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SOFTWARE MEASUREMENT PROCESS

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and
Software Measurement Support
Technical Report

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| 19. ABSTRACT (Continue on reverse if necessary and identify by block number) This report presents an evaluation of current software measurement processes and software measurement support tools. The applicability and requirements for the use of these tools to SDS software development were identified. The evaluation was performed in following steps: (1) collection of extensive metrics data from industry, Government and academic sources, (2) evaluation and analysis of the collected information for specific relevancy within SDIO software domain applications, (3) review of tools databases and product information literature to identify potential metrics tools applicable to SDS Software support, and (4) identification of deficiencies or domain limitations of existing methods and models. The results of our review of available and ongoing metrics program reveal that a metrics methodology is needed for the effective use of metrics and each major system, development/acquisition must develop and tailor its own metrics program. There is a need to emphasize predictive measurands in the earlier phases of the life cycle. (KR) ← | | | |
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LIST OF ACRONYMS

| | |
|--------|---|
| AMMCOM | U.S. Army Armaments Command |
| CSC | Computer System Component |
| CSCI | Computer System Configuration Item |
| IDA | Institute for Defense Analyses |
| IEEE | Institute for Electrical and Electronics Engineering |
| ISEC | U.S. Army Information Systems Engineering Command |
| N-SITE | Near-Term System Integration, Test and Evaluation |
| RADC | Rome Air Development Center |
| SDC | Strategic Defense Command |
| SDIO | Strategic Defense Initiative Organization |
| SDLC | Software Development Life Cycle |
| SDS | Strategic Defense System |
| SIE | Satka (Surveillance, Acquisition, Tracking and Kill Assessment) Integrated Experiment |
| SOA | State of the Art |
| SOW | Statement of Work |
| SPO | System Program Office |
| TASQ | Technology for the Assessment of Software Quality |
| USNPGS | U.S. Naval Post-Graduate School |
| V&V | Verification and Validation |

EXECUTIVE SUMMARY

OBJECTIVES

The work presented in this report was performed under Subtask 2 and 3 of Task Order 33 of the SDIO Systems SETA contract. The purpose of these subtasks was to evaluate current software measurement processes and to evaluate current software measurement support tools. Teledyne Brown Engineering was the technical lead on the subtasks with support from Sparta and TASC.

The subtasks consisted of the following activities:

- o collection of extensive metrics data from industry, Government and academic sources;
- o evaluation and analysis of the collected information for specific relevancy within the SDIO software domain applications;
- o review of tools databases and product information literature to identify potential metrics tools applicable to SDI software support;
- o identification of deficiencies or domain limitation of existing methods and models.

CONCLUSIONS

There are several major conclusions from this subtask. The results of our review of available and ongoing metrics programs reveal that a metrics methodology is needed for the effective use of metrics and each major system, development/acquisition must develop and tailor its own metrics program. SDI is no exception. There is a need to emphasize predictive measurands in the earlier phases of the life cycle (i.e., requirements and design). In the near term, available metrics tool packages can be helpful, but greater use of formal notation to support requirements and design synthesis is required if metrics information rigor and application is to occur in a much more disciplined and predictive manner.

OPEN ISSUES

The selection of application data used with metrics models must be carefully selected, scaled and scoped. Formal metrics models for use in the early life cycle phases must be developed. In turn, a life cycle model, iterative in nature, must be identified that can successfully be used for SDI development. Without a proper life cycle and metric requirements model, the state-of-the-art in predictive metrics will continue to lag behind post-facto metrics for some time to come. Predictive metrics are essential if higher productivity yields and better quality reusable software is to become a reality.

00. INTRODUCTION

This report provides an evaluation of current software measurement processes and tools currently used in the Government, industry and academia.

Section 1 lists, summarizes and analyzes the metrics models from available databases and software documents. Section 2 presents an assessment of how each applicable software metric can be applied within each SDS software subfunction. For each candidate software metric identified, a validation analysis summary will be presented. Section 3 presents the results of analyzing the field experience with two initiatives highlighted. Section 4 identifies capabilities and limitations in current methods. Section 5 presents a literature and database survey identifying existing metrics tools and environments.

The collection of metrics data proved to be both skewed and elusive. Skewed in the sense that much of the existing metrics information that is found to exist and is formalized via models and mathematical relationships is encountered late in the life cycle (i.e., occurring in the implementation phase and beyond). Elusive due to the fact that early life cycle (predictive) metrics are virtually non-existent, and when identified, have no formal foundations (mathematical or relational) to support them for the most part. Furthermore, consensus is still involving on the relative value of specific metrics (e.g., complexity) among metrics "experts". Essentially each program must establish and implement its own metrics and quality program to derive maximum benefit from it.

A section on life cycle models (1.6) has been incorporated into this report. This section is intended to support the need for a new life cycle model consistent with the MIL-STD-2167A requirements. It is also intended to provide further insight on the need for metrics emphasis and their relationships in the initial (early) life cycle phases, and the development of more formal predictive metrics. Such emphasis and identification appears to provide a key component to achieving higher productivity and quality thresholds.

Some of the data collected and conclusions arrived at, while disappointing due to the state-of-the-metric-art, are not surprising and confirm expectations. However, the life cycle section, together with the evidence identified in section 2.1, giving support to a multi-attribute, composite or vector metric representation presents a potential breakthrough in the SOA. The latter metrics form is the subject of the 1990 International Conference on Metrics being held in the United States for the first time in several years.

With respect to a tools/environment database, the Army's TASQ database contains a wealth of information as evidenced by Appendix C and D, and has served as an extremely valuable source of information, representing the latest and most extensive survey in the marketplace.

This document is driven by the software measurement requirements established in the Task Order 33, TR-9033-1, and is consistent in the use of the software domain and function identifications of that document. The document also extends and complements that information of TR-9033-1.

1. REVIEW OF EXISTING METRICS

The overriding theme for this survey and evaluation of applicable software metrics is to point up practical tools for acquisition and developmental program managers to make appropriate estimations and useful assessments on real-world problems. As Dr. J. Short of the Naval Underwater Systems Command indicated, "we get results from our metrics or we change them."

1.1 LITERATURE SURVEY

Prioritizing the metrics literature reading of a project manager or V&V planner is a first step in managing a practical metrics program. The key concepts of quality and productivity factors and criteria within the project life cycle and framework provide the fundamentals for solid planning.

1.1.1 Framework Discussions

An understanding of the structure of the software metrics is facilitated by the definition of the software quality metrics framework. Though introduced by [RADC8502], the IEEE draft Standard for Software Quality Metrics has refined the framework.

The quality metrics framework provides an open-ended, hierarchy for organizing the conceptual elements of the quality metrics domain. These elements are quality attributes, criteria and measurements suitable for organizing quality control rooms and management tracking. The IEEE refinements include the concepts of "direct metrics" (for quality factors like reliability) and "subfactors" (e.g., for correctness). (Refer to Figure 1-1)

[IEEE (draft) P1061]

Standard for a Software Quality Metrics Methodology
Section 3 presents management-oriented objectives.
Section 4 presents the refined Software Quality Metrics
Framework.

A good, comprehensive graduate text on software quality metrics was written by S.D. Conte, H.E. Dunsmore and V.Y. Shen in a collaborative effort between Purdue University and the Microelectronics and Computer Technology Corporation (MCC). The authors present many measurement and analysis examples.

[CONT86]

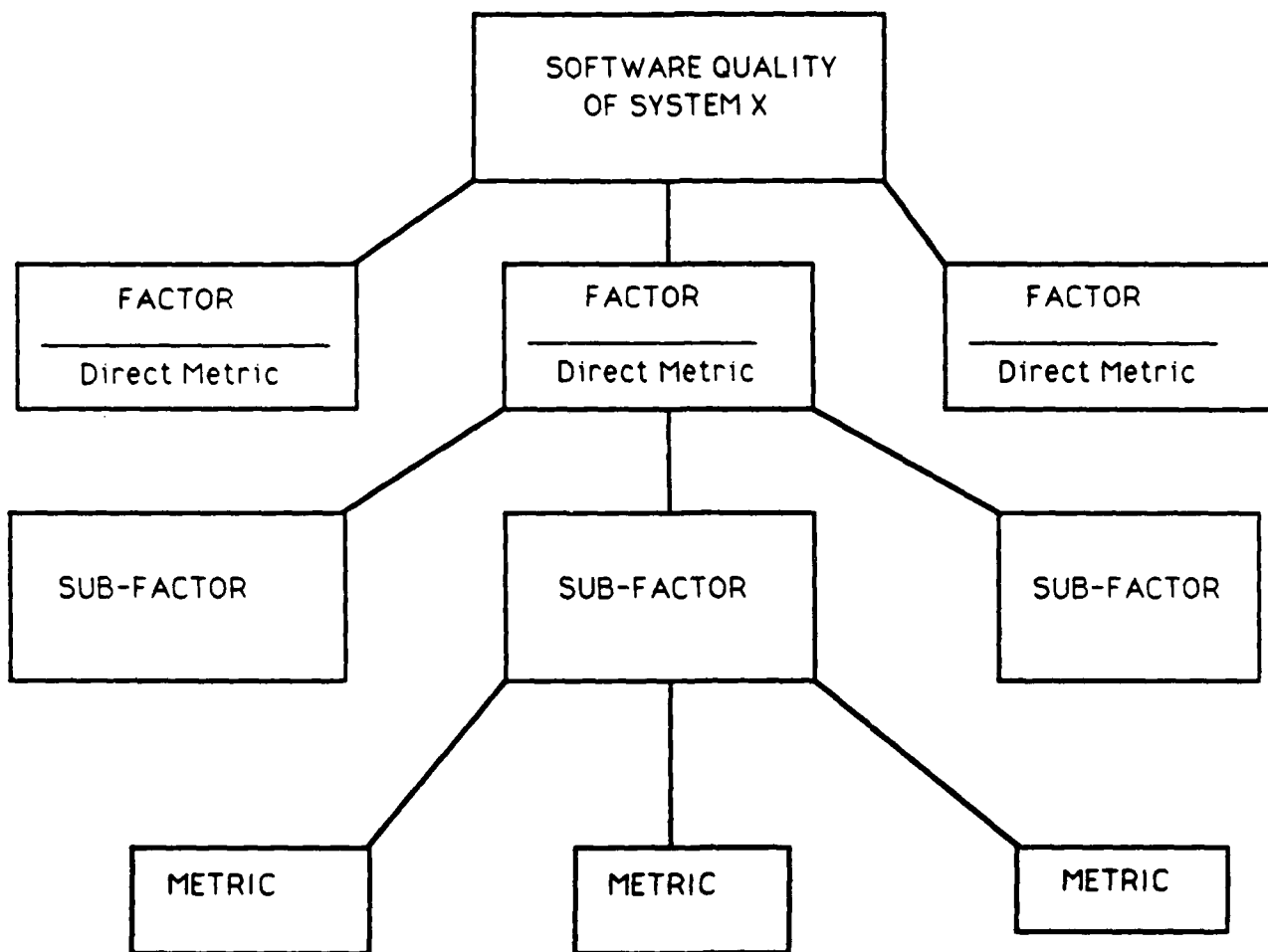
Software Engineering Metrics and Models, Benjamin Cummings, 1986.

Also, more particular to SDIO and the SDS, the (draft) IDA paper P-2132 (draft) [IDA8812] present a terser introduction that would be suitable for an SDS management pamphlet.

[IDA P-2132]

SDS Software Testing and Evaluation: A Review of the State-of-the-Art in Software Testing and Evaluation, Chapter 6. "Software Measurement Technology" present a current review of the state of the art of software quality metrics methodology.

REFINED SOFTWARE QUALITY METRICS FRAMEWORK



IEEE P1061 (DRAFT)

FIGURE 1-1

Chapter 7, "Software Reliability Assessment Technology" presents a concise, yet relevant discussion of the potential shortfall in current reliability metrics for the SDS software metrics requirements.

[RADC-TR-85-37, 3 vols]

Specification of Software Quality Attributes. Vol. 1 introduces the framework and concepts of quality specification and evaluation. Volume 2 is a detailed guidebook for specification. Volume 3 is the evaluation guide with sample checklists and worksheets.

[RADC-TR-87-171 v1]

Methodology for Software Reliability Prediction and Assessment, 3.1 "Software Quality Measurement Framework" includes the original framework discussion with definitions of all reliability concepts.

1.1.2 Management and Quality Indicators and Factors

The Air Force pamphlets AFSCP-800-14 and AFSCP-800-43 present a solid introduction to management (performance) and quality indicators. The pamphlets correlate the management and quality indicators, and then each quality indicator to its applicable software quality factors (as introduced by [RADC8502]. One disturbing statement "...there are no widespread tools available..." depends on the writers concept of "widespread", and is misleading -- tools are available.

The quality indicators pamphlets [-800-14] buries an important concept for management among two graphs and a chart:

4-13... the degree of management insight can be significantly increased by using the software quality indicators. This combination of management and quality indicators should enable the contractor and the SPO to manage software development activities actively instead of reacting to software crises as they arise...

Note: The Army has replicated the Air Force pamphlets with few variations.

[AFSCP-800-14] Software Quality Indicators
[AMCP-70-14]

[AFSCP-800-43] Software Management Indicators
[AMCP-70-13]

Figure 1-2 presents the correlations of factors and indicators as per the pamphlets.

1.1.3 Management Methodology

As their draft evolves, Norman Schneidewind (USNPGS) and others on the IEEE Quality Metrics Standard Committee have emphasized the development of an extensible metrics management method for each software acquisition or evaluating organization. The approach taken by Dr. John Short and his metrics staff at NUSC is similar, emphasizing clear, well-understood metrics objectives, planning at the single project level with SOWs tailored to meet life cycle assessments points. The Air Force methodology guide emphasizes iterative planning, predicting and assessment. [IEEE(d)P1061], [RADC878A/B]

| Software Management and Quality Indicators [AFSCP 800-14] | | | | | | |
|---|-----------------------|-----|------|------|------|-----|
| Quality Indicators | Management Indicators | | | | | |
| | CRU | SDM | RD&S | SPDT | C/SD | SDT |
| Completeness | X | X | X | X | X | X |
| Design Structure | X | | X | X | | X |
| Defect Density | | | X | X | X | X |
| Fault Density | | | X | X | X | X |
| Test Coverage | | | X | X | X | X |
| Test Sufficiency | X | | X | X | X | X |
| Documentation | X | X | X | | | X |

CRU = Computer resource utilization
 SDM = Software development manpower
 RD&S = Requirements definition & stability
 SPDT = Software progress - development & test
 C/SD = Cost/Schedule Deviations
 SDT = Software development tools

| Software Quality Indicators and Factors [AFSCP 800-14] | | | | | | | | | | | |
|--|--------------------------|------|------|------|------|------|------|------|------|------|------|
| Quality Indicators | Software Quality Factors | | | | | | | | | | |
| | Corr | Effc | Flex | Intg | Into | Main | Port | Reli | Reus | Test | Usab |
| Completeness | X | | | | | X | | X | | X | |
| Design Structure | | X | | | | X | | X | | X | |
| Defect Density | X | | | | | X | | X | | X | X |
| Fault Density | X | | | | | X | | X | | X | X |
| Test Coverage | X | | | | | X | | X | | X | |
| Test Sufficiency | X | | | | | X | | X | | X | |
| Documentation | X | | | | | X | | X | | X | X |

Corr = Correctness
 Effc = Efficiency
 Flex = Flexibility
 Intg = Integrity
 Into = Interoperability
 Main = Maintainability
 Port = Portability
 Reli = Reliability
 Reus = Reusability
 Test = Testability
 Usab = Usability

Figure 1-2. Software Management /Quality Indicators & Factors

(Further discussion of Life Cycle importance is in Paragraph 1.6. The NUSC environment is discussed in Paragraph 3.1.)

1.1.4 Reliability

As Musa, Iannino and Okumoto introduce, "Reliability is probably the most important of the characteristics"...of software quality. They define reliability traditionally "the probability that the software will work without failure for a period of time to meet customer requirements." This subsumes many properties of software quality (correctness, friendliness, safety,...) but excludes modifiability, readability (maintainability), which are less quantifiable.

[MUSA87]

Software Reliability - Measurement, Prediction, Application, McGraw Hill, 1987.

This comprehensive text provides practical measurement application guidance problems and solutions for managers and practicing software engineers, as well as the theoretical discussions needed for a college course. It uses the traditional hardware reliability approach taking advantage of the body of systems and control reliability knowledge. There is a reliance on probabilistic projections using random/stochastic techniques.

A key point about this approach: It is based upon unpredictability of programmer errors and unpredictability of execution conditions complicated by machine states. This does not account for the "known error" category (*non-fatal, moderately reducing faults*). Random implies "unpredictable" vs. "uniform". The use of techniques based upon this randomness assumption should not preclude other techniques which would presume some predictability about the failures, faults or defects.

Some further points made by John Musa in his articles should also be noted:

- a. Reliability based on failure statistics is user oriented, more significant and suitable for setting (user-oriented) objectives (for prudent business services and typical information systems).
- b. Defect/correction based quality measures are only significant in terms of contractor performance toward target goals.

Other key works on software reliability are from the Air Force RADDC and the IEEE. The RADDC work provides detail profiling of reliability and testing measurements. The more recent work of the IEEE Software Reliability Measurement Working Group is providing a refined dictionary and guidebook for reliability, including detail directory lookup for individual software metric parameters, a cohesive notation, instructions and evaluation references.

[RADC-TR-87-171]
Methodology (Vol. 1) and Guidebook (Vol. 2) for Software Reliability Prediction and Estimation

[IEEE 982.1]
(Draft) Standard Dictionary of Measures to Produce Reliable Software

[IEEE 982.2]
(Draft) Guide for the Use of the Standard Dictionary of Measures to Produce Reliable Software

As previously mentioned, the IEEE Quality Metrics Standard Committee is providing standard methodology with appendices of measurements, experience reports and validation guides [IEEE P1061].

1.1.5 Aggregate Indicators vs. Simple Measurements

The Air Force pamphlets, [CARD8707] and [GOIC89RC] indicate that primitive measures are to be aggregated with weighting factors based upon the relative value of the functions or modules effected when building the quality indicators. In the Waterfall SDLC these weights can be derived by requirements prioritization at the top level, and then functional factoring as the requirements are delineated. However, in a prototyping development, functional and performance goals may be used to establish relative system functional values.

Apart from the goal-oriented weights, the characteristics of the software architecture affect the relationship between software elements. John Musa has recently alerted us that the criticality of functions within the evolving system software architecture is a paramount consideration when considering software reliability, especially in regard to high-use servo functions or boundary control elements (e.g., Three Mile Island fault).

1.1.6 Validation and Refinement Articles

The technical literature is primarily concerned with the detail validations of particular reliability and maintainability assessment measures and more recently has been focusing upon the validity of predictions. There seems to be agreement among metrics experts that users should carefully plan and build understanding of the unique characteristics of their software and environment. Most of the software measures including balances or weights for development experience and people factors have shown to be more significant than unadjusted measures of the software alone.

We observed that the complexity and productivity models and tools do exist, but their interpretations and validations vary. Not much validation has been done on maintainability although tools do exist. Other issues such as software integrity, portability, usability, and reusability lack tools as well as validations. There are numerous validations and reliability models.

Some of the more significant results reached are listed below:

[TAKA8901] The results of this article indicate that models based on factors such as frequency of program specification change, programmer's skills, and volume of program design document are more reliable than conventional error prediction methods based only on program size.

[CARD8812] The results of this article indicate that complexity indicators based on structural (intermodule) complexity and local (intramodule) complexity seemed to be a useful tool for evaluating design quality before committing the design to code.

[LEW8811] The results of this article indicate that complexity measures are useful in quantifying the design and provide a guide to designing reliable software.

[BOEH8810] Barry Boehm and Philip Papaccio present some cost and quality observations specifically applicable to planned rapid deployment prototyping and other hybrid life cycle notions: low quality - low reliability software costs much more to maintain; high quality software tends to reduce its costs. High quality and low costs are promoted by personnel incentives, work environment and tool enhancements, and by software reuse with low rework. The authors cite use of their database of projects to validate the COCOMO model(s).

