalid behavior by the CT system. Invalid behavior should include illegal parameters and invalid parameter values.*

- *The conformance testing procedures used by the testing laboratory should be made public to help ensure that the conformance assessment process is valid.*

3.2.2 Abstract and Executable Test Suite Coverage

One major point of evaluation of the CT system must be an analysis of how well the CT system covers the ATS (and therefore the ETS) of the AP to which conformance is being tested. Since the ATS development process will have public input, most concerns about coverage will be ironed out for the ATS during the standardization process. However, deficiencies could be identified with the use of the ETS and improved coverage sought.

Recommendation

- *An AP coverage method should be used to establish how well an ATS covers its associated AP.*

Empirical methods of measuring AP coverage are available. One such method is specified in the ITI technical report "Test Coverage Analysis and Measurement (TCAM): A Practical Approach to Determining Coverage" (document ITI TR-87-14.1).

3.3 CT System Builder

The organization charged with building a CT system has to satisfy certain important criteria: a commitment to STEP and independence from all individual participants in the STEP community. Moreover, the CT system builder must also make specific commitment to maintain the CT system and undertake adequate quality assurance measures.

3.3.1 Commitment

The CT system builder must indicate its long-term commitment to STEP and demonstrate its ability to support the CT system. Modifications to a CT system are an ongoing process for any number of reasons. The CT system configuration may be impacted by new versions of hardware and software; although the CT system will have undergone evaluation prior to release, continual debugging is often necessary as more implementations undergo CT; or changes to an AP or its ATS may warrant modification to system code. If the CT system builder chooses not to continually maintain the CT system, a breakdown in the CT service may occur.

Recommendations

- *The CT system builder should be committed to keeping the CT system up-to-date with the base standards and APs as they change.*

- *The CT system builder must maintain adequate liaison with several organizations to keep abreast with ongoing issues.*

  These organizations include: standards committees, peer conformance testing organizations abroad, and user/vendor forums and consortia. Maintaining such contact enables the CT system builder to anticipate future trends and needs, and act promptly to respond to them.

3.3.2 Nonalignment

The product developers who will use the conformance testing service must be assured that the CT system builder is an independent body with no direct commercial affiliations. This is important to maintain impartiality of the CT system and also to encourage the developers to utilize the conformance testing service to improve their products.

Recommendation

- *An independent organization, such as NIST, should be charged with the responsibility of providing the STEP CT system and associated tools. In performing this task, the body should act to remain nonaligned and make acquisition, design, and implementation decisions in keeping with this mandate.*

3.3.3 Maintenance, Revision, and Quality Assurance

As in any other complex project involving hardware and software, the CT system builder has to maintain adequate controls on the revision of the CT system and on error tracking and fixing. Since users and vendors would be able to buy or lease CT systems for in-house use, they should also have access to points where they can report problems.

Once a CT system is accepted for use, there has to be a mechanism for ensuring its continued quality. The organization that chartered the CT system builder should independently assess the quality of the CT system.

The CT system builder should be able to respond to errata and other changes to the standards (APs). Changes in the CT system should be made in an orderly manner and all known users should be informed of new CT system releases.

Recommendations

- *The revision control policies and schemes for the CT system builder should be reviewed by user and vendor groups to determine if they achieve adequate quality control.*

- *The CT system builder should have procedures in place to receive problem reports and act on them in a timely manner.*

If the problem is with the ATS or AP, the ISO TC184/SC4 community and all known users should be notified immediately and work begun to fix it. If the CT system is the problem, work to rectify it should be started and users notified. All problems and fixes should be logged.

- *The CT system builder should have procedures in place for tracking errata and other changes in the APs and determining the impact of these changes on the CT system and ATSs.*

If changes are required, the nature of the work, expected problems, and projected time of completion should be made known to all users of the CT system.