[WEIS8810] Weiss and Weyuker established an extended domain model of software reliability and used the Iannino, Musa, Okumoto rating criteria [IANN84]. The significance is that the notion of tolerable discrepancies of user service are introduced into a refined definition of software reliability, and the domain of program performance is enforced. This work was analytical and preliminary and needs followup, but promises applicability to large systems like the SDS, where the criticality of failures, the severity of defects, and the tolerance levels should be factored into reliability measures. The second author, Elaine J. Weyuker has independent software reliability work. Both were at NYU.

[DAVI8809] This short article analyzed the applicability of complexity measures (McCabe, Halstead) and lines of code in contrast to a group of new measures which analyze computer programs in terms of cognitive "chunks" as proposed by Lamergan, Mayer, Schneiderman and Solway (in various papers) "the software psychologists". The validating scope was limited to a set of small Fortran programs. Some significant observations are:

- a. Halstead's length oriented "E" measure is more robust than anticipated.
- b. Good debug time predictors also predicted the error counts well.
- c. Constructive time for new programs depends more on size than complexity.
- d. Maintenance time is strongly related to program complexity and lesser to overall size.
- e. Data structure complexity is more significant to maintenance effort.
- f. Control flow complexity is more significant to constructive effort.
- g. Reinforces the view of Conte, Dunsmore and Shen that early SDLC phase metadata is fairly accurate at defining the actual data complexity developed. [CONTE8401]

[RAMA8808] This was a successful combination of Halstead's Software Science measures with McCabe's Cyclomatic Complexity Measure, using a set of weighting factors for the length and volume primitives. However, the combined results have no greater validity than the simple combination of separate measures.

[CARD8712] This article demonstrated that the basic relation of software science lacks empirical, as well as theoretic support. Future models of program construction process should be based more closely on observations of what programmers actually do.

[JEFF8707] This article found that the complex relationship between effort (productivity) and elapsed time variation cannot be measured by any of the current time-sensitive cost models.

[PERK8703] This article investigated a Navy-supplied Ada software and showed that an automatable, hierarchical, Ada-specific software metrics framework is an effective aid for improving the quality of Ada software.

[ABDE8609] This article examined 10 metrics: Jelinski and Moranda, Bayesian Jelinski-Moranda, Littlewood, Bayesian Littlewood, Littlewood and Verrall, Keiller and Littlewood, Weibull Order Statistics, Duane, Goel-Okumoto Model, and Littlewood NHPP model. The goal of the paper is to present an approach in deciding which is the most appropriate model to use. The results showed that there is no "best buy" among the 10 metrics. This is because predictive measures perform with varying degrees of accuracy on different software being studied. Therefore, the users need to be able to select and be sure that a chosen prediction metric is performing well for the type of prediction required.

[ALBR8411] This article demonstrates the equivalence between Albrecht's methodology to estimate the amount of the "function" or "function points" the software is to perform, and Halstead's "software science" model of "SLOC" measure. It also demonstrates the high degree of correlation between "function points" and the "SLOC" (source lines of code) of the program, and between "function points" and the work-effort required to develop the code.

[BAS18311A] This paper attempts to validate the Halstead's Software Sciences metrics, McCabe's Cyclomatic Complexity and other standard programs measures. The results of this article indicate that the Software Science metrics, Cyclomatic Complexity and other predictive metrics do not satisfactorily measure the errors occurred during development, and neither of these metrics really measure or predict effort or quality.

[HENR81] The article showed that the measurement of software quality for large-scale systems using information flow to represent the system interconnectivity is an important and viable technique.

1.1.7 Summarizing the Validation Literature

[LEW8811] and [CARD8812] agreed that complexity measures are useful in measuring and quantifying the design effort and provide a guide to designing reliable and high-quality software. In contrast, [BAS18311A] showed that the software science, cyclomatic complexity metrics and other predictive metrics do not satisfactorily measure the errors incurred during the development phase, and neither of these metrics really measures or predicts design effort or software quality. Ramamurthy and Melton [RAMA8808] examined software science and cyclomatic complexity and observed that combining these measures was as effective as making the separate assessments. They proposed a family of weighted measures which simultaneously detect the software characteristics that are detected by the software science measures and the cyclomatic number. [GIBS8903] studied the effect of system structure/complexity on system maintainability; specifically, what effect do structural differences have on maintenance performance, and are

structural differences measurable? The results indicate that the structural differences do impact performance and the metrics being validated (i.e., Halstead's E, McCabe's v(G), Woodward's K, Gaffney's Jumps, Chen's MIN and Benyon-Tinker's C2) can be used as project management tools.

From the article's results, some conclusions can be made:

- a. There is an evolving consensus among complexity metrics validators that the application data used with the complexity models must be carefully selected and the conclusions must be scoped and scaled.
- b. The validity metrics models for estimation and prediction requires continual updating.
- c. There is a need to emphasized predictive measurands in the earlier phases of the life cycle (i.e., requirements and design).
- d. The validation process must continue so that metrics can be effectively used to characterize and evaluate software products and processes.
- e. A metrics methodology is needed for the effective use of metrics and each major system, development/acquisition must develop and tailor its own metrics program.

1.2 DATABASES

Technical interchanges and queries have been performed with the following information sources:

- a. The TASQ Repository maintained for the U.S. Army AMCCOM Product Assurance Directorate in New Jersey. This database contains information on several thousand tools, characteristics and companies. The information is available via a series of in depth classification matrices and vendor descriptors. Appendix C contains selected portions of the TASQ database with potential direct or indirect support potential for the SDS. A complete TASQ expansion is separately bound in single copy as Appendix D (too physically large for reproduction).
- b. The Air Force Systems Command Rome Air Development Center at Griffiss Air Force Base, New York. A number of technical reports from this source are referenced in the document list. The Data Analysis Center for Software (DACS) contains an extensive database and was extremely productive in obtaining information. (See references section)
- c. The Institute of Electrical & Electronics Engineering (IEEE) contains an extensive set of standards, guidelines and draft standards. In addition, other technical IEEE publications are identified that served as an extensive source of information (e.g., Transactions on Software, Computer Magazine, Software Magazine, Spectrum Magazine, and others). The Association of Computing Machinery (ACM) provided additional metrics sources and related information; the "Communications of the ACM" publication served as one of the source documents. (see references section)

- d. Portland State University's Metrics database and Dr. Wayne Harrison provided much assistance in acquiring information. (see references section)
- e. George Mason University's Metrics repository and Dr. Ambrose Goicoechea provided direct assistance in acquiring metrics information. Professor Goicoechea was also instrumental in acquiring European surveys on the state-of-the-practice in metrics. (see references section)
- f. The NASA Goddard Space Flight Center Software Engineering Laboratory and the University of Maryland have an extensive amount of metrics information. Meetings have been held with NASA's Frank McGarry, and University of Maryland (Dr. M. Zelkowitz). The Research Institute in Computer and Information Sciences (RICIS), University of Houston (Dr. C. McKay) was also contacted. RICIS is currently engaged in Mission and Safety Critical software initiatives with NASA's Johnson Space Center, Houston on the Space Station Software Support Environment (SSE). Software environment concerns for the SSE are similar to those that are expected for the SDI's (see references on Basili (Univ. of Md.), McKay)
- g. The Naval Surface Weapons Center (NSWC) at Dahlgren, Virginia provided details about the Statistical Modeling and Estimation of Reliability Functions for Software (SMERFS) and summary data on Navy software support tools.
- h. The Naval Underwater Systems Command (NUSC) provided descriptive data about their management methods for successful software metrics application.
- i. The Headquarters Command at Kirtland AFB described their enhanced productivity model "REVIC" (outlined in Section 5).

1.3 CROSS REFERENCING MODELS BY ATTRIBUTES AND PARAMETERS

The following tables (1.3-1 through 1.3-6) summarize the metric models identified in the literature. Each table groups a set of models by its type of measurement employed. Currently the groups fall into six measurement categories. The categories are: 1) Time Between Failures, 2) Complexity, 3) Failure Count, 4) Fault Seeding, 5) Input Domain Based, and 6) Productivity. Each table indicates what specific software attributes are addressed by each model in the table. This identification establishes the framework for the mapping of software metrics to software types, processes, and domains or SDS subfunctions. Five of the six tables use the same attribute set; while the table on productivity uses an entirely different set. The models dealing with productivity, while concerned with performance and design attributes, are focused on project management issues such as cost, schedule, and the overall development process. For this effort, the software metric models addressing the nine attributes identified in will be covered. In addition to identifying metric models, this section also contains a table (1.3-7) listing the most commonly used parameters in the construction of software metrics.

The majority of tables use nine software attributes. These are the attributes identified in Subtask 1, TR-9033-1. Thirteen attributes (factors) were originally classified by Rome Air Development Center (RADC); however, based on familiarity with SDI component software

requirements several attributes were combined to form the remaining set of eight. In addition, a ninth attribute was proposed in TR-9033-1. This attribute "throughput" addresses the user concerns of computational and communication throughputs. The following alignment shows the current nine attributes and the previously defined attributes that have been combined.

| <u>CURRENT ATTRIBUTE</u> | <u>OLD ATTRIBUTE</u> |
|--------------------------|----------------------|
| 1. Reliability | Reliability |
| 2. Survivability | Survivability |
| 3. Integrity | Integrity |
| 4. Efficiency | Efficiency |
| 5. Maintainability | Maintainability |
| | Correctness |
| | Verifiability |
| | Flexibility |
| | Expandability |
| 6. Usability | Usability |
| 7. Portability | Portability |
| 8. Reuse | Reusability |
| | Reuse |
| 9. Throughput | None |

1.3.1 Software Quality Attribute Definitions

The following definitions are included here for completeness.

Reliability. The probability that software will not cause the failure of a system for a specified time under specified conditions.

Survivability. The built-in capability of the software to perform its required function when a portion of the system is inoperative.

Integrity. The degree to which the software controls unauthorized access to, or modification of, system software and data.

Efficiency. The degree to which the software performs its intended functions with minimum consumption of computer time and storage resources.

Throughput. The degree to which the software demonstrates its capability to process data identified as computational and/or communications related.

Maintainability. The effort required to locate and correct an error in the software.

Usability. The effort required to learn the human interface with the software, to prepare input, and to interpret output of the software.

Portability. The effort required to transfer the software from one hardware or software environment to another.



Table 1.3-1 Attributes for Time Between Failure Models

| MODEL | ATTRIBUTES | | | | | | | | |
|-------------------------------|-------------|------|------|------|--------|------|------|------|------|
| | Performance | | | | Design | | | | |
| | Reli | Surv | Intg | Effc | Thru | Usab | Main | Port | Reus |
| Time Between Failure | | | | | | | | | |
| Jelinski/Moranda | X | X | | | | | | | |
| Schick/Wolverton (Linear) | X | X | | | | | | | |
| Schick/Wolverton (Parabolic) | X | X | | | | | | | |
| Moranda (Geometric De-eut) | X | | | | | | | | |
| Moranda (Hybrid Geomet Poiss) | X | | | | | | | | |
| Goel/Okumoto | X | | | | | | | | |
| Littlewood/Verrall | X | | | | | | | | |
| Lloyd/Lipow | X | | | | | | | | |

Table 1.3-2 Attributes for Complexity Models

| MODEL | ATTRIBUTES | | | | | | | | |
|-----------------------------|-------------|------|------|------|--------|------|------|------|------|
| | Performance | | | | Design | | | | |
| | Reli | Surv | Intg | Effc | Thru | Usab | Main | Port | Reus |
| Complexity | | | | | | | | | |
| Halstead | X | | | | | | | X | |
| McCabe | X | | | | | | | X | |
| Woodward (Knot Counts) | X | | | | | | | X | |
| Chen (Nested Decision Stmt) | X | | | | | | | X | |
| Gaffney | X | | | | | | | X | |
| Benyon-Tinker | X | | | | | | | X | |
| Gilb's (Binary Decision) | X | | | | | | | X | |
| Chapin's Q | X | | | | | | | X | |
| Segment-Global Usage Pair | X | | | | | | | X | |
| Myer's (McCabe extension) | X | | | | | | | X | |
| Hansen's (McCabe/Halstead) | X | | | | | | | X | |
| Oviedo's (Data/Ctrl Flows) | X | | | | | | | X | |

Effc = Efficiency
 Intg = Integrity
 Main = Maintainability
 Port = Portability
 Reli = Reliability
 Reus = Reusability
 Surv = Survivability
 Thru = Throughput
 Usab = Usability



Table 1.3-3 Attributes for Failure Count Models

| MODEL | ATTRIBUTES | | | | | | | | |
|----------------------------|-------------|------|------|------|------|--------|------|------|------|
| | Performance | | | | | Design | | | |
| | Reli | Surv | Intg | Effc | Thru | Usab | Main | Port | Reus |
| Failure Count | | | | | | | | | |
| Goel/Okumoto | X | | | | | | | | |
| Schneidewind | X | | | | | | | | |
| Goel | X | | | | | | | | |
| Musa | X | | | | | | | | |
| Shooman | X | | | | | | | | |
| Moranda | X | % | | | | | | | |
| Jelinski/Moranda | X | % | | | | | | | |
| Moranda | X | % | | | | | | | |
| Schick/Wolverton | X | % | | | | | | | |
| Goel/Okumoto (Gen Poisson) | X | % | | | | | | | |
| Brooks/Motley | X | % | | | | | | | |
| IBM Poisson | X | % | | | | | | | |

% Each model contains a different representation for a hazard function that may be adaptable to support survivability

Table 1.3-4 Attributes for Fault Seeding Models

| MODEL | ATTRIBUTES | | | | | | | | |
|---------------|-------------|------|------|------|------|--------|------|------|------|
| | Performance | | | | | Design | | | |
| | Reli | Surv | Intg | Effc | Thru | Usab | Main | Port | Reus |
| Fault Seeding | | | | | | | | | |
| Mills | X | | | | | | | | |

Effc = Efficiency
 Intg = Integrity
 Main = Maintainability
 Port = Portability
 Reli = Reliability

Reus = Reusability
 Surv = Survivability
 Thru = Throughput
 Usab = Usability



Table 1.3-5 Attributes for Input Domain Based Models

| MODEL | ATTRIBUTES | | | | | | | | |
|---------------------|-------------|------|------|------|------|--------|------|------|------|
| | Performance | | | | | Design | | | |
| | Reli | Surv | Intg | Effc | Thru | Usab | Main | Port | Reus |
| Input Domain Based | | | | | | | | | |
| Nelson | X | | | | | | | | |
| Ho | X | | | | | | | | |
| Ramamoorthy/Bastani | X | | | | | | | | |

Effc = Efficiency
 Intg = Integrity
 Main = Maintainability
 Port = Portability
 Reli = Reliability
 Reus = Reusability
 Surv = Survivability
 Thru = Throughput
 Usab = Usability

Table 1.3-6 Attributes for Productivity Models

| MODEL | ATTRIBUTES | | | |
|-----------------------------|------------|------|------|------|
| | Size | Cost | Comp | Devp |
| Productivity | | | | |
| Software Size | X | | | |
| Personnel | | X | | |
| Volatility | | X | X | |
| Resource Utilization | | | | |
| Complexity | X | X | X | |
| Schedule Progress | X | X | X | X |
| Design Progress | | | X | |
| CSU Development Progress | X | | X | X |
| Testing Progress | | X | X | X |
| Incremental Release Content | X | X | X | X |

Size = Size of the Program
 Cost = Total Cost
 Comp = Completion Date
 Devp = Effect of the Development Process

Table 1.3-7 Parameters Associated with Metric Classes

| PARAMETERS | METRIC CLASSES | | | | |
|---|----------------|-------------|--------|--------|-------------|
| | T B F | C P X | F C | F S | I D B |
| Observed time between failures | X | | | | |
| Calculated hazard function | X | | | | |
| Subjective Random Variable | X | | | | |
| Cum No. of Observed failures | | | X | X | |
| No. of faults detected during a time period | | | X | X | |
| No. of faults seeded into program | | | | X | |
| Failure rate | | | X | X | |
| Expected No. of faults to be detected | | | X | X | |
| Amount of execution time | | | X | | |
| No. of control transfers | | X | X | | |
| No. of instructions in the program | | X | X | | |
| Debugging time since time of integration | | | X | | |
| No. of faults corrected | | | X | | |
| No. of entries/exits per module | | X | | | |
| Software science measures | | X | | | |
| Design structure | | X | | | |
| Data flow complexity | | X | | | |
| Requirements traceability | | X | | | |
| Software documentation | | X | | | |
| No. of operands & operators | | X | | | |
| "Binary" decisions in program logic | | X | | | |
| No. of external interfaces | | X | | | |
| Segment use of global variables | | X | | | |
| No. of intersecting control statements | | X | | | |
| No. of compound predicates | | X | | | |
| Inputs by subdomains | | | | | X |

Metrics Classes:

TBF = Time Between Failures

CPX = Complexity

FC = Failure Count

FS = Fault Seeding

IDB = Input Domain Based

Reusability. The degree to which the software can be used in multiple applications.

1.4 SCREENING INAPPROPRIATE SOFTWARE METRICS

A review of the metrics contained in paragraph 1.3 reveals that no single metric is capable of supporting decisions across an entire software domain as defined in Subtask 1, TR-9033-1. Each metric supports measurements in one or two software attributes; e.g., Reliability, Maintainability, etc. The implication here, is that perhaps several metrics will need to be combined to form a composite model capable of supporting decisions on the 36 SDS subfunctions or the defined software domains. The analysis concludes that no available metric should be dropped from consideration.

1.5 MAPPING SOFTWARE METRICS TO TYPES AND PROCESSES

Each of the software metrics classes presented is mapped into its applicable major function and subfunction, using the attribute rankings developed in TR-9033-1.

1.5.1 Ranking Attributes by Software/Process Types

First, the characteristics of each subfunction were studied to determine the relative weights of the attributes. This analysis was performed in Subtask 1 and is explained in SDIO Task 33, TR-9033-1 SDS Software Measurement Requirements, Para. 2.3 "Characteristics of Software." The following characteristics were postulated: a) Criticality, b) Embedded vs. general purpose, c) Space/Ground based, d) Life cycle, e) Algorithmic Content, f) Size, g) Risk, and H) Intended use.

Then, in TR-9033-1, Para. 2.4, the characteristics of each subfunction were used to determine the attribute rankings for each SDS Subfunction.

Table 1.5-1 summarizes the subfunction attribute rankings, concentrating upon the "high" and "medium" rankings; the remaining subfunction-attribute correlations were all "low."

1.5.2 Subfunction Metrics Applicabilities

The applicability of the metrics classes and models to each of the quality attributes was presented in Para. 1.3 and Tables 1.3-1 through 1.3-6. These applicabilities are used as a basis to derive the subfunction metrics applicabilities.

Table 1.5-2 presents the extrapolations to metrics classes from the attribute and applicability rankings, and Table 1.5-3 presents the derivation rules used.

1.5.3 Development Process Applicability

Prior to the analytical evaluation of the metrics in regard to the subfunction requirements, (presented in Para. 2) we need to consider how the development process can affect metrics applicabilities. The possibility of employing off-the-shelf and preused software components presents a different software metrics environment than the single-vendor prototype concept, and the traditional requirements-based, multi-phased development.

Table 1.5-1. Software Functions with Ranked Attributes (from TR-9033-1)

| Major Function No. | Subfunction Title | High/Med Applicable Attributes | | | | | | | | |
|--------------------|--------------------|--------------------------------|------|------|------|------|------|------|------|------|
| | | Reli | Surv | Intg | Thru | Usab | Main | Port | Reus | Effc |
| 1 Detect | 1 Plumes | H | H | H | H | | | | | M |
| | 2 Coldbodies | H | H | H | H | | | | | H |
| | 3 RF | H | H | H | H | | M | M | | M |
| 2 Identify | 4 Resolve Obj. | H | H | H | M | | | | | M |
| | 5 Discr | H | H | H | M | | | | | M |
| | 6 Assess Kills | H | H | H | M | | | M | | M |
| 3 Track | 7 Correlate | H | H | H | H | | | | | M |
| | 8 Initiate | H | H | H | H | | | | | M |
| | 9 Estimate | H | H | H | H | | | M | | M |
| | 10 Predict I&I | H | H | H | M | | | | | M |
| 4 Communicate | 11 Interplatform | H | H | H | H | | | | M | H |
| | 12 Ground-Space | H | H | H | M | | M | M | | M |
| | 13 Ground | M | M | M | M | M | H | M | H | |
| 5 Assess | 14 Threat | H | H | H | | | | | | |
| | 15 SDS | H | H | H | | | | | | |
| 6 Wpn Contrl | 16 SBI Asgn&Ctrl | H | H | H | H | | | | | M |
| | 17 GBI Asgn&Ctrl | H | H | H | M | | H | | | M |
| | 18 SBI Guide&Ctrl | H | H | H | H | | | | | H |
| | 19 GBI Guide&Ctrl | H | H | H | M | | H | | | M |
| 7 Platfm Mgt | 20 Cmd Env Ctrl | H | M | H | M | M | H | M | | M |
| | 21 Ctrl Onbd Env | H | H | H | H | | | | | M |
| | 22 Cmd Attit&Pos | H | M | H | M | M | H | M | | M |
| | 23 Ctrl Attit&Pos | H | H | H | H | | | | | M |
| | 24 Sense Status | H | H | H | M | | | | | M |
| | 25 Assess Status | H | M | H | M | M | H | M | | M |
| | 26 Cmd Reconfig | H | M | H | M | M | H | M | | M |
| | 27 Reconfigure | H | H | H | H | | | | | M |
| 8 Spprt Dev | 28 Tools | M | M | M | | M | M | M | | M |
| 9 Simulate | 29 HWIL | M | H | H | M | M | M | | | M |
| | 30 Demonstration | M | H | M | M | M | M | M | | M |
| 10 Spprt Acqu | 31 Developer Test | M | M | M | M | H | H | H | H | M |
| | 32 Developer Env | H | M | H | M | H | M | | | M |
| | 33 Factory Test | M | M | M | | H | H | H | H | |
| | 34 Acceptance Test | M | M | M | M | | M | | | M |
| 11 Spprt Mgt | 35 MIS DB Maint | M | M | H | M | H | H | H | H | M |
| | 36 Track Mgt Info | M | | H | | H | H | H | H | M |

ATTRIBUTES: Reli = Reliability Main = Maintainability
 Surv = Survivability Usab = Usability
 Intg = Integrity Reus = Reusability
 Effc = Efficiency Port = Portability Thru = Throughput



Table 1.5-2 Deriving Metrics Rankings from Subfunction Attributes

| FUNCTIONS No. Subfunction | ATTRIBUTES | | | | | | | | | METRICS CLASSES | | | | |
|------------------------------|------------|------|------|------|------|------|------|------|------|-----------------|-----|----|----|-----|
| | Reli | Surv | Intg | Thru | Usal | Mair | Port | Reu: | Effc | TBF | Cpx | FC | FS | IDB |
| Detect | | | | | | | | | | | | | | |
| 1 Plumes | H | H | H | H | | | | | M | H | H | H | H | H |
| 2 Coldbodies | H | H | H | H | | | | | H | H | H | H | H | H |
| 3 RF | H | H | H | H | | M | M | | M | H | H | H | H | H |
| Identify | | | | | | | | | | | | | | |
| 4 Resolve Obj. | H | H | H | M | | | | | M | H | H | H | H | H |
| 5 Discriminate | H | H | H | M | | | | | M | H | H | H | H | H |
| 6 Assess Kills | H | H | H | M | M | M | M | | M | H | H | H | H | H |
| Track | | | | | | | | | | | | | | |
| 7 Correlate | H | H | H | H | | | | | M | H | H | H | H | H |
| 8 Initiate | H | H | H | H | | | | | M | H | H | H | H | H |
| 9 Estimate | H | H | H | H | | | M | | M | H | H | H | H | H |
| 10 Predict I&I | H | H | H | M | | | | | M | H | H | H | H | H |
| Communicate | | | | | | | | | | | | | | |
| 11 Interplatform | H | H | H | H | | | | M | H | H | H | H | H | H |
| 12 Ground-Space | H | H | H | M | | M | M | | M | H | H | H | H | H |
| 13 Ground | M | M | M | | M | H | M | H | | M | M | M | M | M |
| Assess | | | | | | | | | | | | | | |
| 14 Threat | H | H | H | | | | | | | H | H | H | H | H |
| 15 SDS | H | H | H | | | | | | | H | H | H | H | H |
| Wpn Control | | | | | | | | | | | | | | |
| 16 SBI Asgn&Ctrl | H | H | H | H | | | | | M | H | H | H | H | H |
| 17 GBI Asgn&Ctrl | H | H | H | M | | H | | | M | H | H | H | H | H |
| 18 SBI Guide&Ctrl | H | H | H | H | | | | | H | H | H | H | H | H |
| 19 GBI Guide&Ctrl | H | H | H | M | | H | | | M | H | H | H | H | H |
| Platfm Mgt | | | | | | | | | | | | | | |
| 20 Cmd Env Ctrl | H | M | H | M | M | H | M | | M | H | H | H | H | H |
| 21 Ctrl Onbd Env | H | H | H | H | | | | | M | H | H | H | H | H |
| 22 Cmd Attit&Pos | H | M | H | M | M | H | M | | M | H | H | H | H | M |
| 23 Ctrl Attit&Pos | H | H | H | H | | | | | M | H | H | H | H | H |
| 24 Sense Status | H | H | H | M | | | | | M | H | H | H | H | M |
| 25 Assess Status | H | M | H | M | M | H | M | | M | H | H | H | H | M |
| 26 Cmd Reconfig | H | M | H | M | M | H | M | | M | H | H | H | H | M |
| 27 Reconfigure | H | H | H | H | | | | | M | H | H | H | H | H |
| Spprt Dev | | | | | | | | | | | | | | |
| 28 Tools | M | M | M | | M | M | M | M | M | M | M | M | M | |
| Simulate | | | | | | | | | | | | | | |
| 29 HWIL | M | H | H | M | M | M | | | M | H | M | H | M | M |
| 30 Demonstration | M | H | M | M | M | M | M | | M | H | M | H | M | M |
| Spprt Acqu | | | | | | | | | | | | | | |
| 31 Developer Test | M | M | M | M | H | H | H | H | M | M | H | M | M | M |
| 32 Developer Env | H | M | H | M | H | M | | | M | H | H | H | H | H |
| 33 Factory Test | M | M | M | | H | H | H | H | | M | H | M | M | M |
| 34 Acceptance Test | M | M | M | M | | M | | | M | M | M | M | M | M |
| Spprt Mgt | | | | | | | | | | | | | | |
| 35 MIS DB Maint | M | M | H | M | H | H | H | H | M | M | H | M | M | M |
| 36 Track Mgt Info | M | | H | | H | H | H | H | M | M | H | M | M | M |

METRIC CLASSES: "TBF" -- Time Between Failures
 "FC" -- Failure Count Models "Cpx" -- Complexity
 "IDB" -- Input Domain Based "FS" -- Fault Seeding



Table 1.5-3: Metrics Ranking Derivation Rules

| ATTRIBUTE RANKING | | METRIC CLASS/MODEL RANKING |
|------------------------|-----|---|
| <RELIABILITY "RELI"> | ==> | <TIME BETWEEN FAILURES "TBF"> &<COMPLEXITY "CPX"> &<FAILURE COUNT "FC"> &<FAULT SEEDING "FS"> &<INPUT DOMAIN BASED "IDB"> |
| <SURVIVABILITY "SURV"> | ==> | <TBF> & <FC> |
| HIGH "H" | ==> | H |
| MEDIUM "M" | ==> | M |
| H & M | ==> | H |
| H & H | ==> | H |
| M & M | ==> | M |

Two classes of metrics assume access to source code: Complexity Models (Halstead, McCabe, Woodward, etc.) and the Mills Fault-Seeding Model, which also requires the alteration of the source or the software adaptation data (parameters, etc.). The failure-sensitive (TBF & FC) and input domain (IDB) and many productivity metrics models are independent of the source code, and do appear applicable to hybrid development processes.

Other developmental process implications are discussed next in regard to the software development life cycle (SDLC).

1.6 LIFE CYCLE

1.6.1 Life Cycle Models

This section on life cycles has a fourfold purpose:

- a. To establish a reference life cycle to support the categorization of metrics, and the particular phase with which they are associated or used;
- b. To establish a foundation and reference point from which subsequent and different life cycle forms can be derived or related;
- c. To establish a reference model that can be used in the identification of new metric forms and types, and the phase in which they will be employed;
- d. To provide the basis for establishing new metrics methodologies and usage emphasis.

To support the categorization of metrics, a reference or standard life cycle required identification together with its identified phases. The software life cycle used is that defined in [MIL-STD-2167A]. A number of other life cycle variations were found (RADC878A, IEEE Std. P982.2/D6, [BOEH81]) and examined. Life cycles were found to vary in the number and definition of phases. However, these differences for the most part were found to be organizational, with the content essentially the same as Tables 1.6-1,2&3 illustrate. Life cycle variations were minor, and all of these models can be mapped into each other with relative ease, as well as the waterfall model of TR-9033-1.

Newer life cycle models (i.e., Spiral, technology, iterative) that more appropriately support complex development activities such as prototyping and reusability paradigms were not considered for evaluation. The newer models have not been used to the extent that the classical waterfall model has, and thus not much experience and data are available. However, their iterative nature, ("build a little, test a little, correct/adjust, repeat the process again"), coupled with the formality of some of the prototypes used in this iterative process, is more appropriately suited to modern day developments. Large and complex system developments that must endure changing requirements, as well as undergo evolutionary or incremental changes must be supported by iterative processes that provide the ability to revisit and reexamine design incursions and baseline changes. It is, therefore, recommended that a more indepth examination of iterative life cycle models be made in the context of this report.

Items a. and d. are considered within the scope of this task, items b. and c. are outside the scope of this effort. The basis for the scope statements is the pragmatic task emphasis of identifying existing and available software and system measurement, and variably reliable predictors of high utilitarian value to managers and technical personnel.

A few observations about the referenced software development life cycles contained in Tables 1.6-1,2,3:

- User and developer bidirectional communications and information flow are not well supported (e.g., human engineering and software engineering). This is indicative of the lack of feedback paths within the life cycles required to resolve deficiencies, issues and problems as they arise;
- Events and activities are sequential in nature, with very little support for iterative processes. The 2167A life cycles support prototyping and design reusability. Iterative processes are required to tune or refine prototypes as design information evolves and is elaborated upon;
- Resulting products from such are limited and constrained. The varying degrees of prototype and reuse formalisms will require tailoring of existing specifications, as well as require new ones. Additionally, associated design reviews will also require customizing (e.g., reuse preliminary design review, prototype specification design review).

More sophisticated configuration, delivery and requirements packaging, such as incremental development, incremental deployment, evolutionary development, transactional threading, and technology insertion have given rise to newer, less well defined models. Models to support various advanced life cycle requirements have had slow acceptance (formal prototype, executable prototype, spiral, automation-based model).

The applicability of each metric to the life cycle phases must be clearly identified. This is essential in planning for effective visibility and predictability in advance of development. A metric used to assess code structure is one that is invoked late in the development life cycle where much time and resources have already been consumed (post-facto). A metric or predictor used in the early or initial life cycle phases (i.e., requirements/design synthesis) can provide anticipatory or predictive insight before long term resources are committed, where it is much more cost-effective [BOEH81] to make design tradeoffs and correct problems.

TABLE 1.6-1

COMPARING MIL-STD-2167A & RADC-TR-87-171

| MIL-STD-2167A | | RADC-TR-87-171 | |
|---------------|---------------------------|----------------|-------------------------------|
| <u>No.</u> | <u>Phase</u> | <u>No.</u> | <u>Phase</u> |
| 1 | S/W Reqts. Analysis | 1 | S/W Reqts. Analysis |
| 2 | Preliminary Design | 2 | Preliminary & Detailed Design |
| 3 | Detailed Design | | |
| 4 | Coding & Unit Test | 3 | Coding & Unit Test |
| 5 | CSC Integration & Test | 4 | CSC Integration & Test |
| 6 | CSCI Testing | 5 | CSCI Testing |
| 7 | System Integ. & Testing | 6 | System Integ. & Testing |
| 8 | Oper. Test & Evaluation | 7 | Oper. Test & Evaluation |
| 9 | Deployment & Distribution | 8 | Production & Deployment |

TABLE 1.6-2

COMPARING MIL-STD-2167A & [BOEH81] WATERFALL PHASES

| MIL-STD-2167A | | [BOEH81] WATERFALL LIFE CYCLE | |
|---------------|---------------------------|-------------------------------|------------------------------|
| <u>No.</u> | <u>Phase</u> | <u>No.</u> | <u>Phase</u> |
| 1 | S/W Reqts. Analysis | 1 | Software Reqts./Validation |
| 2 | Preliminary Design | 2 | Product Design/Verification |
| 3 | Detailed Design | 3 | Detailed Design/Verification |
| 4 | Coding & Unit Test | 4 | Code/Unit Test |
| 5 | CSC Integration & Test | 5 | Integ./Product Verification |
| 6 | CSCI Testing | | |
| 7 | System Integ. & Testing | 6 | Implementation System Test |
| 8 | Oper. Test & Evaluation | 7 | Op's & Maint./Revalidation |
| 9 | Deployment & Distribution | | |

TABLE 1.6-3

COMPARING RADC-TR-87-171 & [BOEH81] WATERFALL PHASES

| RADC-87 LIFE CYCLE | | [BOEH81] WATERFALL LIFE CYCLE | |
|--------------------|---------------------------------|-------------------------------|------------------------------|
| <u>No.</u> | <u>Phase</u> | <u>No.</u> | <u>Phase</u> |
| 1 | S/W Reqts. Analysis | 1 | Software Reqts./Validation |
| 2 | Preliminary and Detailed Design | 2 | Product Design/Verification |
| 3 | Coding & Unit Test | 3 | Detailed Design/Verification |
| 4 | CSC Integration & Test | 4 | Code/Unit Test |
| 5 | CSCI Testing | 5 | Integ./Product Verification |
| 6 | System Integ. & Testing | 6 | Implementation System Test |
| 7 | Oper. Test & Evaluation | 7 | Op's & Maint./Revalidation |
| 8 | Production & Deployment | | |

As indicated in Subtask 1, TR-9033-1, approximately 70% of all "software errors" actually occur early in the development cycle. This gives great importance to identifying and implementing those metrics which can be applied in the early design phases. An examination of a well defined characteristic life cycle model (e.g., RADC's) as presented in Table 1.6-4, with its associated reliability measure model (Table 1.6-5) reveals the following:

- The identification of a prototyping phase and an extensible reusability dependent life cycle (i.e., reusable architecture, design, specifications and code) requires the identification of new metrics or redefinition of others. Thus, the entry for reuse metrics (Table 1.6-4) would also appear in the preliminary and detailed design phase; while a new one would be entered in this same phase for prototyping.
- Secondly, the associated reliability measurement model of Table 1.6-5 would require similar adjustments in its metrics formula representation.
- Thirdly, a shift in emphasis would occur, from estimation to predictive metrics, if emphasis were placed on prototyping a system in order to obtain early visibility into the design and ferret out initial design issues.

The impact on the reliability model predictive and estimation metrics (Table 1.6-5) relationships (see reference for formula details) can be altered significantly if new terms, such as NR and NP are added to this established model.

Furthermore, in both the RADC and IEEE models, predictive metrics (category 1) used in the early life cycle phases are the ones where the least amount of information is available and where formal relationships are least understood.

| METRICS | RADIC LIFE CYCLE | | | | | | | | | |
|--------------------------------|--------------------------------------|-------------------------------|-----------------------|---------------------------|--------------------------|-----------------------|-----------|--------------------------|----------------------|------------------|
| | Concept Develop't Acquis'n Initial'n | Mission System Softw. Defin'n | System Requi'ts Anal. | Prelim. and Detail Design | Coding and Units Testing | CSC and Integr'n Test | CSCI Test | System Integr'n and Test | Oper. Test and Eval. | Produce & Deploy |
| • Application Type (A) | X | | | | | | | | | |
| • Development Environment (D) | | X | | | | | | | | |
| • Software Characteristics (S) | | | | | | | | | | |
| + Anomaly Mgt (SA) | | | | X | X | | | | | X X X |
| + Traceability (ST) | | | | X | X | | | | | X X X |
| + Quality Review (SQ) | | | | X | X | | | | | X X X |
| - Language Type (SL) | | | | | X | | | | | X X X |
| - Program Size (SS) | | | | | X | | | | | X X X |
| - Modularity (SM) | | | | | X | | | | | X X X |
| - Extent of Reuse (SU) | | | | | X | | | | | X X X |
| - Complexity (SX) | | | | | X | | | | | X X X |
| - Standards Review (SR) | | | | | X | | | | | X X X |
| Failure Rate During Test (F) | | | | | | | | | X | |
| + Test Effort (TE) | | | | | | | | | X | X |
| + Test Methodology (TM) | | | | | | | | | X | X |
| + Test Coverage (TC) | | | | | | | | | X | X |
| - Workload (EW) | | | | | | | | | X | X |
| - Input Variability (EV) | | | | | | | | | X | X |
| NR-- For Extensive Reuse | | | | | | | | | | |
| NP -- For Prototyping | | | | | | | | | | |

Table 1.6-4: Composite Metrics Across the Waterfall Life Cycle

New Metrics Required:

NR-- For Extensive Reuse

NP -- For Prototyping



TABLE 1.6-5

SOFTWARE RELIABILITY MEASUREMENT MODEL
 RADC-TR-87-171 PREDICTIVE AND ESTIMATION METRICS

PART 1: PREDICTIVE METRICS

| | | | |
|--|---|----|----|
| Application Type | A | | |
| Development Environment | D | | |
| Software Characteristics | S | | |
| Requirements and Design Representation | | S1 | |
| Anomaly Management | | | SA |
| Traceability | | | ST |
| Quality Review Results | | | SQ |
| Software Implementation | | S2 | |
| Language Type | | | SL |
| Program Size | | | SS |
| Modularity | | | SM |
| Extent of Reuse | | | SU |
| Complexity | | | SX |
| Standards Review Results | | SR | |

 $R_p = A \times D \times S$ where

$$S = S1 \times S2$$

$$S1 = SA \times ST \times SQ$$

$$S2 = SL \times SS \times SM \times SU \times SX \times SR$$

PART 2: ESTIMATION METRICS

| | | | |
|-----------------------------|---|--|----|
| Failure Rate During Testing | F | | |
| Test Environment | T | | |
| Test Effort | | | TE |
| Test Methodology | | | TM |
| Test Coverage | | | TC |
| Operating Environment | E | | |
| Workload | | | EW |
| Input Variability | | | EV |

 $RE = F \times T$, during testing where

$$T = TE \times TM \times TC \text{ and}$$

$RE = F \times E$, during OT&E where

$$E = EW \times EV$$



Focusing on MIL-STD-2167A thus establishes the need for the definition of a more extensive and formal life cycle that can address the activities and processes for prototyping and reusability among others.

1.6.2 Life Cycle Experience Classification

Table 1.6-6 represents an experience classification matrix of measures and the life cycle phase in which their use is appropriate. The table divides the measures into three categories:

Category 1 - identifies measures that have been formalized (e.g., by a mathematical foundation) and have limited or insufficient operational validation

Category 2 - identifies measures that have been formalized and have a moderate experience validation

Category 3 - identifies measures that have been formalized and have an extensive experience basis.

The table serves to identify measures (category 1) that may have a higher utilitarian value than the currently utilized metrics of category 3 [IEEE P982] that are well understood and industry recognized (e.g., McCabe, Halstead). It is interesting to note that category 3 measures fall into the later phases of the life cycle further supporting the claim that they are post-facto measures (i.e., occur from the coding phase to the operations and maintenance phase) for the most part where significant resources have been consumed and committed. While category 3 measures represent approximately 20% of the total and are represented by the majority of tools that exist in the marketplace, category 1 measures account for approximately 50% and are not supported by many tools and environments. The remainder fall into category 2 (approximately 30%).