- *CT system releases should be accompanied by comprehensive documentation including: system fixes since last release, AP changes affecting the new release, and remaining known problems.*

- *The organization that initiates and funds developing the CT system must have in place procedures by which problems and complaints could be independently accepted and progress monitored. Procedures to resolve such problems have to be set up and implemented.*

- *The CT system builder should consider, and CT services and procedures reflect, the quality assurance requirements identified in the ISO 9000 series[5] or equivalent.*

3.4 The CT System Evaluation Process

The CT system builder may desire to maintain a committee (comprised of representatives from CT participating organizations) with the mandate of evaluating all relevant aspects of the CT system and the CT system builder (see previous sections). Only after satisfactory completion of these procedures would the CT system builder claim recognition of its CT system. The following subsections make broad recommendations on CT system qualification. If CT systems are to be developed and put in place, the burden of evaluation must not be too heavy.

3.4.1 Evaluation of the CT System

The CT system builder would seek acceptance of its CT system through the committee mentioned in Section 3.4. The committee would evaluate the CT system. This evaluation should be based on criteria that have been discussed in the sections above (repeatability, comparability of test results, etc.). All evaluation done during this process would use ETS tools already approved by the committee.

Throughout the evaluation process, the committee must work with the CT system builder to resolve any problems encountered without compromising the quality and integrity of the CT system itself. Upon acceptance of the CT system, complete and detailed documentation would be released to show that the CT system meets the criteria for recognition.

3.4.2 Recognition

The granting of recognition would be done for a specific CT system and a specific set of APs, the versions of each being specified. Recognition would be valid until specifically withdrawn by the committee which constantly monitors CT activity. Withdrawal of recognition would occur if it were determined that the CT system builder failed to show commitment to maintain the CT system and/or adequately perform the usual tasks of bug fixing, upgrading, and user support.

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[5] ISO 9000, Quality management and quality assurance standards - guidelines for the selection and use.
ISO 9001, Quality systems - model for quality assurance in design/development, production, installation and servicing.
ISO 9002, Quality system - model for quality assurance in production and installation.
ISO 9003, Quality systems - model for quality assurance in final inspection and test.
ISO 9004, Quality management and quality system elements - guidelines.
[The above international standards are available through the ISO Secretariat: 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland.]

4. Milestones

The previous sections in this report emphasized that development of STEP application protocols and associated implementations require the availability of conformance testing capabilities to reap the benefits of standardization. It is essential to have in place a conformance testing capability within the United States as early as possible. The United States should thus have an aggressive STEP CT development program of its own, not relying on other countries. The benefits are many: bringing competitiveness to the industry, nurturing the growth of expertise at home, and strengthening the position of U.S. members in international standards bodies.

The first step in developing STEP CT capabilities in the United States is to come up with a plan and a realistic schedule for CT system development and deployment. Such a plan should be in line with the needs of major STEP users and should take into account the current state of the standards development efforts. This section enumerates a set of milestones for developing and deploying a STEP CT system and starting a CT service. These milestones should be coordinated with the NIST Development Plan for STEP CT Services.[6]

There are three major task groups:

- CT System Development
- CT System Validation
- Technology Transfer and Testing Laboratory Accreditation

4.1 CT System Development

This subsection details the milestones for the task of CT system development.

4.1.1 Generating a Requirements and Development Plan

This milestone will be the culmination of a requirements analysis task that will focus on three important issues affecting design and development of the CT system. The milestone will be the generation of a high-level requirements document, a development plan, and an inter-organization advisory team. Together these will provide important input to the system design process and focus on building the capabilities to test conformance to the selected APs.

First, general system requirements need to be identified to feed into later tasks. This task will solicit input from interested parties (users, vendors, standards bodies) on what is needed in a CT system. Early involvement in the CT process will serve to unify the participants' view and offer a forum for discussion. Also, users' concerns will be taken into account from the start. This task will be done by requesting information from all concerned, and by hosting one or more workshops to discuss and evaluate issues and select options.

Second, the CT system developer should invite voluntary participation from interested organizations. These organizations may want to seek assurance that work is progressing on

[6]Kemmerer, Sharon, National PDES Testbed Development Plan, STEP Conformance Testing Service, NISTIR 4641, August 1991.

schedule and in alignment with the needs of the user and vendor communities, activities of the standards bodies, and international STEP activities.