A contributing factor to the unavailability of metrics information rigor in the early phases of the life cycle is the fact that use of formal notation to support requirements and design synthesis is not available or utilized within the industry for the most part. The sparse use of formal notation within the life cycle reveals a serious technology and communications gap between the systems and software engineering communities. Use of a formal syntax (e.g., BNF notation) or system design language, with the same level of formalism as those that exist in the implementation phase of the life cycle (i.e., programming language) has the benefit of being machine processable and analyzable.

The coexistence of both a formal system design and a programming language provides the basis for applying complexity, efficiency, reliability, etc., measures in a more consistent and predictive manner. The existence of a formal system design language allows an early assessment of design integrity and completeness that can in turn be used to predict code and structural complexity, and ease of integration. Formal notation would provide metrics measurements and models with a more extensive and effective range of application.

Part 1: LIGHT EXPERIENCE METRICS BY LIFE CYCLE PHASE

| Category 1 Metric | Conc | Rqmts | Des | Implem | Test | Intg/Tes | O&M |
|--------------------------------------|------|-------|-----|--------|------|----------|-----|
| Cum. Failure Profile | x | x | x | x | x | x | x |
| Cum. Failure Profile | x | x | x | x | x | x | x |
| Functional/ Modular Test Coverage | | | | | x | x | x |
| Defect Indices | x | x | x | x | x | x | x |
| Errors Distributions | | x | x | x | x | x | x |
| S/W Maturity Index | x | x | x | | | x | x |
| Number Entry/Exits Per Module | | | x | x | | | x |
| Graph-Theoretic Complexity for Arch. | | x | x | | | | x |
| Design Structure | | | x | | | | x |
| Software Purity Level | | | | | x | x | x |
| Requirements Compliance | | x | | | | | x |
| Data or Info. Flow Complexity | | | x | x | | | x |
| Residual Faults Count | | | | | x | x | x |
| Testing Sufficiency | | | | | x | x | |
| Required Software Reliability | x | x | x | x | x | x | x |
| Software Release Readiness | | | | | x | x | |
| Test Accuracy | | | | | x | | |
| Indep. Process Reliability | | | | | | x | x |
| Combined HW/SW Operational Reli. | | | | | x | x | x |

Part 2: MODERATE EXPERIENCE METRICS BY LIFE CYCLE PHASE

| Category 2 Metric | Conc | Rqmts | Des | Implem | Test | Intg/Tes | O&M |
|---|------|-------|-----|--------|------|----------|-----|
| Fault Density | x | x | x | x | x | x | x |
| Cause & Effect Graphing | | x | x | x | x | | x |
| Manhours per Major Defect Detected | | x | x | x | x | x | x |
| Number of Conflicting Rqmts | | x | | | | | x |
| Minimal Unit Test Case Determination | | | | x | x | | x |
| Run Reliability | | | | | x | x | x |
| Estimated Number of Faults Remaining | | | | | x | x | x |
| Test Coverage | | x | x | | x | x | x |
| Reliability Growth Function | | | | | x | x | x |
| Software Documentation & Source Listing | | | | x | x | x | x |
| Completeness | | x | x | | | | x |
| System Performance Reliability | | x | x | x | x | x | x |

Part 3: GREATER EXPERIENCE METRICS BY LIFE CYCLE PHASE

| Category 3 Metric | Conc | Rqmts | Des | Implem | Test | Int/Tes | O&M |
|---|------|-------|-----|--------|------|---------|-----|
| Defect Density | x | x | x | x | x | x | x |
| Requirements Traceability | | x | x | | | | x |
| Software Science Measures | | | | x | | | x |
| Cyclomatic Complexity | | | | x | x | | x |
| Mean Time To Discover The Next K Faults | | | | | x | x | x |
| Failure Analysis Using Elapsed Time | | | | | x | x | x |
| Mean Time To Failure | | | | | x | x | x |
| Failure Rate | | | | | x | x | x |

Table 1.6-6: SOFTWARE METRICS EXPERIENCE CLASSIFICATION

1.6.3 Summary

Paragraphs 1.6.1 and 1.6.2, together with the other sections of this report, are intended to provide the basis for the following:

- a. Much more metric information and formalism is concentrated on the later phases of the life cycle (i.e., from coding/implementation to the operations and maintenance phases). The reference section provides additional strong support for the statement.
- b. The cost to correct errors or deficiencies in the later phases increases by at least one to two orders of magnitude. This is attributable to the consumption of resources and labor intensive activities that have occurred by the time that implementation or coding is reached [BOEH81].
- c. The coding and related phases (e.g., CSC phase) of the life cycle are the least significant cost drivers. It is recognized, thus specific references are not required, that maintenance is the costliest phase, as a result of redesign, requirements changes, poor design visibility and specifications.
- d. Current development efforts that have focused on the early phases of the life cycle, predictive metrics and the early detection of problems have had very good productivity (cost and schedule) and have produced quality software with fewer catastrophic errors. IBM's Space Shuttle Program, NUSC's Submarine Combat System, Unisys Trident Submarine Navigation Program, and Teledyne Brown's SDI SIE and N-SITE programs are examples of such. Though these efforts are few in number, a consistent theme is emerging.

Indications are that focusing on predictive/early life cycle use of metrics and focusing on the early life cycle phases themselves, will provide a better quality and cost-effective design. Yet predictive metrics and the measures of category 1 (Table 1.6-6) are the ones with the least experience factors and understanding.

2. ANALYTIC EVALUATION OF SOFTWARE METRICS

2.1 FEATURE ANALYSIS

As outlined in Subtask 1, TR-9033-1, several software domains can be constructed using combinations of characteristics and factors applied to 36 SDS subfunctions. An assessment of how each applicable software metric can be applied within each SDS subfunction will be presented. Each table in Appendix B identifies the SDS subfunction and the nine software attributes along with their relative rankings as presented in Subtask 1, TR-9033-1, for that subfunction. Each relative ranking is assigned a score. The scores are arbitrarily assigned a value from 1, for low, to 5, for high.

A vector is created, for each identified metric, using the scores assigned from the relative rankings given in TR-9033-1. For example, the first subfunction identified is "Detect Plumes". Associated with that subfunction are the following attributes with their relative rankings. Beside each relative ranking is its associated score.

| Quality Attributes | Relative Rankings | Score |
|--------------------|-------------------|-------|
| Reliability | High | 5 |
| Survivability | High | 5 |
| Integrity | High | 5 |
| Efficiency | Moderate | 3 |
| Throughput | High | 5 |
| Usability | Low | 1 |
| Maintainability | Low | 1 |
| Portability | Low | 1 |
| Reuse | Low | 2 |

Taking the McCabe metric from Table 1.3-2, note that this metric is used in measuring reliability and maintainability. For Detecting Plumes, the need for reliability as defined in TR-9033-1 is high, while the need for maintainability is low. Since these are the only two attributes measured by this metric the following vector is created:

| | | <u>Detect Plumes</u> TR-9033-1 Rankings | | | | | | | | |
|--------|--|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | | H | H | H | H | L | L | L | L | M |
| | | <u>Reli</u> | <u>Surv</u> | <u>Intg</u> | <u>Thru</u> | <u>Usab</u> | <u>Main</u> | <u>Port</u> | <u>Reus</u> | <u>Effc</u> |
| McCabe | | 5 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |

Recognize that each subfunction has a different set of attribute rankings and therefore creates a different vector set.

Using the McCabe metric for another SDS subfunction, e.g., "Command Environment Control", the vector is different and it appears more relevant to this subfunction than Detecting Plumes.

Command Environment Control

TR-9033-1 Rankings

| | H | M | H | M | M | H | M | L | M |
|--------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | <u>Reli</u> | <u>Surv</u> | <u>Intg</u> | <u>Thru</u> | <u>Usab</u> | <u>Main</u> | <u>Port</u> | <u>Reus</u> | <u>Effc</u> |
| McCabe | 5 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 |

The McCabe metric, though still deficient in six of the eight attributes, matches the requirements of the Command Environment Control subfunction better since it would be able to measure 2 of the 3 attributes designated as a high need.

The reader should note the large number of zeroes included in the vectors shown in Appendix B. This indicates that the established metrics do not support many of the SDS required attributes. It appears that much work still needs to be accomplished in creating metrics that address those attributes. One method of attacking this deficiency would be to use an emerging class of metrics designated as multi-attribute metrics. Some pioneering work is currently on-going at George Mason University and other academic institutions around the country. In fact, the National Science Foundation sponsors a Special Interest Group on Multi-Criteria Decision Making (MCDM) which meets periodically to discuss the state-of-the-art in software measurement.

An alternative approach would be to investigate the feasibility of creating metrics for those attributes not currently addressed. After those metrics are created, a composite (or collective) set of metrics could be applied to each SDS subfunction. The greatest payback would be achieved by applying those composite or multi-attribute metrics that address the attributes with high or moderate relative ranking. If funds still remained in the quality assurance purse after covering higher level attributes, then the attributes designated as low ranking could be addressed.

Caution must be exercised in interpreting the values (scores) in the created vectors. No one should make a judgement that one metric is "better" than another because a vector value is larger, e.g., 5 vs. 1. Remember the scores are highly dependent on the relative ranking derived in TR-9033-1 for each SDS subfunction. Even the same metric can have several different vectors, depending again on the SDS subfunction being evaluated. The assessment that can be made for a vector with higher scores is that the application of that metric to its specific SDS subfunction will provide information about an attribute assessed, in TR-9033-1, to be more critical. This report does not claim to rank the metrics. It attempts to show where specific metrics can best be applied effectively across all 36 SDS subfunctions.

The well-defined metrics which were analyzed in this section are generally applied late in the software development life cycle (SDLC). They are normally classified as estimation type metrics rather than predictive. The current trend is to develop and apply predictive metrics early in the SDLC to aid not only program managers, but also development personnel in identifying



unfavorable trends early in development where corrective action can be taken with minimum cost and schedule impacts. As previously presented in Table 1.6-4, the more research and development done to inspire predictive metrics for the preliminary and detailed design phase of the life cycle, the better the control will be on future developmental efforts.



3. EXPERIENCE ASSESSMENT

A number of major programs were identified as potential sources that would provide field experience and relevant insight into software metrics. Several programs were eliminated initially due to their states of maturity or information availability. NASA's Space Station initiatives are in their initial phases, thus a shift to other programs with a greater experiential base was merited (e.g., NASA/IBM Shuttle program). However, that is not to say that the Space Station program does not have a quality or metrics program. Some of the RICIS literature and effort clearly focuses on mission and safety critical software and related issues for the Space Station.

The Joint Tactical Fusion program has a viable metrics initiative. Though information requested is forthcoming, the classified nature of the program precludes the screening of relevant metrics information in time for this report. However, review of models used and metrics initiatives are consistent with and support conclusions reached in this report.

Formally instituted metrics programs on major systems acquisition are not readily identifiable, with the exception of those noted in the following sections. For the most part, metrics efforts are contained within larger quality assurance programs or as smaller independent research initiatives within DoD. However, where metrics programs have been highlighted as part of major program acquisitions, much success has followed those developments/acquisitions.

3.1 THE NAVAL UNDERWATER SYSTEMS COMMAND (NUSC)

The NUSC facility at Newport, Rhode Island, has been using a suite of software metrics to manage submarine combat systems acquisitions for the last four years. Dr. John Short, Dept. Manager, was instrumental in setting the management guidance for a cohesive method of contractor oversight using software metrics throughout the life cycles of each of the emerging developments.

The management concept at work is risk management: to manage project and resource risks by assessments, predictions, validations and risk mitigations. The process starts with RFP development and proceeds apace of the life cycles. Key players within NUSC and the contractors are given training and briefings by the NUSC software metrics staff.

The NUSC database and experience is focused on the Navy Submarine Combat System Applied Software Metrics Program. NUSC has approximately 10 million lines of source code (MSLOC) in process with projects varying between 0.5 and 4.0 MSLOC.

The NUSC software metrics program applications have initially centered on CMS-2 language applications, with two recent exceptions, the CCS MK 2 and AN/BSY-2 programs using Ada and MIL-STD-2167. Key tools used in the NUSC program are LOTUS 1-2-3 as the spreadsheet for information collection of such items as faults, problem trouble reports (PTR), and PTR testing, supported by an ORACLE database; at least 4 development models (SLIM, COCOMO, SECOMO, SASET); 2 reliability models (MUSA, DUANE); a complexity analyzer and code analyzer (AdaMat); a variety of PC-based management tools, and other non-metrics tools. In summary, the Navy's program is focused on applied, tailorable and practical applications oriented metrics. Although the implementation phase is monitored and evaluated, initial life cycle phases are strongly emphasized. The collection and analysis of problem trouble reports, together with statistical evaluation of them (rate of occurrence, rate of resolution, resolution to occurrence correlation) plays a critical role in

predicting software quality for NUSC. The effort has potentially significant relevance to the SDI initiative and parts and processes of their program may be exported/reused directly to become cornerstones of SDI metrics/quality programs.

The submarine systems environment has several similar characteristics to SDI component systems, including austere survivability and reliability requirements. In certain cases, the environment and operating conditions may be even more severe since maintenance corrections and fault repairs during operational conditions at sea are not allowed. In many instances, reliability and MTBF's are pushed to the limit. Large megabit transmission links are non-existent to effect downloading of new or enhanced software versions as may be found in SDI space-based subsystems. The information exchange with NUSC is in its initial phase, and further technical interchanges are envisioned.

3.2 NAVAL SURFACE WARFARE CENTER - DAHLGREN

Dr. William Farr at NSWL Strategic Systems Dept. has been active on the IEEE Software Reliability Measurement Working Group Steering Committee and a contributor to the IEEE draft standard P982.1 committee. Dr. Farr has developed a package of 8 metrics models dubbed "SMERFS" (Statistical Modelling and Estimating of Reliability Functions for Software) and last reported over 50 different users. One of which, NASA-Johnson Space Flight Center, will be discussed next. (A module package with usage documents have been received--refer to Section 5.5.2).

3.3 IBM AT NASA-JOHNSON SPACE FLIGHT CENTER

David Hamilton of IBM at NASA in Houston has been a SMERFS user and reports highly satisfactory results using the SMERFS-based Schneidewind Model. He has had one years' use with the SMERFS package. It should be noted that SMERFS is a post-facto metrics application.

The IBM Space Shuttle Programs' "On Board Primary Software Reliability Prediction" effort source information was examined for insight into metrics and models used. Paraphrasing their approach - "The emphasis of this program centers on providing good software via the removal of failure mode causes based on the early identification of design flaws at the 'front-end' of the process (i.e., requirements & design) rather than 'defense (e.g., redundancy)' against them." A key IBM approach to detecting software errors is to use Statistical Modelling of detection history data in a configuration management database. The methodology is to apply the SMERFS, a multi-model interactive computer program, to appropriate discrepancy data in the database. Model validation centers on predicting reliability. Much of the data used for analysis is derived from previously developed software that is repeatedly analyzed, catalogued and statistically analyzed. The SMERFS models are then used to find corresponding "form and fit representations". The model that best fit their data is the Schneidewind Model which uses exponentially decreasing error detection rates and a poisson process failure detection.

The validity of this approach, apart from a front-end emphasis, depends upon:

- a. the application of software engineering methodologies;
- b. well-defined processes;

- c. performing labor intensive and extensive multi-path activities (e.g., code to function/vice-versa correlation, backward chaining analysis)
- d. "(a) software error history sufficiently analyzed to allow application of (the) reliability model".

Note: In the domain of SDI software, c. and d. are not practical due to the amount and complexity of the software, and the lack of historical data available relative to it. Many of the SDI software applications are being developed for the first time.



4. CAPABILITIES, LIMITATION AND DEFICIENCIES OF MODELS

The prioritization of SDS software metrics requirements appeared to be high for Reliability, Survivability, Integrity, and Efficiency software attributes. There was moderate or medium priority for Maintainability, Portability, Usability, and Reusability, in that order. The assessment of the software metrics maturity presents a different ordering: Efficiency, Reliability, Maintainability begin most matured, with considerable less for Survivability, and negligible, if any, support for Portability, Usability and Reusability attributes. The rest of this section will summarize the capabilities of the field of software metrics models to support each of these areas.

4.1 GENERAL LIMITATIONS

[CONT86] makes some general caveats after introducing the notion of a (composite) "Quality of Software" metric (1.2.2). The book gives the following warnings:

- a. Like items must be measured and compared together "apples with apples".
- b. When metrics are moved from one environment to another, they should be re-calibrated.
- c. Metrics are to support not replace management savvy.
- d. Software metrics are poor personnel evaluators.
- e. Any metric model output is not better than its input.
- f. The metrics program cost should be less than its benefits.

4.2 RELIABILITY MODELS

Both the Time Between Failures (TBF) and the Failure Count models have had considerable evaluation and study. Recently, John Musa stated that failure count and time was the correct basis for reliability assessment and prediction as opposed to fault or defect counting and projection [MUSA8903]. However, as stated in [IDA P-2132, 7.3] "Current software reliability technology suffers from some fundamental problems and limitations". This paper states that the convenient adoption of hardware reliability measures obscures the fundamental difference between hardware and software reliability: that though hardware is subject to physical aging, software is not. Fresh analysis into the nature of software reliability and trustworthiness by Parnas suggest that a combinatorial/probabilistic indicator may be needed: the probability that no critical fault remains.

[IDA P-2132] also raises doubts that studies based upon non-critical fault rates in software targets of average reliability are deterministic toward predictions of criticality in highly reliable software. The IDA paper goes on to quote Goel at the IDA Testing and Evaluation Workshop that available approaches are too simplistic, and they cast the very pessimistic statement "Because of the fundamental limitations of current software reliability assessment methodologies ... further work on enhancing current methodologies (sic) is unlikely to yield satisfactory results." (Assuming that the Parnas criteria is used -- determination of the probability of a failure-causing fault.)

This pessimistic cast of the IDA paper was presaged back in 1986 by Abdel-Ghaly, Chan and Littlewood, in their review of ten reliability models. The authors pointed out that predictive quality is the only consideration for a user of software reliability models and a good "model" is not sufficient to produce good predictions. They found that the inference rules and the predictive procedure were significant to the relative success of the various models [ABDE8609].

The authors present an approach for validating candidate models for a specific application. The results showed that there was no single "best buy" among them. The ten models were: Jelinski - Moranda, Bayesian Jelinski-Moranda, Littlewood, Bayesian Littlewood, Littlewood-Verral, Keiller-Littlewood, Weibull Order Statistics, Duane, Goel-Okumoto Model, and Littlewood NHPP.

4.3 COMPLEXITY/MAINTAINABILITY

More recent analysis of maintainability predictors using measures as program specification change rates, programmer's skill levels, and volume of design documentation, has considerable effect on error rates. Both [TAKA8901] and [GIBS8903] showed that structural differences do impact programmer's performance. Specifically, system improvements result in considerable improvements in programmer's performance. Gibson and Senn's study investigated this by asking three experienced professional programmers to perform three maintenance tasks on three functionally equivalent, but different in complexity, versions of a COBOL system.

Six metrics were used in this study: the Halstead's E, McCabe's cyclomatic complexity, Woodward's K, Gaffney's Jumps, Chen's MIN (Maximum Intersects Number), and Benyon-Tinker's Cx. The metrics reflected both the improvements in the system (in terms of ease in maintenance as system complexity is decreased) as well as in programmer maintenance performance. The Halstead's E, McCabe's Cyclomatic Complexity, Woodward's K, and Gaffney's Jumps reflect a decrease in complexity with improvement in system structure (control flow complexity). The Chen's MIN and Benyon-Tinker's Cx on the other hand reflect the offsetting increase in complexity due to IF nesting and number of modules.

This study was consistent with earlier work by Evangelist and work by Basili, Selby and Philips, investigating the validity of complexity measures as independent predictors of effort and or psychological complexity [EVAN84, EVAN83, BASI83]. These investigators concluded that the metrics by themselves were no better than lines-of-code, but when the personnel being studied was held constant (single programmer studied across multiple projects), there appeared to be some relative correlation with actual work and times to complete.

Since the metrics have shown to be meaningful in studies where the work object is changed, but the programmer performing the work is fixed, further work studying programmer variables is needed. A detailed problem solving and work trait profiling system may be possible to account for significant programmer differences, and be a basis to increase the validity of complexity metrics for maintainability predictions.

4.4 EFFICIENCY MODELS

The use of modeling to predict sequential software efficiency is quite mature. Typically a simulation language is used to model the intended software architecture. As development proceeds, more data is fed into the simulator, and the accuracy of the predictions improves. General purpose simulators like Simscript and GPSS have been available for many years, as have texts and articles [ADKI7704], [SCHN7704].

However, as pointed out by the IDA team in their review of testing technology available for concurrent and real-time programs, the methodology is relatively new. One recent technology is the TAGS Simulation Compiler offered by Teledyne Brown. Another is *Auto-G* from Advanced Systems Architectures of England. A third is *Statemate* by "iLOGIX", an Israeli vendor.

However promising these packages are, they require further investigation and validation.

4.5 EFFICIENCY/PRODUCTIVITY MODELS

Halstead's original "Software Science E" was a model to forecast programming effort based upon complexity and size work parameters. The *COCOMO* and *SECOMO* models are based on lines of code and other intermediate cost drivers. These models have been in use on many programs and should be considered mature [BOEH81], however, David Card and others have found that the factors of change in the software maintenance environment may not be so predictable.

The maintenance cost model was studied in [CARD8807]. The results showed that the standard maintenance cost models based on lines of code measures proved inadequate in estimating maintenance cost. This is due to the different productivity rates of maintenance and the accumulation effect of program changes.

4.6 INTEGRITY/SECURITY MODELS

The existence of an integrity model is not obvious, but both the Air Force and Navy have developed systems security risk assessment methods [NEUG85, pg. 4-74, 75], which may be used to assess system integrity factors in terms of annual levels of loss. Both methods are fairly inaccurate, using "fuzzy-metrics" (approximated orders of magnitude). This concept of fuzzy metrics may have some application to the assessment of integrity as may other elements of the security models: vulnerability inventories, threat catalogues, service and data asset valuation, and time-based exposure projections. Fairly recent research into fuzzy systems [NEGO81] and modeling [NEGO87] theory has developed the mathematical foundations needed to refine such applied risk models, but much more study is needed.

4.7 PORTABILITY, USABILITY, REUSABILITY

Models to support assessments of portability, usability and reusability are not available. This realization was also derived by the SPARTA team [SPART8903]. These attributes were ranked as medium in the aggregate rankings, so some assessment of their relative value for research and development is warranted.

4.8 COMPOSITE METRICS

Though both [CONT86] and [RADC878A] present a grand accumulation formula for assessing the many quality factors and arriving at a single coefficient, there is considerable skepticism that such a calculation would obscure the meaningfulness to seasoned managers. Another method is outlined in [GOIC81] and [SING87] -- Multicriteria Modeling and/or Fuzzy Multicriteria Modeling.

[SING87, pg. 1827] presents a good introductory example. For a software quality metrics application refer to the discussions about the Naval Underwater Systems Command.



5. AVAILABLE SOFTWARE METRICS SUPPORT

This section presents the Subtask 3 survey, features assessment and recommendation of available software metrics tools and environments.

5.1 EXISTING TOOLS AND ENVIRONMENTS

An extensive list of tools and environments have been extracted from TBE's TASQ database for examination. A more extensive list of tools and environments reviewed and others that are under review is contained in Appendix C.

From this task's point of view, two categories of tools have been established: tools directly supporting a metric (e.g., McCabe, Halstead, Complexity) and ancillary support tools (i.e., tools that can support or assist in the collection or analysis of a metric). Ancillary support tools consist of the following categories:

- Program Management & Support Tools
- Computer-Aided Software Engineering Tools
- Linkers, Loaders, Debuggers
- Test Generators
- Spreadsheets
- Databases
- Environments

Thus, while spreadsheets such as LOTUS 1-2-3 can be extremely useful in collecting and classifying metrics and measurements, spreadsheets are not considered metrics tools.

5.2 ANALYTIC EVALUATION OF TOOLS/ENVIRONMENTS

A number of metrics tools have been identified:

| <u>Tool</u> | <u>Source</u> |
|--|----------------------------------|
| SMART | USA-CECOM/TBE |
| SMERFS | NSWC-Dahlgren/Wm. Farr |
| McCabe Metric | Intermetrics |
| Halstead Metric | Intermetrics |
| Complexity Measures Tool | EVB |
| Complexity Metric | Computer Systems Design |
| Analyze | Autometric, Inc. |
| Complexity Measure | PD SIMTEL 20 |
| ADADL | Software Systems Design, Inc. |
| Byron | Intermetrics |
| Analyze | AdaSoft |
| Adamat | Dynamics Research Corp. |
| Complexity Analysis Tool | McCabe Associates |
| Ada Complexity Analysis Tool (ACAT), (McCabe) | Teledyne Brown Engineering |
| AdaPIC | Arcadia Consortium |
| Logiscope | Verilog |
| COCOMO | TRW-Redondo Beach |
| SECOMO | RADC-DACS |

With the emphasis for the Strategic Defense Initiatives to capitalize on modern software engineering methods and approaches, and the Ada Technologies initiatives, only a few of these tools will be discussed further.

5.2.1 Software Management and Reporting Tool (SMART)

The SMART package is targeted for deployment at the U.S. Army Communications - Electronics Command (CECOM) July-August 1989. The first program it will be applied on is the Advanced Field Artillery Tactical Data System (AFATDS).

The software metrics goal is to implement the Software Management and Quality Indicators as per AFSCP-800-43 and AFSCP-800-14 in an efficient, extensible architecture. The software metrics indicators and data management will be based on IBM PC-compatible machines using the popular "dBase3" formats with the "Clipper" data base language system.

Table 5-1 shows some of the data tracked by SMART.

**TABLE 5-1
OVERVIEW OF SMART SOFTWARE DATA**

TYPE INDICATOR

Deviations
Waivers
Software Trouble Reports
Test Incident Forms
Engineering Change Proposals
Software Improvement Reports
Software Discrepancy Reports
Computer Resource Utilization
Software Development Manpower
Requirements Definition and Stability
Software Progress - Development and Test
Cost/Schedule Deviations
Software Development Tools
Completeness
Design Structure
Defect Density
Fault Density
Test Coverage
Software Maturity
Documentation

TABLE 5-2
LIST OF SAMPLE GRAPHICS FOR SMART

COMPUTER RESOURCE UTILIZATIONS (3)

Primary Memory
Secondary Memory
CPU Utilization
I/O Utilization

SOFTWARE DEVELOPMENT MANPOWER (WBS)

REQUIREMENTS DEFINITION AND STABILITY (2 LEVELS)

System; CSCI

DEVELOPMENT AND TEST

Scheduled/Actual; CSCI & CSC

COST/SCHEDULE DEVIATIONS

SOFTWARE DEVELOPMENT TOOLS

COMPLETENESS

Requirements %/month
Implementation %/month

DESIGN STRUCTURE

Modularity
Complexity/Dependency

DEFECT DENSITIES

Requirements
Design
Code

FAULT (FAILURE) DENSITY

TEST COVERAGE

SOFTWARE MATURITY

DOCUMENT TROUBLES (BY MODULE)

5.2.2 Statistical Modeling and Estimation of Reliability Functions for Software (SMERFS)

SMERFS was developed several years ago as an aid in the evaluation of software reliability. In its original design it was targeted for mainframe and mini-computer environments. Since then it has also been adapted to operate on micro-computers, specifically IBM-PC/XT compatibles.

The current version of SMERFS has incorporated eight software reliability models. The models include the following: (1) Musa's Execution Model, (2) Goel-Okumoto Non-Homogeneous Poisson Model, (3) Adapted Goel-Okumoto Non-Homogeneous Poisson Model, (4) Moranda's Geometric Model, (5) Schafer's Generalized Poisson Model, (6) Schneidewind's Model, (7) Littlewood-Verrall Bayesian Model, and (8) the Brooks-Motley Model.

SMERFS contains a driver which is claimed to make it machine independent. The driver is a subset of the American Standards Institute (ANSI) specifications for the FORTRAN 77 compiler. Several user selectable options are available within the driver and allow the system to be configured to produce: better predictions; output plots and catalogued output files. Currently SMERFS is operational on three main computer groups at the Naval Surface Weapons Center (NSWC), Dahlgren, VA. The three computer groups include the CDC CYBER 170/875, the Vaxcluster 11/785, and a large number of IBM-compatible PCs. Dr. William H. Farr, of NSWC, and Mr. Oliver D. Smith, of EG&G Washington Analytical Services Center, Inc. both claim that transferring SMERFS to other computers should be very easily accomplished. [FARR8812]

Besides containing operating instructions within its interactive mode, two additional pieces of documentation are available for use with SMERFS. The two supplemental reports are: (1) SMERFS Library Access Guide (NSWC-TR-84-371, Rev. 1), and (2) SMERFS User's Guide (NSWC-TR-84-373, Rev. 1). These two publications allow a potential user to preview the system. Examples are provided throughout the User's Guide, allowing a potential user to acquire an overview of the SMERFS processing. In addition, the guide also shows actual software reliability analyses performed on the CDC CYBER 170/875.

The SMERFS systems show tremendous potential for use in the SDI environment with a minimum of modification.

5.2.3 McCabe Complexity Tools

Tools based on McCabe Complexity Analysis are of limited use in the Ada domain, unless SDI applications use older implementation languages (e.g., COBOL, CMS-2, FORTRAN). Technical Report MC87- McCabe II-0003, Extending McCabe's Cyclomatic Complexity Metric for Analysis of Ada Software, [TBE8703] U.S. Army AMCCOM; Dover, N.J. under contract DAAA21-85-D-0010 identifies extensions that are required of McCabe's Theorems if Ada, or other modern language is the implementation language. McCabe complexity applications are limited to pre-Ada higher order languages that do not contain modern software engineering abstraction process or language constructs such as packages, generics or tasking mechanisms. Thus, pre-Ada tools that fall into this category (which is most of them) will require updating.

The above referenced report has resulted in technical report MC87-McCabe II-0005, Modified A-Level Software Design Specification for the Ada Complexity Analysis Tool which Automates the Extended McCabe's Cyclomatic Complexity Metric, [TBE8704] U.S. Army

AMCCOM; Dover, N.J., contract DAAA21-85-D- 0010, establishing the requirements for an Ada Complexity Analysis Tool (ACAT) to support Ada implementations.

A number of Ada based or derived program design language (*PDL*) analysis tools have emerged over the past several years. Two of those listed, *Byron* and *ADADL*, are mature enough to be employed to perform code analysis completeness and consistency checking, cross referencing, structure checking, code verification completeness and correctness, and interface analysis.

ADADL has both a McCabe and an *ADADL* complexity metric for both pseudocode and the Ada code for each program unit. Both of these complexity metrics have not been evaluated for degree of appropriateness.

These are estimation metrics tool used on pseudocode or Ada (late life cycle phase application). It should also be noted that a standard DoD Ada PDL does not and may never exist, thus PDL tool invocation is at the implementers or applications level discretion. Automatic code generation or a shift in design emphasis to an *SADMT [IDA8804A&B]* or like representation may obviate the need for such in the future.

5.2.4 Software Engineering Cost Model (SECOMO)

SECOMO is an interactive software cost estimation tool, based on the *COCOMO* cost model, for calculating the total technical and support manpower requirements of a Life Cycle Software Engineering (LCSE) Center. SECOMO is maintained and distributed by the Rome Air Development Centers Data and Analysis Center for Software (DACS) at a \$50 charge.

SECOMO includes a "Care" cost limit for the fire-up phase of an LCSE Center.

Developed and maintained by the IIT Research Institute and RADC, it is kept current with the TRW/Barry Boehm *COCOMO* users days recommendations.

Significant enhancements are:

- An Ada parameters set
- Pull down menus and user efficiencies
- Site-timing parameters

Army Materiel Command sites which are user include:

- CECOM
- AVSCOM
- AMCCOM
- MICOM

Navy sites include: NSWC-Dahlgren, NUSC - New London, NCSC - Panama City, FL; NTS - Orlando.

5.2.5 Revised Enhanced Version in COCOMO "REVIC"

REVIC is another COCOMO enhancement maintained by an Air Force Center. The headquarters command at Kirtland AFB, New Mexico has developed an extensive set of project performance data which they use to tune the REVIC model. Updates and enhancements to baseline COCOMO and to SECOMO are brought into REVIC. (No Charge) HQCMP/EPR, Kirtland AFB, NM 87117-5000.

The REVIC User Group "RUG" is chaired by Dr. George Hozier at the University of New Mexico.

The active users include many Air Force sites and contractors:

Air Force Commands
ESD, RADC, ACS-Pentagon

Contractors
The Aerospace Corporation
Boeing
Hughes
GE
TRW
Lockheed
Textron

5.3 EXPERIENCE ASSESSMENTS

Adamat, both versions of Analyze, and Logiscope are mature metrics tools for extensive complexity analysis. Logiscope, at this time, does not support Ada source code, the others do. Adamat appears to have (based on literature review) the most extensive set of metrics criterion. A partial list is identified:

Anomaly Management: Default initialization, basic loops containing a conditional exit or return, strong type checking and constraint checking, raising user defined exceptions, range checking, etc.

Independence: Isolation of input/output routines, isolation of tasking statements and declarations, independence from system- dependent modules, access types, package system, use of length clauses, etc.

Modularity: Use of private and limited private types, single type declarations in package specifications, etc.

Self-Descriptions: Use of comments, use of identifier names, etc.

Simplicity: Boolean expressions, labels, decision points, branches, branch constructs, nesting levels, use of literals, procedure calls, etc.

System Clarity: Parenthesized expressions, no default mode parameters, access types declared private, loops-modules-blocks names, etc.

The TASQ and ISEC [TBE8609] tools/environment databases are extensive and robust (containing several thousand tools). Initial metrics queries have resulted in a sparse tool identification. A formal and more extensive categorization will be completed by mid-April, and will be categorized per the matrix contained in Appendix D for completeness. All tools identified in Appendix C will also be matrix categorized as such. A metrics tools expansion list much beyond that identified in this section is not expected. Recent dialogue with Ada environment developers and tool vendors at such exhibits/expositions as TRIADA, 7th Annual National Ada Conference, CASE EXPO, NSIA, etc., reveal that metrics tools are sparse and not the focus of their development efforts. This is understandable in light of the state and maturity of Ada technology. The latter may account for the individual DoD service initiatives aimed at software quality programs and tool initiatives such as those identified in this report and focusing on metrics. The SDI will in all probability require its own tailored metrics and quality control program similar to those of NUSC, NASA and AMMCOM. Much of the present developer/vendor effort is directed at environments, compiler maturation and efficiency, and related support tools (e.g., linkers, loaders, editors).

Many of the Ada developers at this time are looking for third party vendors to provide them with complementary/synergistic metrics tools (Rational and Alsys are examples of such).

The emphasis on predictive metrics and early life cycle phase emphasis has identified major metrics tool deficiencies in these areas - virtually non-existent. Well defined metrics, measurement relationships and formalisms in the early phases supported by tools have yet to appear to provide the productivity impact they are expected to have. The AdaPIC tool set (a futures project) ongoing within the Arcadia consortium, holds some promise, but these new tools have yet to be developed [WOLF8903]. Similarly, TBE's ACAT is under development.

Unfortunately many of the AdaPIC tools will not address the early life cycle phases, but are aimed at complementing the emerging development environment. Specifically, more systems engineering metrics tools are required to support system synthesis and couple with the early software engineering processes.

5.4 REQUISITE ENVIRONMENT/TOOLSET FEATURES

As stated in Section 5.3, the proposed TASQ format (identified in the matrix of Appendix D) will be utilized to provide the next elaboration update of tools contained in Appendix C.

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APPENDIX A
PROPOSED IEEE METRICS TERMINOLOGY

**PROPOSED IEEE STANDARD QUALITY AND RELIABILITY
METRICS TERMINOLOGY**

| <u>Term/Phrase</u> | <u>Definition</u> |
|-----------------------|--|
| <i>Concept Phase</i> | The period of time in the software life cycle during which system concepts and objectives needed by the user are identified and documented. Precedes the Requirements Phase. |
| <i>Critical Range</i> | Metric values used to classify software into categories of acceptable, marginal and unacceptable. |
| <i>Critical Value</i> | Metric value of a validated metric which is used to identify software which has unacceptable quality. |
| <i>Defect</i> | A product anomaly. Examples include such things as: 1) omissions and imperfections found during early life cycle phases and 2) faults contained in software sufficiently mature for test or operation. See also "fault". |
| <i>Direct Metric</i> | A metric that represents and defines a software quality factor, and which is valid by definition (e.g., mean time to software failure for the factor reliability). |
| <i>Error</i> | Human action that results in software containing a fault. Examples include omission or misinterpretation of user requirements in a software specification, incorrect translation or omission of a requirement in the design specification (ANSI/IEEE Std 729-1983). |
| <i>Factor Sample</i> | A set of factor values which is drawn from the metrics data base and used in metrics validation. |
| <i>Factor Value</i> | A value (see "metric value") of the direct metric that represents a factor. |
| <i>Failure</i> | 1) The termination of the ability of a functional unit to perform its required function (ISO; ANSI/IEEE Std 729-1983). 2) An event in which a system or system component does not perform a required function within specified limits. A failure may be produced when a fault is encountered (ANSI/IEEE Std 729-1983). |

| | |
|------------------------------|---|
| <i>Fault</i> | 1) An accidental condition that causes a functional unit to fail to perform its required function (ISO, ANSI/IEEE Std 729-1983). 2) A manifestation of an error in software. A fault, if encountered, may cause a failure. Synonymous with bug (ANSI/IEEE Std 729-1983). |
| <i>Measure</i> | 1) A quantitative assessment of the degree to which a software product or process possesses a given attribute (IEEE P982.1/D3.0). 2) To ascertain or appraise by comparing to a standard; to apply a metric (IEEE P1061). |
| <i>Measurement</i> | 1) The act or process of measuring. 2) A figure, extent, or amount obtained by measuring. |
| <i>Metrics Framework</i> | A tool used for organizing, selecting, communicating and evaluating the required quality attributes for a software system; a hierarchical breakdown of factors, subfactors and metrics for a software system. |
| <i>Metrics Sample</i> | A set of metrics values which is drawn from the metrics data base and used in metrics validation. |
| <i>Metric Validation</i> | The act or process of ensuring that a metric correctly predicts or accesses a quality factor. |
| <i>Metric Value</i> | An element from the range of a metric; a metric output. |
| <i>Predictive Assessment</i> | The process of using a predictor metric(s) to predict the value of another metric. |
| <i>Predictive Metric</i> | A metric which is used to predict the values of another metric. |
| <i>Primitive</i> | Data relating to the development or use of software that is used in developing measures or quantitative descriptions of software. Primitives are directly measurable or countable, or may be given a constant value or condition for a specific measure. Examples include error, failure, fault, time, time interval, date, number of noncommentary source code statements, edges, nodes. |
| <i>Process Step</i> | Any task performed in the development, implementation or maintenance of software (e.g., identify the software components of a system as part of the design). |

| | |
|--------------------------------|---|
| <i>Process Metric</i> | Metrics used to measure characteristics of the methods, techniques, and tools employed in acquiring, developing, verifying, operating and changing the software system. |
| <i>Product Metric</i> | Metrics used to measure the characteristics of the documentation and code. |
| <i>Quality Attribute</i> | A characteristic of software; a generic term applying to factors, sub-factors, or metric values. |
| <i>Quality Factor</i> | An attribute of software that contributes to its quality. |
| <i>Quality Requirement</i> | A requirement that a software attribute be present in software to satisfy a contract, standard, specification, or other formally imposed. |
| <i>Quality Sub-factor</i> | A decomposition of a quality factor or quality sub-factor document. |
| <i>Sample Software</i> | Software selected from a current or completed project from which data can be obtained for use in preliminary testing of data collection and metric computation procedures. |
| <i>Software Component</i> | General term used to refer to an element of a software system, such as module, unit, data or document. |
| <i>Software Quality Metric</i> | A function whose inputs are software data and whose output is a single (numerical) value that can be interpreted as the degree to which software possesses a given attribute that affects its quality. |
| <i>Software Reliability</i> | The probability that software will not cause the failure of a system for a specified time under specified conditions. The probability is a function of the inputs to and use of the system as well as a function of the existence of faults in the software. The inputs to the system determined whether existing faults, if any, are encountered (ANSI/IEEE Std 729-1983). |

Software Reliability Management

The process of optimizing the reliability of software through a program which emphasizes software error prevention, fault detection and removal, and the use of measurements to maximize reliability in light of project constraints such as resources (cost), schedule, and performance.