Third, APs have to be chosen for the CT system. This choice will depend on the priorities of the funding agency in conjunction with prospective users of the technology. As far as possible, APs that have advanced to or are close to becoming draft international standards (DIS) should be selected.

4.1.2 Accept Abstract Test Cases

It has been recommended that standards bodies/committees developing the APs bear the responsibility of generating ATSs. This task will examine the ATSs thus generated. Ambiguities that could affect ATS interpretation during the development of ETSs should be brought to the attention of ISO TC184/SC4 and resolved at this stage. This examination may also analyze coverage and make recommendations to the appropriate committee for changes to improve coverage or reduce redundancy.

4.1.3 Define or Accept Abstract Test Methods

This task will accept abstract test methods for CT of STEP-based implementations. The output will be a document describing, in general terms, the abstract test methods that will be used for the selected APs.

ISO WD 10303-34 of STEP is concerned with defining and describing abstract test methods which take into account the control and observation points of STEP implementations. Since this CT system development task will be the first for STEP, it may well be possible that for the APs selected, the abstract test methods in STEP Part 34 may need to be modified or redefined.

4.1.4 Generate a Detailed CT System Requirements Specification

This task will develop a requirements specification for the CT system. The previous four tasks will have generated implicit and explicit requirements for the CT system.

This task will describe the needed capabilities of the CT system. Moreover, the requirements specification should be flexible enough for modification. As the first CT effort for STEP, it is almost certain that changes will be required as work on STEP progresses and new requirements emerge.

4.1.5 Develop CT System Architecture and Design

This task will develop a detailed architectural design and a detailed internal design. The architectural design will decompose the CT system into system modules, interfaces, and interconnections and provide detailed descriptions of these items. It will also specify the hardware and software configuration used to build and operate the CT system.

The detailed internal design will select and/or define algorithms and data structures that will be used to build the CT system components according to the requirements specification. This task will also consider and identify existing tools, utilities, and services to efficiently implement these objects.

The plan to implement the CT system will be refined, taking into account evolving requirements of STEP CT as STEP becomes standardized and priorities change.

4.1.6 Develop/Procure Platform and Development Tools

The output of this task will be a functional hardware/software platform on which development can begin and unit testing can be done. As the development of the CT system progresses, more equipment and tools may have to be added to the platform to assess the capability and functionality of the modules developed. A detailed list of the kinds of tools usually needed for CT can be found in Section 2.3.4.

4.1.7 Develop Abstract Test Suites

For each AP selected, an ATS is necessary. The output of this task will be ATSs for the selected APs with complete and comprehensive documentation.

An ATS will have to be accepted and supported internationally and be consistent with worldwide STEP efforts. Thus, a procedure to process existing ATSs through ISO must be put in place.

Some of the ATSs may have to be developed. These should go through the same acceptance procedure referred to above. As emphasized before, all accepted ATSs should be well documented and internationally standardized.

4.1.8 Construct and Integrate CT System

This task will use the detailed CT system architecture and design as input to build the CT system. The output of this task will be an alpha version of the CT system accompanied by comprehensive documentation.

This is a significant development component of the CT effort and will incorporate an ETC generator for the selected APs; compilers and parsers for the STEP description language, ISO CD 10303-11, EXPRESS; and comprehensive documentation and a capabilities list using the requirements specifications as a baseline. As far as possible, the components of the CT system will be unit-tested as they are built. However, substantial system testing will need to be done separately as described in the following section.

4.2 CT System Validation

After completion of the CT system, the system will have to be thoroughly tested. An undesirable concept is to build a test bed that is bigger than the CT system being evaluated. Such a process could spiral out of control and make the whole CT concept collapse upon itself.

4.2.1 Develop CT System Validation Plan

Developing a validation plan for the CT system will be necessary. In the absence of (certifiably) conformant product implementations that could be used to "reverse-validate" the CT system and also to avoid any controversy in the STEP community, a limited, independent assessment is appropriate. The output of this task will be a validation process and an implementation plan to validate the first CT system.

4.2.2 Validate CT System

This task will use an independent test bed to validate the CT system. The validation and "fixing" of the CT system will be done iteratively: problems discovered will be fixed and the CT system retested starting from a reasonable baseline. The output of this task will be a fully validated CT system ready to be used to perform CT on product implementations based on the selected APs.