Validated Metric

A metric whose values have been statistically associated with corresponding quality factor values.

APPENDIX B

METRICS RANKING TABLES BY SUBFUNCTION

< B-1 through B-36 >

APPENDIX C
**BROAD SELECTION OF SOFTWARE/
ENVIRONMENT SUPPORT TOOLS**

LEGEND

| < COLUMN HEADING > <u>"Field Value"</u> | <u>DESCRIPTION</u> |
|--|--|
| < APPL-N > | Major Category |
| 1. "SWAT" | o Software Analysis Tool |
| 2. "PSM" | o Project Setup/Monitor |
| 3. "OLEA" | o On Line Expert Assistance |
| < TYPE > | Sub Category |
| | (Meaning Full Functional Descriptors are Used) |
| < TOOL-NAM > | Tool Name |
| < COMPANY > | (Self Explanatory) |
| < CITY > | " |
| < STATE > | " |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| SWAT | APSE | ADA DEV. ENV | DATA GEN. CORP | WESTBORO MA | | | | | | |
| SWAT | ASSEMBLER | MICRO ASSEMB | MICROTEC RESEA | SANTA CLARA CA | V | S | A | | | P |
| SWAT | ASSEMBLER | MACRO ASSEM | PSS | SANTA MONICA CA | | | | | | |
| SWAT | ASSEMBLER | FRAMEWORK AS | SPECIALIZED SYS | SEATTLE WA | | | | | | |
| SWAT | ASSEMBLER | ASSEMBLER | 2500 AD S/W | BUENAVISTA CA | V | S | A | | | P |
| SWAT | ASSEMBLER | ASSEM-LINK | OASYS | WALTHAM MA | V | S | A | | | |
| SWAT | ASSEMBLER | 1750A ASSEM | PSS | SANTA MONICA CA | | | | | | |
| SWAT | AUTO TEST GE | TDGEN | S/W RESEARCH IN | SAN FRANCISCO CA | V | | | | | P |
| SWAT | AUTOTESTGEN | T | PROGRAMMING ENV | TINTON FALL NJ | | | | | | P |
| SWAT | CASE | XL/PROGRAMME | INDEX TECHNOLOG | CAMBRIDGE MA | V | S | A | | | P |
| SWAT | CASE | VISIBLE ANAL | VISIBLE SYS COR | NEWTON MA | | | | | | P |
| SWAT | CASE | TIS/XA | CINCOM | NORCROSS GA | I | | | | | P |
| SWAT | CASE | TEAMWORK/SD | CADRE | PROVIDENCE RI | V | S | A | | | |
| SWAT | CASE | TEAMWORK/SA | CADRE | PROVIDENCE RI | V | S | A | | | |
| SWAT | CASE | TEAMWORK/RT | CADRE | PROVIDENCE RI | V | S | A | | | |
| SWAT | CASE | TEAMWORK/PCS | CADRE | PROVIDENCE RI | | | | | | P |
| SWAT | CASE | TEAMWORK/IM | CADRE | PROVIDENCE RI | V | S | A | | | |
| SWAT | CASE | TEAMWORK/ADA | CADRE | PROVIDENCE RI | V | S | A | | | |
| SWAT | CASE | TEAMWORK/ACC | CADRE | PROVIDENCE RI | V | S | A | | | |
| SWAT | CASE | TAGS | TELEDYNE BROWN | HUNTSVILLE AL | V | S | A | | | |
| SWAT | CASE | SUPERCASE | ADV TECH INTER | NEW YORK NY | V | | | | | |
| SWAT | CASE | SUPER PDL | ADV TECH INTER | NEW YORK NY | V | | | | | |
| SWAT | CASE | SOURCE VIEW | HEARTLAND | LAWRENCE KS | | | | | | |
| SWAT | CASE | SMALL TALK80 | PARCPLACE SYSTE | PALO ALTO CA | I | S | A | | | M |
| SWAT | CASE | SDD | ORACLE CORP | BELMONT CA | I | | | | | |
| SWAT | CASE | SAW | MICROCASE | VALRICO FL | V | S | | | | P |
| SWAT | CASE | S/W T/PICTUR | INTERACTIVE DEV | NATICK MA | V | S | A | | | |
| SWAT | CASE | PSL/PSA | META SYSTEMS | ANN ARBOR MI | I | | | | | P |
| SWAT | CASE | PROMOD/SA | PROMOD | LAGUNA HILLS CA | V | | | | | P |
| SWAT | CASE | PROMOD/RT | PROMOD | LAGUNA HILLS CA | V | | | | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| SWAT | CASE | PROMOD/MD | PROMOD | LAGUNA HILLS CA | | V | | | | P |
| SWAT | CASE | PROKIT WORKB | MCDONNELL DOUGL | ST LOUIS MO | | | | | | P |
| SWAT | CASE | PRISM | INDEX TECHNOLOG | CAMBRIDGE MA | | | | | | P |
| SWAT | CASE | PRIDE | M. BRYCE ASSOC | PALM HARBOR FL | | V | | | | M |
| SWAT | CASE | POWER TOOLS | ICONIX | SANTA MONICA CA | | | | | | M |
| SWAT | CASE | POSE | COMP SYS ADVI | WOODCLIFFLAKE NJ | | | | | | |
| SWAT | CASE | MODEL | COMP COMMAND & | PHILADELPHIA PA | I | V | | | | P |
| SWAT | CASE | MICROSTEP | SYSCORP | AUSTIN TX | | | | | | |
| SWAT | CASE | MATRIX | INTEGRATED SYS | HARTFORD CT | | V | S | A | | P |
| SWAT | CASE | MACDESIGNER | EXCEL SOFTWARE | MARSHALLTOWN IA | | | | | | M |
| SWAT | CASE | MACBUBBLES | STAR SYS, INC | SILVER SPRING MD | | | | | | M |
| SWAT | CASE | MACANALYST | EXCEL SOFTWARE | MARSHALLTOWN IA | | | | | | M |
| SWAT | CASE | HYPERVIEWMIC | TEN X TECHNOLOG | AUSTIN TX | | | | | | |
| SWAT | CASE | H.P.TEAMWORK | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | CASE | GENERATOR II | STRATEGIC ADVAN | TOPEKA KS | | | | | | P |
| SWAT | CASE | EXCELERATOR | INDEX TECHNOLOG | CAMBRIDGE MA | I | V | S | A | | P |
| SWAT | CASE | EXCELER/RTS | INDEX TECHNOLOG | CAMBRIDGE MA | | V | S | A | | P |
| SWAT | CASE | EPOS | SW PRODUCTS SE | NEW YORK NY | | V | S | A | | P |
| SWAT | CASE | EIFFEL | INTERACTIVE SW | GOLETA CA | | V | S | A | | P |
| SWAT | CASE | DESIGNER | MENTOR GRAPHICS | ORLANDO FL | | V | | A | | |
| SWAT | CASE | DESIGN AID | NASTEC | FALLS CHURCH VA | | V | | | | P |
| SWAT | CASE | CUSTOMIZER | INDEX TECHNOLOG | CAMBRIDGE MA | | | | | | P |
| SWAT | CASE | CRADLE | YOURDON INC | MCLEAN VA | | | | | | |
| SWAT | CASE | CARDTOOLS | READY SYSTEMS | PALO ALTO CA | | V | | | | P |
| SWAT | CASE | BLUES | ADVANCED LOGICA | BEVERLY HILLS CA | | | | | | M |
| SWAT | CASE | AUTOCODE | INTEGRATED SYS | HARTFORD CT | | V | S | A | | |
| SWAT | CASE | AUDITOR | MENTOR GRAPHICS | ORLANDO FL | | V | | A | | |
| SWAT | CASE | ANATOOL | ADVANCED LOGICA | BEVERLY HILLS CA | | | | | | M |
| SWAT | CASE | ANALYST/RT | MENTOR GRAPHICS | ORLANDO FL | | V | | A | | |
| SWAT | CASE | ANAL/DES | YOURDON INC | MCLEAN VA | | | | | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|------------------|------|-----|-----|--------|-----|-----|
| SWAT | CODE CONVERT | FORTRIX-ADA | RAPITECH | SUFFERN | NY I | V | | | | P |
| SWAT | CODE CONVERT | COBLIX-C | RAPITECH | SUFFERN | NY | | | | | |
| SWAT | CODEGENERATO | PRO/SOURCE | PROMOD | LAGUNA HILLS | CA | V | | | | P |
| SWAT | COMPARATOR | S/COMPARE | ALDON COMPUTER | OAKLAND | CA I | V | | | | |
| SWAT | COMPARATOR | EXDIFF | SW RESEARCH IN | SAN FRANCISCO | CA I | V | S | | | |
| SWAT | COMPARATOR | COMPAREX | A FEW GOOD PEOP | CREST PARK | CA I | | | | | |
| SWAT | COMPARATOR | COMPARE/HARM | ALDON COMPUTER | OAKLAND | CA I | V | | | | |
| SWAT | COMPARATOR | CA-ACCUCHECK | COMP ASSOC INT | GARDEN CITY | NY I | | | | | |
| SWAT | COMPILER | Z80 C COMPIL | 2500 AD S/W | BUEJAVISTA | CA | V | | | | P |
| SWAT | COMPILER | Z80 C COMPIL | SW DEVELOPMENT | DOWNERS GROVE IL | | V | S | A | | |
| SWAT | COMPILER | VAST-2 | INTEL SCIENTIFI | BEAVERTON | OR | | | | | |
| SWAT | COMPILER | VADS | VERDIX CORP | CHANTILLY | VA | V | S | | | |
| SWAT | COMPILER | TARTAN ADA | TARTAN LAB, INC | PITTSBURGH | PA | V | S | | | |
| SWAT | COMPILER | REX-SMA | SYS & S/W INC | COSTA MESA | CA | V | S | A | | |
| SWAT | COMPILER | REX-PL/M/86 | SYS & S/W INC | COSTA MESA | CA | V | S | A | | |
| SWAT | COMPILER | REX-C/86 | SYS & S/W INC | COSTA MESA | CA | V | S | A | | P |
| SWAT | COMPILER | PROLOG COMP | ARITY CORP | CONCORD | MA | | | | | P |
| SWAT | COMPILER | OREGON MOD2 | OREGON S/W INC | PORTLAND | OR | V | S | | | |
| SWAT | COMPILER | MICRO CONT C | ARCHIMEDES S/W | SAN FRANCISCO | CA | V | | | | P |
| SWAT | COMPILER | MAC ADA COMP | MERIDIAN | LAGUNA HILLS | CA | | | | | P |
| SWAT | COMPILER | JOVIAL COMPI | ADVANCED COMPUT | NEW YORK | NY I | V | | | | |
| SWAT | COMPILER | JOVIAL COMP | INTERACT CORP | NEW YORK | NY I | V | | | | |
| SWAT | COMPILER | JOV73 COMP | PSS | SANTA MONICA | CA | | | | | |
| SWAT | COMPILER | HP9000 FORTR | HEWLETT PACKARD | HUNTSVILLE | AL | | | | | |
| SWAT | COMPILER | HP-UXC COMPI | HEWLETT PACKARD | HUNTSVILLE | AL | | | | | |
| SWAT | COMPILER | HP-UX PASCAL | HEWLETT PACKARD | HUNTSVILLE | AL | | | | | |
| SWAT | COMPILER | HP-UX ADACOM | HEWLETT PACKARD | HUNTSVILLE | AL | | | | | |
| SWAT | COMPILER | HARRIS ADA C | HARRIS CORP | FT. LAUDERDAL | FL | | | | | |
| SWAT | COMPILER | HAPSE/SE | HARRIS CORP | | | | | | | |
| SWAT | COMPILER | HAPSE | HARRIS CORP | FT LAUDERDALE | FL | | | | | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|--------------------|-----|-----|-----|--------|-----|-----|
| SWAT | COMPILER | GOULD ADA CO | GOULD, INC. | HUNTSVILLE AL | | | | | | |
| SWAT | COMPILER | FORTAN COMP | ADVANCED COMPUT | NEW YORK NY I | V | | A | | | P |
| SWAT | COMPILER | EMCORE COMPI | EMCORE COMP. CO | ATLANTA GA | | | | | | |
| SWAT | COMPILER | DACS | DDC-1 INC | PHOENIX AZ | V | | | | | |
| SWAT | COMPILER | COMPILERS | LANGUAGE PROCES | | | S | | | | P |
| SWAT | COMPILER | C CROSS COMP | LATTICE INC | LOMBARD IL | | | | | | P |
| SWAT | COMPILER | APL PLUS | STSC INC | ROCKVILLE MD I | V | | | | | P |
| SWAT | COMPILER | ADA-86 | SOFTTECH | WALTHAM MA | V | | | | | M |
| SWAT | COMPILER | ADA TOOL SET | CONVEX COMPUTER | RICHARDSON TX | | | | | | |
| SWAT | COMPILER | ADA COMPILER | CONCURRENT COMP | HUNTSVILLE AL | | | | | | |
| SWAT | COMPILER | ADA COMPILER | ADVANCED COMPUT | NEW YORK NY | V | | | | | |
| SWAT | COMPILER | ADA COMPILER | ALSYS | WALTHAM MA I | | S | A | | | P |
| SWAT | COMPILER | ADA COMPILER | PSS | SANTA MONICA CA | | | | | | M |
| SWAT | COMPILER | ADA COMPILER | IRVINE COMPILER | IRVINE CA | V | S | | | | |
| SWAT | COMPILER | ADA 1750A CO | INTERACT CORP | NEW YORK NY I | | | | | | |
| SWAT | COMPILER | 88000 COMP | GREEN HILLS SW | GLENDAL CA | V | S | | | | |
| SWAT | COMPILER | 68000 COMP | GREEN HILLS SW | GLENDAL CA | V | S | | | | P |
| SWAT | COMPLIER | OBJECTIVE-C | STEPSTONE CORP | SANDY HOOK CT | V | S | A | | | P |
| SWAT | COMPLILER | GENEPAK | APPLIED MICROSY | REDMOND WA | V | S | A | | | P |
| SWAT | CROSS ASSEM | BSW/CROSS AS | BERKELEY SOFTWO | BERKELEY CA | | | | | | |
| SWAT | CROSS ASSEMB | UNWARE CROSS | S/W DEVELOPMENT | DOWNERS GROVE IL | V | S | A | | | |
| SWAT | CROSS ASSEMB | CROSS ASSEMB | COMP SYS CONS | CONYERS GA | | | | | | |
| SWAT | CROSS ASSEMB | CROSS ASSEMB | INTERMETRICS SW | CAMBRIDGE MA | V | S | A | | | P |
| SWAT | CROSS COMP | C CROSS COMP | INTERMETRICS SW | CAMBRIDGE MA | V | S | A | | | P |
| SWAT | CROSS COMPIL | PASCAL COMP | MICROTEC RESEA | SANTA CLARA CA | V | S | A | | | P |
| SWAT | CROSS COMPIL | HIGH C CROSS | META WARE INC | SANTA CRUZ CA I | V | S | | | | P |
| SWAT | CROSS COMPIL | FORTAN CROSS | MICROTEC RESEA | SANTA CLARA CA | V | S | A | | | P |
| SWAT | CROSSCOMPIL | CROSSCOMPIL | MICROTEC RESEA | SANTA CLARA CA | V | S | A | | | P |
| SWAT | DAT ANALYZER | CAPBAK | S/W RESEARCH IN | SAN FRANCISCO CA I | V | S | | | | |
| SWAT | DDL | BYRON | INTERMETRICS SW | CAMBRIDGE MA I | V | | | | | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|----------|--------------|-----------------|---------------|-----|-----|-----|--------|-----|-----|
| SWAT | DEBUG | PROBE-68K SY | S/W COMPONENTS | SANTA CLARA | CA | | | | | |
| SWAT | DEBUGGER | XDB | APPLIED MICROSY | REDMOND | WA | V | S | A | | P |
| SWAT | DEBUGGER | VALISOFT/286 | APPLIED MICROSY | REDMOND | WA | V | S | A | | P |
| SWAT | DEBUGGER | VALID/XEL | APPLIED MICROSY | REDMOND | WA | V | S | A | | P |
| SWAT | DEBUGGER | VALID/SOFT | APPLIED MICROSY | REDMOND | WA | V | S | A | | P |
| SWAT | DEBUGGER | UDB | OASYS | WALTHAM | MA | V | S | A | | |
| SWAT | DEBUGGER | TRACK | PERFORMANCE S/W | RICHMOND | VA | V | S | | | |
| SWAT | DEBUGGER | SYMDUMP | ONLINE S/W INT | | | | | | | |
| SWAT | DEBUGGER | SYMBOLIC DEB | INTERACT CROP | NEW YORK | NY | V | S | | | |
| SWAT | DEBUGGER | SIMCASE | ARCHIMEDES S/W | SAN FRANCISCO | CA | | | | | P |
| SWAT | DEBUGGER | SIM/DEBUGGER | 2500 AD S/W | BUEJAVISTA | CA | V | | | | P |
| SWAT | DEBUGGER | RT SOURCE | READY SYSTEMS | SUNNYVALE | CA | | S | | | |
| SWAT | DEBUGGER | RT SCOPE | READY SYSTEMS | PALOALTO | CA | V | | | | |
| SWAT | DEBUGGER | REX-SOFTPROB | SYS & S/W INC | COSTA MESA | CA | V | S | A | | P |
| SWAT | DEBUGGER | INTERTEST | ONLINE S/W INT | CALVERTON | MD | V | S | A | | P |
| SWAT | DEBUGGER | GENEPROBE | APPLIED MICROSY | REDMOND | WA | V | S | A | | |
| SWAT | DEBUGGER | FDEBUG | OASYS | WALTHAM | MA | V | S | A | | |
| SWAT | DEBUGGER | EMUPAK | APPLIED MICROSY | REDMOND | WA | V | S | A | | P |
| SWAT | DEBUGGER | DEBUGGER-SIM | MICROTEC RESEA | SANTA CLARA | CA | V | S | A | | P |
| SWAT | DEBUGGER | CSR BUG BYTE | COMP SYS RESEAR | AVON | CT | V | S | A | | |
| SWAT | DEBUGGER | CROSS DEBUG | HEWLETT PACKARD | HUNTSVILLE | AL | | | | | |
| SWAT | DEBUGGER | CONCUR DEBUG | INTEL SCIENTIFI | BEAVERTON | OR | | | | | |
| SWAT | DEBUGGER | CICS-dBUG-AI | COMPUWARE CORP | BIRMINGHAM | MI | V | S | A | | P |
| SWAT | DEBUGGER | CICS RADAR | COMPUWARE CORP | BIRMINGHAM | MI | V | S | A | | |
| SWAT | DEBUGGER | CICS ABEND-A | COMPUWARE CORP | BIRMINGHAM | MI | V | S | A | | |
| SWAT | DEBUGGER | CDEBUG | OASYS | WALTHAM | MA | V | S | A | | |
| SWAT | DEBUGGER | CDB | THIRD EYE S/W | MENLO PARK | CA | V | S | A | | P |
| SWAT | DEBUGGER | ARTSCOPE6802 | READY SYSTEMS | SUNNYVALE | CA | V | S | A | | |
| SWAT | DEBUGGER | AIEM | S/W SYS DESIGN | CLAREMONT | CA | V | S | A | | P |
| SWAT | DESIGN | COMPOSER | XINOTECH RESEAR | MINNEAPOLIS | MN | V | S | A | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| SWAT | DESIGN LANG. | POWER PDL | ICONIX | SANTA MONICA CA | | V | | | | P M |
| SWAT | DESIGNLANGPR | RE-SPEC | S/W PRODUCTS SE | NEW YORK NY | | V | S | A | | P |
| SWAT | DEV.ENVIRON | SYS BUNDLES | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | DISASSEMBLER | 680X/6502 SU | COMP SYS CONS | CONYERS GA | | | | | | |
| SWAT | DOC FORMAN | PHILE-68K FI | S/W COMPONENTS | SANTA CLARA CA | | | | | | |
| SWAT | DOC FORMAT | DOC TEMPLATE | INTERMETRICS SW | CAMBRIDGE MA | | V | S | A | | P |
| SWAT | DOC FORMAT | DOC GEN | INTERMETRICS SW | CAMBRIDGE MA | | V | S | A | | P |
| SWAT | DOC FORMATER | BUILD | LEVERAGE S/W IN | | | | | | | |
| SWAT | DRIVER | VALID/ES DRI | APPLIED MICROSY | REDMOND WA | | V | S | A | | P |
| SWAT | DYNAM SIM | TPNS | IBM | HUNTSVILLE AL | I | | | | | |
| SWAT | DYNAM SIM | SIMULATOR | OASYS | WALTHAM MA | | V | S | A | | |
| SWAT | DYNAM SIM | IPSC SIMULAT | INTEL SCIENTIFI | BEAVERRTON OR | | V | S | | | |
| SWAT | DYNAM SIM | BATCH TERMIN | IBM | HUNTSVILLE AL | I | | | | | |
| SWAT | DYNAM. SIM | 1750 ISA SIM | INTERACT CORP | NEW YORK NY | | V | S | | | |
| SWAT | DYNAMIC | TRACE | AK, INC. | SAN JOSE CA | I | | | | | P |
| SWAT | DYNAMIC | TESTGEN | S/W SYS DESIGN | CLAREMONT CA | | V | S | A | | P |
| SWAT | DYNAMIC | TCAT | S/W RESEARCH IN | SAN FRANCISCO CA | | V | S | A | | P |
| SWAT | DYNAMIC | S-TCAT/C | S/W RESEARCH IN | SAN FRANCISCO CA | | V | S | A | | P |
| SWAT | DYNAMIC | PSOS-68K SYS | S/W COMPONENTS | SANTA CLARA CA | | | | | | |
| SWAT | DYNAMIC | PCA | DEC | NASHUA NH | | V | | | | |
| SWAT | DYNAMIC | J73AVS | WRIGHT PAT AFB | DAYTON OH | I | V | | | | |
| SWAT | DYNAMIC | HI LEV. SW | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | DYNAMIC | FPE | SOFTOOL CORPORA | GOLETA CA | | V | | | | |
| SWAT | DYNAMIC | FACES | COSMIC | | I | | | | | |
| SWAT | DYNAMIC | CPE | SOFTOOL CORPORA | GOLETA CA | | V | | | | |
| SWAT | DYNAMIC | C-PE | SOFTOOL CORPORA | GOLETA CA | | V | | | | |
| SWAT | DYNAMIC SIM | XCELL + | PRITSKER & ASSO | | | | | | | P |
| SWAT | DYNAMIC SIM | TESS | PRITSKER & ASSO | | | | | | | P |
| SWAT | DYNAMIC SIM | SLAM II | PRITSKER & ASSO | WEST LAFAYETT IN | | | | | | P |
| SWAT | ENG. SIM | NEKTON | INTEL SCIENTIFI | BEAVERTON OR | | | | | | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| SWAT | ENVIRON LANG | PASCAL-2 | OREGON S/W INC | PORTLAND OR | | V | S | | | |
| SWAT | ENVIRONMENT | NAG FORTRAN | NUMERICAL ALGON | DOWNERS GROVE IL | | V | S | | | |
| SWAT | ENVIRONMENT | MODULA2/68 | ANA SYSTEMS | FOSTER CITY CA | | V | S | | | P |
| SWAT | ENVIRONMENT | MOD2/68-CD | ANA SYSTEMS | FOSTER CITY CA | | V | S | A | | |
| SWAT | ENVIRONMENT | ADV TOOL KIT | ARITY CORP | CONCORD MA | | V | | | | P |
| SWAT | FLOW CHART | PROMOD/DC | PROMOD | LAGUNA HILLS CA | | V | | | | P |
| SWAT | FLOW CHART | EASYFLOW | HAVENTREE | THOUSAND ISL. NY | | V | | | | P |
| SWAT | FLOW CHARTER | JCLFLOW | CONSUMER SYSTEM | LOMBARD IL | I | | | | | |
| SWAT | FLOWCHART | PASSAGE | INTEL SCIENTIFI | BEAVERTON OR | | | | | | |
| SWAT | FLOWCHART | FEEFLOW | ICONIX | SANTA MONICA CA | | | | | | M |
| SWAT | FLOWCHART | CLEAR + | CLEAR SOFTWARE | BROOKLINE MA | I | | | | | |
| SWAT | HW STIMULAT | ECHOVAX | ARIUM | ANAHEIM CA | | V | | | | |
| SWAT | HW TEST EQUI | ASIC ANALYZE | GOULD INC DESIG | CUPERTINO CA | | V | S | A | | |
| SWAT | INTERPRETER | SAFE C INTER | CATALYTIX | CAMBRIDGE MA | | V | S | A | | |
| SWAT | IPSE | MAESTRO | SOFTLAB INC | CHICAGO IL | I | | | | | |
| SWAT | LANGUAGE | UNH PROLOG | UNIV OF NH | DURHAM NH | | V | | | | P |
| SWAT | LANGUAGE | METASTEP ASS | STEP ENGINEERIN | SUNNYVALE CA | | V | | | | |
| SWAT | LIBRARY | PROGRAM LIB | INTERMETRICS SW | CAMBRIDGE MA | | V | S | A | | P |
| SWAT | LIBRARY | LIBRARIAN | S/W DEVELOPMENT | DOWNERS GROVE IL | | V | S | A | | P |
| SWAT | LIBRARY | LIBRARIAN | MICROTEC RESEA | SANTA CLARA CA | | V | S | A | | P |
| SWAT | LIBRARY | IPSC-VX VECL | INTEL SCIENTIFI | BEAVERTON OR | | V | | | | |
| SWAT | LIBRARY | INTERWORK II | INTEL SCIENTIFI | BEAVERTON OR | | V | | | | |
| SWAT | LIBRARY | GRACE | EVB S/W ENG INC | FREDERICK MD | I | V | S | A | | P |
| SWAT | LIBRARY | CEPHES | OASYS | WALTHAM MA | | V | | | | M |
| SWAT | LINKER | LINKER | S/W DEVELOPMENT | DOWNERS GROVE IL | | V | S | A | | |
| SWAT | LINKER | LINKER | 2500 AD S/W | BUEUAVISTA CA | | V | S | A | | P |
| SWAT | LINKER | GENELINK | APPLIED MICROSY | REDMOND WA | | V | S | A | | P |
| SWAT | LINKER | 1750A LINK | PSS | SANTA MONICA CA | | V | S | A | | P |
| SWAT | LINKER/ASSEM | OLA | OREGON S/W INC | PORTLAND OR | I | V | S | A | | |
| SWAT | LINKERS | LINKING LOAD | MICROTEC RESEA | SANTA CLARA CA | | V | S | A | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|---------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| SWAT | MACRO | MACROS | 2500 AD S/W | BUEUAVISTA CA | | | | | | |
| SWAT | METHODOLOGY | SADT | SOFTTECH | WALTHAM MA | | | | | | |
| SWAT | MICRO PROCES | UNIWARE 6800 | SW DEVELOPMENT | DOWNERS GROVE IL | V | S | A | | | |
| SWAT | OS | HP-UX OS 300 | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | OS | HP-UX OS 200 | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | PATH ANALYZ | PAT | SAIC | ARLINGTON VA | I | V | A | | | |
| SWAT | PATH ANALYZE | BASIS BRANCH | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | POST EX. ANA | TRAPS | TRAV TECH. INC. | NEWMAN GA | I | V | | | | |
| SWAT | POST EXECUTI | EXTRACT | ALDON COMPUTER | OAKLAND CA | | | | | | |
| SWAT | PROGRESSTEST | AUTOTESTER | SW RECORDING | DALLAS TX | | | | | P | |
| SWAT | PROJ. ENVIRO | HP-UX TOOLS | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | PUBLICATION | DESIGN BOOK | TASC | ARLINGTON VA | | | | | | |
| SWAT | QUALITY METR | DQM | HUGHES | | | | | | | |
| SWAT | QUALITY METR | CMT | EVB SW ENG INC | FREDERICK MD | I | V | S | A | P | M |
| SWAT | QUALITY METR | BAT/DAT | MCCABE & ASSOC | COLUMBIA MD | | | | | P | |
| SWAT | QUALITY METR | ACT/CAT | MCCABE & ASSOC | COLUMBIA MD | | | | | P | |
| SWAT | REG TRACE | RVTS | TELEDYNE BROWN | HUNTSVILLE AL | | | | | P | |
| SWAT | REG TRACE | RTRACE | NASTEC | FALLS VA | | | | | | |
| SWAT | REGRESSION T | TEST/IMS | CONSUMER SYSTEM | LOMBARD IL | | | | | | |
| SWAT | REGRESSION T | TEST MANAGER | DEC | NASHUA NH | | V | | | | |
| SWAT | REGRESSION T | SMARTS | SW RESEARCH IN | SAN FRANCISCO CA | | V | | | P | |
| SWAT | REGRESSION T | IPAT | INTEL CORPORATI | SANTA CLARA CA | | | | | P | |
| SWAT | REGRESSION T | FASTASK | ICONIX | SANTA MONICA CA | | | | | | M |
| SWAT | REGRESSION T | CICS PLAYBAC | COMPUWARE CORP. | BIRMINGHAM MI | | I | | | | |
| SWAT | REGRESSION TE | SW PERFORMA | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | REPRESSION T | DCATS | SYS DES & DEV | BOULDER CO | | | | | P | |
| SWAT | REQ TRACE | THOR | SAIC | HUNTSVILLE AL | | | | | | |
| SWAT | REQ TRACE | RT2 | BOEING | SEATTLE WA | | | | | | |
| SWAT | REQ TRACE | REX | LEVERAGE SW IN | ALEXANDRIA VA | | | | | P | |
| SWAT | REQ TRACE | RETT | SW SYS DESIGN | CLAREMONT CA | | V | S | A | P | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| SWAT | REQ TRACE | PROCAP/TMS | PROMOD | LAGUNA HILLS CA | | V | | | | P |
| SWAT | REQ TRACE | ARTS | LOCKHEED | | | | | | | |
| SWAT | REQ. ANALYZE | ARIS | SW SYS DESIGN | CLAREMONT CA | | V | S | A | | P |
| SWAT | REQ. TRACE | TURBO TRACE | COMP SCI INNOV | PALM BAY FL | | V | | | | |
| SWAT | RESTRUC.PROG | SMARTCHART | ICONIX | SANTA MONICA CA | | | | | | M |
| SWAT | RUNTIME | STANDALONE A | SAIC | HUNTSVILLE AL | | | | | | |
| SWAT | SW TEST HW | SPA | HEWLETT PACKARD | HUNTSVILLE AL | | | | | | |
| SWAT | SIM LANGUAGE | SIMSCRIPT II | CACI INC | LA JOLLA CA | I | | | | | P |
| SWAT | SIMULATOR | SIMULATOR | COMP SYS CONS | CONYERS GA | | | | | | |
| SWAT | SOURCE CONVE | CA-CONVERTOR | COMP ASSOC INT | GARDEN CITY NY | I | | | | | |
| SWAT | STANDARDS CO | JCLAUDIT | CONSUMER SYSTEM | LOMBARD IL | I | | | | | |
| SWAT | STATIC | SCOREBOARD | TRAV TECH INC | NEWMAN GA | I | | | | | P |
| SWAT | STATIC | SCA | DEC | NASHUA NH | | V | | | | |
| SWAT | STATIC | SAP | COSMIC | | | V | | | | |
| SWAT | STATIC | SAFE C RUNTI | CATALYTIX | CAMBRIDGE MA | | V | S | A | | |
| SWAT | STATIC | RXVP80 | GEN RESRCH CORP | SANTA BARBARA CA | | V | | | | |
| SWAT | STATIC | RA | FORD | | | | | | | |
| SWAT | STATIC | PROCAP | PROMOD | LAGUNA HILLS CA | | V | | | | P |
| SWAT | STATIC | MSAT | ELECTRONIC PROV | FT. HUACHUCA | | V | | | | |
| SWAT | STATIC | MAT | SAIC | ARLINGTON VA | I | V | | | | |
| SWAT | STATIC | LOGISCOPE | VERILOG USA | ALEXANDRIA VA | | V | S | A | | |
| SWAT | STATIC | LASE | LITTON | | | V | | | | |
| SWAT | STATIC | ISAS | SINGER | TUSCON AZ | | V | | | | |
| SWAT | STATIC | GYPSY VERIFI | COMPUTATIONALOG | AUSTIN TX | | | S | | | |
| SWAT | STATIC | AMS | HARRIS CORP | MELBOURNE FL | | V | | | | |
| SWAT | STATIC | ADF | M. BRYCE ASSOC | PALM HARBOR FL | | V | | | | |
| SWAT | STATIC | ADAMAT | DYNAMICS RESEAR | ANDOVER MA | | V | S | | | |
| SWAT | STATIC | ADADL | SW SYS DESIGN | CLAREMONT CA | | V | S | A | | P |
| SWAT | STRESS TEST | VERIFY | ONLINE SW INT | CALVERTON MD | I | | | | | |
| SWAT | STRESS TEST | AUTOMATOR MI | INTERACTIVE SOL | BOGOTA NJ | | | | | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | TX | NY | GA | CA | MA | NJ | CA | NJ | NJ | MA | MA | MA | CA | CA | CA | CA | CA | NJ | OR | CA | OR | MA | NJ | CA | CA | MA | NJ |
|--------|--------------|--------------|-----------------|--------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| SWAT | SYS SIMULATI | PAWS | INFO RESEARCH A | AUSTIN | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | TEST GENERAT | CA-DATAMACS | COMP ASSOC INT | GARDEN CITY | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | TRANSLATOR | TRANSLATOR | COMP SYS CONS | CONYERS | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | TRANSLATOR | TRANSLATOR | 2500 AD S/W | BUEUAVISTA | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | TRANSLATOR | FACT | SOFTOOL CORPORA | GOLETA | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | TRANSLATOR | ENG TO C/C T | CATALYTIX | CAMBRIDGE | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | UNDEVELOPED | STAT | AMCCOM | PARSIPPANY | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | UNDEVELOPED | SOFTCAT | ATAC | MOUNTAINVIEW | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | UNDEVELOPED | ESRA | AMCCOM | PARSIPPANY | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | UNDEVELOPED | DES COMPL ME | AMCCOM | PARSIPPANY | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | UTILITY | SNDRCV | OASYS | WALTHAM | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | UTILITY | OBJMODCONVER | OASYS | WALTHAM | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SWAT | X-COMPILER | CROSS COMPIL | ALSYS | WALTHAM | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | | XED MENU PRO | COMPUTER METHOD | CHATSWORTH | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | ACU. OPTION | WBS | COMP COGNITION | SAN DIEGO | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | ACU. OPTION | PO&R | COMP COGNITION | SAN DIEGO | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | ACU. OPTION | PAYROLL | COMP COGNITION | SAN DIEGO | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | ACU. OPTION | ACCOUNTS PAY | COMP COGNITION | SAN DIEGO | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CASE | PROJECT SOFT | ATHERTON TECHNO | SUNNYVALE | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | TEAM VISION | TEAM 1 SYS INC | SUNNYVALE | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | SCONS | CORP COMP SYS | SUNNYVALE | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | PVCS | POLYTRON | HOLMDEL | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | PROMOD CM | PROMOD | BEAVERTON | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | POLYMAKE | POLYTRON | LAKE FOREST | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | ENDEVOR C1 | BST | BEAVERTON | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | CUE | K&H PROJ SYS IN | WESTBORO | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | CMT | EXPERTWARE INC | SPARTA | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | CCC | SOFTOOL CORP | SANTA CLARA | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG MGT | AIDE-DE-CAMP | S/W MAIN. & DEV | GOLETA | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PSM | CONFIG. MGMT | DELTA | CORPORATE COMPU | CONCORD | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | HOLMDEL | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| PSM | COST MODEL | SPACE | CECOM PA&T | FT MONMOUTH NJ | | | | | | P |
| PSM | COST MODEL | SOFTQUAL | CARMAN GROUP | PLANO TX | | | | | | P |
| PSM | COST MODEL | SOFTCOST-R | REIFER CONSULT. | TORRANCE CA | | | | | | P |
| PSM | COST MODEL | SOFTCOST ADA | REIFER CONSULT. | TORRANCE CA | | | | | | P |
| PSM | COST MODEL | SLIM | QUANTITATIVE SW | MCLEAN VA | | | | | | P |
| PSM | COST MODEL | SIZE PLANNER | QUANTITATIVE SW | MCLEAN VA | | | | | | P |
| PSM | COST MODEL | SECOMO | TELOS FED SYS | SHREWSBURY NJ | | | | | | P |
| PSM | COST MODEL | P3 | QUANTITATIVE SW | MCLEAN VA | | | | | | P |
| PSM | COST MODEL | COCOPRO | ICONIX | SANTA MONICA CA | | | | | | M |
| PSM | COST MODEL | COCOMO | TRW-DSG | RENDONDO BEAC CA | | | | | | |
| PSM | COST MODEL | ASSET-R | REIFER CONSULT. | TORRANCE CA | | | | | | P |
| PSM | DOCUMENT MGT | SLATE | BBN SW PRODUCT | CAMBRIDGE MA | | S | | | | |
| PSM | DOCUMENT MGT | INTERLEAF TP | INTERLEAF | | I | V | S | A | | M |
| PSM | DOCUMENT MGT | DST | EXPERTWARE INC | SANTA CLARA CA | I | V | S | A | | P |
| PSM | DOCUMENT MGT | CRYSTAL DMS | SYNTACTICS | SANTA CLARA CA | | | S | A | | P |
| PSM | DOCUMENT MGT | CONCORDIA | SYMBOLICS | CAMBRIDGE MA | | | S | A | | P |
| PSM | DOCUMENT MGT | 4TH-WRITE | ADVENTUREWARE | ALLISON PARK PA | I | V | | | | P |
| PSM | EDITOR | VI-PLUS | UNIPRESS SW | EDISON NJ | I | V | S | A | | P |
| PSM | EDITOR | KEYONE EDITO | OASYS | WALTHAM MA | | V | S | A | | P |
| PSM | EDITOR | EMACS | UNIPRESS SW | EDISON NJ | I | V | S | A | | P |
| PSM | EDITOR | CEPAGE | SW ENGIN INC. | | I | V | S | A | | P |
| PSM | EDITOR | C-MACS | UNIPRESS SW | EDISON NJ | I | V | S | A | | P |