4.3 Technology Transfer and Testing Laboratory Accreditation

The STEP CT system developed in the above tasks will represent a major step toward building a credible capability to perform CT on STEP-based products. This CT capability will be akin to developing new technology, may bring with it new testing approaches, and will represent a significant advancement in the area of standardized product data representation.

To disseminate this new technology and leverage its utility many times over, it has to be transferred to testing laboratories that would then independently perform CT. To begin to assess the quality and credibility of these testing laboratories, one may choose to ensure the testing laboratories chosen for the task have a reputation for quality work in areas related to STEP. It is also necessary that the CT technology be transferred to the testing laboratories in the right manner and that the testing laboratories possess a certain level of expertise in the technology area in which they are offering CT services. Thus, it is necessary to have in place detailed procedures for technology transfer and testing laboratory accreditation. This task could use the GOSIP or POSIX accreditation methods as models.

4.3.1 Establish a Conformance Testing Service

The first task is to start a CT service at the site where the CT system was developed. This would assess the new procedures as well as further evaluate the CT system before release to other sites. Offering this service requires detailed procedures to perform CT along with forms for CT reports and logs, means of arbitration, and fee structures. This task develops a framework for offering CT services including: technical, commercial, administrative, and legal guidelines. It also includes advertising and initiating STEP CT services.

4.3.2 Develop Technology Transfer Plan

As discussed above, technology transfer will be an important task in making STEP CT services available. This task develops a plan to transfer the CT technology to candidate testing laboratories.

4.3.3 Develop Testing Laboratory Accreditation Procedure

This task develops procedures to:

- Select testing laboratories for transfer of the CT technology based on their technical, commercial, and administrative capabilities.
- Assess and evaluate the testing laboratories on the basis of their expertise in STEP, quality and experience of personnel, adequate equipment and quality control, and adherence to CT procedures.

Too much bureaucracy in this process will lead to high costs, a gatekeeper mentality, and ultimately, failure in creating a useful CT system.

4.3.4 Invite and Approve Candidate Laboratories

This task advertises for testing laboratory applicants. It will evaluate these applicants on the basis of the criteria described in task 4.3.3 above. The output of this task is a set of testing laboratories that have passed the selection criteria.

4.3.5 Start Up Conformance Testing Service

This task transfers the CT technology to the selected testing laboratories. The output of this task is a register of testing laboratories with a list of the APs for which they offer CT services.

5. *Summary and Conclusion*

Developing STEP conformance testing capability will be an important task in the near future. This report discussed the important issues and established a baseline for high-level needs and requirements, CT system evaluation procedures, and milestones for building and offering a STEP CT system in the United States.

The issues discussed in this report have emphasized the following:

- Appropriate conformance testing is an economical proposition in the long run and should be pursued actively in order to encourage adoption of the standard.
- Although developing and establishing facilities for CT is expensive, the long-term cost of not doing CT is even more expensive.
- Conformance testing may be needed for implementations that utilize databases of product data as well as exchange implementations.
- For the United States to rely on other countries to undertake CT would lessen the capability of American companies to compete in the international marketplace.
- The needs of the STEP product vendor community must be addressed, with open CT systems being an important contribution.
- CT software tools are a very important component of CT systems. They automate CT tasks and help develop new ATSs and supporting ETSs.
- Evaluation of CT systems and services is an important issue. Evaluation must ensure that CT is accurate, honest, and fair while not being an undue burden on the testing laboratories.
- The CT system builder must be committed, nonaligned, and provide quality assurance.

The discussions in this report led to the following conclusions:

- The United States should initiate the building of a STEP CT system.
- The STEP CT system that is built should be available for use by all interested parties at a nominal cost. Easy availability will help produce better products, improve the level of vendors' expertise, and build user and vendor confidence.
- The CT system that is built should be highly automated and also include utilities and software tools to automate, to a large extent, the tasks of interpreting CT results, developing ETSs, and generating conformance test reports.
- The ISO TC184/SC4 should be responsible for developing and/or ratifying ATSs for application protocols.

- The initial CT service should start small based on a limited set of APs. The CT capability should expand as needed.

- There should be a process to address the needs of vendors and users before and during the design and development of the CT system. The main goal is to serve the users.

6. Glossary

abstract test case (ATC): One or more files, encapsulating the test purpose, which provide the basis from which parameterized executable test cases are derived.

abstract test method: The description of how an IUT is to be tested, given at the appropriate level of abstraction to make the description independent of any particular implementation of testing tools or procedures, but with enough detail to enable executable test cases to be generated from this test method.

(laboratory) accreditation: The formalized initial and continuing process of ensuring a testing laboratory is competent to carry out specific (types of) tests.

> NOTE - The term "laboratory accreditation" covers the recognition of both the technical competence and the impartiality of a testing laboratory. Accreditation is normally awarded following successful laboratory assessment and is followed by appropriate surveillance.

accreditation body: A body that conducts and administers a laboratory accreditation scheme and grants accreditation.

> NOTE - An accreditation body may wish to delegate fully or partially the assessment of a testing laboratory to another competent body (assessment agency). While it is recognized that this may be a practical solution to extending recognition of testing laboratories, it is essential that such assessment be equivalent to that applied by the accreditation body and that the accreditation body take full responsibility for such extended accreditation.

certificate of conformity, certificate of conformance: A document issued under the rules of a certification system indicating that adequate confidence is provided that an IUT is in conformity with a specific standard or technical specification as determined through use of a specified abstract test method.

certification body: An impartial body possessing the necessary competence and reliability to operate a certification system, and in which the interests of all parties concerned with the function of the system are represented.

client (of a testing laboratory): The organization that submits an implementation for conformance testing.

comparability (of results): Characteristic of conformance assessment processes, such that execution on the same SUT, in different testing laboratories, leads to the same overall summary.

conformance assessment process: The complete process of accomplishing all conformance testing activities necessary to determine the conformance of an implementation to an application protocol.

conformance test report: A document written at the end of the conformance assessment process, which provides both summary and detailed information. The first part gives the overall summary of the conformance of the IUT to the standard for which conformance testing was carried out; the second gives the details of the testing carried out for a particular standard.

conformance testing: The testing of a candidate product for the existence of specific characteristics required by a standard; testing the extent to which an IUT is a conformant implementation. (source: ISO WD 10303-1, "Overview and Fundamental Principles," August 3, 1990.)

executable test case (ETC): A realization of an abstract test case. (The form of the realization is still under development.)

GOSIP: Government Open Systems Interconnection Profile.

Implementation Under Test (IUT): That part of a product which is to be studied under testing, which should be an implementation of one or more characteristics of the standard(s).

interoperability testing: Related to acceptance testing, but specifically applied to the examination of the information exchange between two specific IUTs and the ability of each IUT to use such information.

NOTE - This does not form part of conformance testing.

IUT: See Implementation Under Test.

POSIX: Portable Operating System Interface for Computer Environments.

repeatability (of results): Characteristic of a test case, such that repeated executions on the same SUT under the same conditions lead to the same test verdict, and by extension a characteristic of a test suite.

SUT: See System Under Test.

System Under Test (SUT): The computer hardware, software, and communication network required to support the IUT.

test campaign: The process of executing the (parameterized) executable test suite for a particular IUT.

test report: See conformance test report.

test suite: A complete set of test cases, possibly combined into nested test groups, that is necessary to perform conformance testing for a standard or group of standards.

Note: This term is deprecated unless prefixed by abstract or executable.

testing laboratory: An organization that carries out the conformance assessment process. This can be a third party, a user organization, or an identifiable part of the supplier organization.

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This report focuses on important issues that will arise during an effort to offer a full-scale STEP conformance testing service to U.S. industry. The content presented here draws from ITI's past conformance testing experience in order to provide a perspective of the real-life problems associated with developing and offering testing services. Thus, to the decision-maker and funding agency considering active participation in STEP CT, this report identifies major issues confronting CT in general, and STEP CT in the United States in particular. It also offers insight into the direction that U.S. activity should proceed.

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