| PSM | EDITOR | APOGEE EDIT | BINARY RESEARCH | FT WASHINGTON PA | I | V | S | A | | P |
| PSM | EDITOR | ADADL EDITOR | SW SYS DE | CLAREMONT CA | I | V | S | A | | P |
| PSM | GRAPHICS PK | TELEGRAF | COMPUTER ASSOC. | ATLANTA GA | I | V | | | | |
| PSM | GRAPHICS PK | TAB GEN OPTI | CONTEXT | BEAVERTON OR | | | | A | | |
| PSM | GRAPHICS PK | STATGRAPHICS | STSC | ROCKVILLE MD | | | | | | P |
| PSM | GRAPHICS PK | SCDDRAW | MCDONNELL DOUGL | | | | | | | P |
| PSM | GRAPHICS PK | RENDOR | MULTIWARE INC | DAVIS CA | | V | | | | |
| PSM | GRAPHICS PK | QUAL GRAPHIC | QUALITY S/W PRO | BEVERLY HILLS CA | I | V | S | A | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|---------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| PSM | GRAPHICS PK | Q-CHART | QUADRATRON SYS | SHERMAN OAKS CA | I | V | S | A | P | |
| PSM | GRAPHICS PK | PICSURE | PRECISIONVISUAL | BOULDER CO | I | V | S | A | | |
| PSM | GRAPHICS PK | PICSURE | PRECISIONVISUAL | BOULDER CO | I | V | S | A | | |
| PSM | GRAPHICS PK | PICED EDITOR | CONTEXT | BEAVERTON OR | | | | | | |
| PSM | GRAPHICS PK | PGB 300 | UNIPRESS SW | EDISON NJ | I | V | S | A | P | |
| PSM | GRAPHICS PK | MGSP | MULTIWARE INC | DAVIS CA | | V | | | | |
| PSM | GRAPHICS PK | MCPAINTII | CLARIS | MOUNTAIN VIEW CA | | | | | | M |
| PSM | GRAPHICS PK | MCDRAW II | CLARIS | MOUNTAIN VIEW CA | | | | | | M |
| PSM | GRAPHICS PK | IPT GRAFSMAN | SOUTHWIND SW | WICHITA KS | | V | S | A | P | |
| PSM | GRAPHICS PK | GRAPHIC GATE | CONTEXT | BEAVERTON OR | | | | | | |
| PSM | GRAPHICS PK | GRAFX GRAPHI | D&E SW INC | CLINTON MD | | V | | | | |
| PSM | GRAPHICS PK | GRAFMAKER | PRECISIONVISUAL | BOULDER CO | I | V | S | A | P | |
| PSM | GRAPHICS PK | EZGRAF | SOUTHWIND SW | WICHITA KS | | V | S | A | | |
| PSM | GRAPHICS PK | DOC | CONTEXT | BEAVERTON OR | | | | | | |
| PSM | GRAPHICS PK | DI 3000 | PRECISIONVISUAL | BOULDER CO | I | V | S | A | | |
| PSM | GRAPHICS PK | DFDDRAW | MCDONNELL DOUGL | | | | | | | P |
| PSM | GRAPHICS PK | DESIGN | META SOFTWARE | CAMBRIDGE MA | I | | S | | P | M |
| PSM | GRAPHICS PK | CUSTOMGANTT | SOFTRAK SYS | SALT LAKE CTY UT | | V | S | | P | |
| PSM | GRAPHICS PK | ARTISAN | MEDIA LOGIC INC | SANTA MONICA CA | | | | | | |
| PSM | METHODODOLOGY | STRADIS | MCDONNELL DOUGL | | | | | | | |
| PSM | MGT TRAINER | GREMEX | COSMIC | ATHENS GA | I | | | | | |
| PSM | OFFICE AUTO. | SMARTWARE | INFORMIX S/W | LENEXA KS | | | S | A | P | |
| PSM | PERF MEA SYS | I/CSCS | K&H PROJ SYS IN | SPARTA NJ | | V | | | | |
| PSM | PROB TRACKER | STR TRACKER | AMCCOM | PICATINNY ARS NJ | | V | | | | |
| PSM | PROJ MANAGER | WINGS | AGS MGT. SYS. | KING OF PRUSS PA | I | V | | | P | |
| PSM | PROJ MANAGER | VUE | NIS, INC. | SAN JOSE CA | I | V | S | A | | |
| PSM | PROJ MANAGER | TIME LINE | SYMANTEC | CUPERTINO CA | | | | | | P |
| PSM | PROJ MANAGER | TELLAPLAN | COMPUTER ASSOC. | ATLANTA GA | I | V | S | A | | |
| PSM | PROJ MANAGER | SUPERPROJECT | COMPUTER ASSOC. | SAN JOSE CA | | | | | | P |
| PSM | PROJ MANAGER | QWIKNET | PSDI | VALLY FORGE PA | | | | | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| PSM | PROJ MANAGER | QUICK-PLAN | MITCHELL MGT | WESTBOROUGH MA | | | | | P | |
| PSM | PROJ MANAGER | PROJECT/2 | PSDI | VALLY FORGE PA | | V | | | | |
| PSM | PROJ MANAGER | PROJECT WORK | APPLIED BUS TEC | NEW YORK NY | | | | | P | |
| PSM | PROJ MANAGER | PROJECT PLAN | PRIMAVERA | | | | | | | |
| PSM | PROJ MANAGER | PRIDE-PSM | M. BRYCE & ASSO | PALM HARBOR FL | I | V | S | A | | |
| PSM | PROJ MANAGER | PRESTIGE PC | K&H PROJ SYS IN | SPARTA NJ | | | | | P | |
| PSM | PROJ MANAGER | PREMIS | K&H PROJ SYS IN | WAYNE PA | | V | | | | |
| PSM | PROJ MANAGER | POWER | EXPERTWARE INC | SANTA CLARA CA | | | | | P | |
| PSM | PROJ MANAGER | PLOTTRAK | SOFTRAK SYS | SALT LAKE CTY UT | | V | S | | P | |
| PSM | PROJ MANAGER | PLANNER | PROD. SOL., INC | WALTHAM MA | | V | | | | |
| PSM | PROJ MANAGER | PERT TIME II | COSMIC | ATHENS GA | I | | | | | |
| PSM | PROJ MANAGER | PC-MAPPS | MITCHELL MGT | WESTBOROUGH MA | | | | | P | |
| PSM | PROJ MANAGER | PAC MICRO | AGS MGT. SYS. | KING OF PRUSS PA | | | | | P | |
| PSM | PROJ MANAGER | PAC III | AGS MGT. SYS. | KING OF PRUSS PA | I | V | | | | |
| PSM | PROJ MANAGER | NIPS | COSMIC | ATHENS GA | | | | | | |
| PSM | PROJ MANAGER | MULTIPROJ-P | TECHNISOF | LEVENDIA CA | | | | | P | |
| PSM | PROJ MANAGER | MULTIPROD-O | TECHNISOF | LEVENDIA CA | | | | | P | |
| PSM | PROJ MANAGER | MIS | COSMIC | ATHENS GA | | V | | | | |
| PSM | PROJ MANAGER | MICROTRAK | SOFTRAK SYS | SALT LAKE CTY UT | | V | S | | P | |
| PSM | PROJ MANAGER | MICROPLANNER | MICRO PLAN INT. | SAN FRANCISCO CA | | | | | P | M |
| PSM | PROJ MANAGER | MICROPLAN 6 | MICRO PLAN INT. | SAN FRANCISCO CA | | | | | P | |
| PSM | PROJ MANAGER | MICRO-MAPPS | MITCHELL MGT | WESTBOROUGH MA | I | | | | | |
| PSM | PROJ MANAGER | MASTERPLAN | QUALITY S/W PRO | BEVERLY HILLS CA | I | V | S | A | P | |
| PSM | PROJ MANAGER | MASTERPLAN | UNIPRESS S/W | EDISON NJ | I | V | S | A | P | |
| PSM | PROJ MANAGER | MAPPS-AI | MITCHELL MGT | WESTBOROUGH MA | I | | | | | |
| PSM | PROJ MANAGER | MAPPS | MITCHELL MGT. | WESTBOROUGH MA | I | V | | | | M |
| PSM | PROJ MANAGER | MACPROJECT | CLARIS | MOUNTAIN VIEW CA | | | | | | |
| PSM | PROJ MANAGER | INSTAPLAN | INSTAPLAN | | | | | | | |
| PSM | PROJ MANAGER | HARVARD PM30 | S/W PUBLISHING | ATLANTA GA | | | | | P | |
| PSM | PROJ MANAGER | FORESIGHT | HILLORY S/W/IN | BRIELLE NJ | | | | | P | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|--------------|------------------|------------------|-----|-----|-----|--------|-----|-----|
| PSM | PROJ MANAGER | EASYTRAK | DIGITAL PLANNER | NEWPORT BEACH CA | I | V | S | A | | M |
| PSM | PROJ MANAGER | EASY PROJECT | TECHNISOFIT | LEVENDIA CA | | | | | P | |
| PSM | PROJ MANAGER | C-PLAN | DSD CORP. | BOTHELL WA | | V | | | P | |
| PSM | PROJ MANAGER | ASAPMS | ASA | NEW YORK NY | I | V | S | A | P | |
| PSM | PROJ MANAGER | ARTEMIS PC | METIER | HOUSTON TX | | | | | P | |
| PSM | PROJ MANAGER | ARTEMIS | METIER | HOUSTON TX | | | | | P | |
| PSM | PROJ MANAGER | AEPEX | TIMBERLINE S/W | BEAVERTON OR | | | | | P | |
| PSM | PROJ MANAGER | ACUITY LINE | COMP COGNITION | SAN DIEGO CA | I | V | S | A | | |
| PSM | PROJ SCHEDUL | SET | COSMIC | ATHENS GA | I | | | | | |
| PSM | PROJ SCHEDUL | PROJECT | MICROSOFT CORP | REDMOND WA | | | S | | P | |
| PSM | PROJ SCHEDUL | PPARS | COSMIC | ATHENS GA | | | | | | |
| PSM | PROJ SCHEDUL | PACE/PRRA | COSMIC | ATHENS GA | | | | | | |
| PSM | PROJ SCHEDUL | PACE | COSMIC | ATHENS GA | | | | | | |
| PSM | PROJ SCHEDUL | MARS | COSMIC | ATHENS GA | | V | | | | |
| PSM | PROJ SCHEDUL | FMAP | COSMIC | ATHENS GA | I | | | | | |
| PSM | PROJ SCHEDUL | PROJ SCHEDUL | GTSI | CHANTILLY VA | | | | | P | |
| PSM | PROJ TRACKER | PROTRACS | APPLIED MICROSOY | ROSWELL GA | | | | | P | |
| PSM | PUBLICATION | PM HANDBOOK | APPLIED INFO DE | OAKBROOK IL | | | | | | |
| PSM | QUAL METRICS | ANALYZE | AUTOMETRIC | LINTHICUM MD | I | V | S | A | P | |
| PSM | SCREEN MANAG | FORMIX | MCSI | EDEN PRAIRIE MN | I | V | S | A | P | |
| PSM | SECURITY | OMNIGUARD | ONLINE S/W INT | CALVERTON MD | I | | | | | |
| PSM | SOW ASSIST | SOW ASSIST | BELVOIR RD&E | FT BELVOIR VA | | | | | P | |
| PSM | SPREADSHEET | WINGZ | INFORMIX S/W | LENEXA KS | | | | | | M |
| PSM | SPREADSHEET | TACTICIAN | SOUTHWIND S/W | WICHITA KS | | V | S | A | P | |
| PSM | SPREADSHEET | SYMPHONY | LOTUS DEVEL COR | | | | | | P | |
| PSM | SPREADSHEET | SUPERCALC5 | COMPUTER ASSOC. | SAN JOSE CA | | | | | P | |
| PSM | SPREADSHEET | SCO PROF | UNIPRESS S/W | EDISON NJ | I | V | S | A | P | |
| PSM | SPREADSHEET | Q-PLAN | QUADRATRON SYS | SHERMAN OAKS CA | I | V | S | A | P | |
| PSM | SPREADSHEET | Q-CALC | QUALITY S/W PRO | BEVERLY HILLS CA | I | V | S | A | P | |
| PSM | SPREADSHEET | Q-CALC | UNIPRESS S/W | EDISON NJ | I | V | S | A | P | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|--------------|---------------|------------------|------------------|-----|-----|-----|--------|-----|-----|
| PSM | SPREADSHEET | PILOT EIS | PILOT | BOSTON MA | | V | | | | |
| PSM | SPREADSHEET | MULTIPLAN | MICROSOFT CORP | REDMOND WA | | | | | P | |
| PSM | SPREADSHEET | LOTUS 1-2-3 | LOTUS DEVEL CORP | REDMOND WA | | | | | P | |
| PSM | SPREADSHEET | EXCEL | MICROSOFT CORP | REDMOND WA | | S | | | P | |
| PSM | SPREADSHEET | CHART | MICROSOFT CORP | REDMOND WA | | S | | | P | |
| PSM | SPREADSHEET | 20/20 | ACCESS TECH | SOUTH NATICK MA | I | V | | | | |
| PSM | SQA EXPERT | SQAM | AMCCOM | PICATINNY ARS NJ | | V | | | | |
| PSM | TRAN UTILITY | PLANLINKS | COMPUTER ASSOC. | SAN JOSE CA | I | V | | | A | |
| PSM | TRAN UTILITY | DCA FILTER | CONTEXT | BEAVERTON OR | | | | | A | |
| PSM | VUE OPTION | RESOURCE LEVE | NIS, INC. | SAN JOSE CA | I | V | | | A | |
| PSM | VUE OPTION | PLOTTER GRAP | NIS, INC. | SAN JOSE CA | I | V | | | A | |
| PSM | VUE OPTION | MULTI PROJ A | NIS, INC. | SAN JOSE CA | I | V | | | A | |
| PSM | VUE OPTION | COST MODULE | NIS, INC. | SAN JOSE CA | I | V | | | A | |
| PSM | WORDPROCESSR | XED | COMPUTER METHOD | CHATSWORTH CA | | V | | | P | |
| PSM | WORDPROCESSR | WORKBENCH | ADDISON-WESLEY | READING MA | | | | | P | M |
| PSM | WORDPROCESSR | SCOLYRIX | UNIPRESS SW | EDISON NJ | I | V | | | P | |
| PSM | WORDPROCESSR | Q-TYPESET | QUADRATRON SYS | SHERMAN OAKS CA | I | V | | | P | |
| PSM | WORDPROCESSR | Q-ONE | QUADRATRON SYS | SHERMAN OAKS CA | I | V | | | P | |
| PSM | WORDPROCESSR | MACWRITE | CLARIS | MOUNTAIN VIEW CA | | | | | | M |
| PSM | WORKSTATION | ENGINE WRITER | CONTEXT | BEAVERTON OR | | | | | A | |
| PSM | WORKSTATION | ENGI WRITER+ | CONTEXT | BEAVERTON OR | | | | | A | |
| PSM | WORKSTATION | CONTEXT WRIT | CONTEXT | BEAVERTON OR | | | | | A | |
| PSM | WORKSTATION | CONTEXT EDIT | CONTEXT | BEAVERTON OR | | | | | A | |
| OLEA | ESR | XCON | DEC | HUNTSVILLE AL | | V | | | | |
| OLEA | ESR | VS ACCELERAT | COYNE KALA INC | ARLINGTON VA | | | | | | |
| OLEA | ESR | TIMM TUNER | GEN RESRCH CORP | MCLEAN VA | | V | | | | |
| OLEA | ESR | TEST BENCH | CARNEGIE GROUP | PITTSBURGH PA | | | | | | P |
| OLEA | ESR | PLANNING WS | KNOWLEDGEWARE | ATLANTA GA | | | | | | P |
| OLEA | ESR | GENSIS | HELP38 SYSTEMS | MINNETONKA MN | I | | | | | |
| OLEA | ESR | GEN SIMULAT | PREDICTION SYS | | | | | | | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|-------|---------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| OLEA | ESR | EXTEND | SONICS ENTERPR | ATLANTA GA | | | | | | P |
| OLEA | ESR | DESIGN WSTAT | KNOWLEDGEWARE | | | | | | | |
| OLEA | ESR | DESIGN GENER | COMPUTER SCIENC | | | | | | | |
| OLEA | ESR | CONCEPT MODU | WISDOM SYSTEM | CHAGRM FALLS OH | | S | | | | |
| OLEA | ESR | AXLE | GOLDHILL COMPUT | CAMBRIDGE MA | | | | | | P |
| OLEA | ESR | ARMS | TELEDYNE BROWN | HUNTSVILLE AL | | | | | | |
| OLEA | ESR | ANALYSIS W/S | KNOWLEDGEWARE | ATLANTA GA | | | | | | P |
| OLEA | ESR | | FORT BENNING | | | | | | | |
| OLEA | NL | SMART TRANSL | THE ASSOCIATED | NEWPORT RI | | | | | | |
| OLEA | NL | SMART EXP ED | SMART COMM INC | NEW YORK NY | | | | | | |
| OLEA | NL | PERIPHASE | SMART COMM INC | NEW YORK NY | | | | | | |
| OLEA | NL | NL/PASER | ALPNET | SALT LAKE CIT UT | I | V | S | | | P |
| OLEA | NL | NATRL ACCESS | L/TEK INC | DAVIS CA | | | | | | |
| OLEA | NL | NAT LANG TOO | TEXAS INSTRUMEN | AUSTIN TX | | | | | | |
| OLEA | NL | LANGUAGECRAF | COGNITIVE SYS | NEW HAVEN CT | | V | | | | |
| OLEA | NL | INTELLECT | CARNEGIE GROUP | PITTSBURG PA | 3 | V | | | | |
| OLEA | NNW | NEURO SHELL | AI CORP | WATLTAM MA | I | | S | | | |
| OLEA | NNW | NEURALWKS PRO | WARD SYSTEMS GR | FREDERICK MD | | | | | | P |
| OLEA | NNW | NEURALWKSEXP | NEURALWARE INC | SEWICKLEY PA | | | S | | | P |
| OLEA | NNW | NEURAL-NET | NEURALWARE INC | SEWICKLEY PA | | | S | | | P |
| OLEA | NNW | NESTOR DEVEL | INTEC | TEMPE AZ | | | | | | P |
| OLEA | NNW | N-NET | NESTOR INC | PROVIDENCE RI | | | S | | | P |
| OLEA | NNW | N-NET | AI CORP | | | | | | | |
| OLEA | NNW | ASPIN | AI WARE | CLEVELAND OH | | V | | | | P |
| OLEA | NNW | AI NET | BARRON ASSOCIAT | STANDARDSVILL VA | | V | | | | M |
| OLEA | NNWST | NN100/NN170 | AI WARE INC | CLEVELAND OH | | | S | | | P |
| OLEA | NNWST | NN-100 | INTEC | | | | | | | P |
| OLEA | SHELL | X1 RULE | INTEC | | | | | | | P |
| OLEA | SHELL | X1 PLUS | EXPERTEACH INC | INCLINE VILLA NV | | | | | | P |
| OLEA | SHELL | | EXPERTEACH INC | INCLINE VILLA NV | | | | | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|-----------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| OLEA | SHELL | PAPERBACK S/W | BERKELEY CA | | | | | | P |
| OLEA | SHELL | DEC | HJUNTSVILLE AL | V | | | | | |
| OLEA | SHELL | DEC | HUNTSVILLE AL | V | | | | | |
| OLEA | SHELL | DYNAMIC MASTER | ATLANTA GA | | | | | | P |
| OLEA | SHELL | GEN RESRCH CORP | MCLEAN VA | I | | | | | P |
| OLEA | SHELL | SOFTSYNC INC | NEW YORK NY | | | | | | |
| OLEA | SHELL | COSMIC | ATHENS GA | V | | S | | | |
| OLEA | SHELL | SUN MICROSYSTEM | MOUNTAINVIEW CA | | | S | | | |
| OLEA | SHELL | MIT | CAMBRIDGE MA | | | | | | |
| OLEA | SHELL | INFERENCE ENGIN | CAMBRIDGE MA | | | | | | P |
| OLEA | SHELL | CHARTERED ELECT | SAN FRANCISCO CA | | | | | | P |
| OLEA | SHELL | SYS DESIGN INT | NEW CASTLE DE | | | | | | |
| OLEA | SHELL | RADIAN CORP. | AUSTIN TX | V | S | A | | | P |
| OLEA | SHELL | CARNEGIE GROUP | PITTSBURG PA | V | S | | | | |
| OLEA | SHELL | QUANTUM INKNOWR | SANTA CLARA CA | | | | | | P |
| OLEA | SHELL | TEXAS INSTRUMEN | AUSTIN TX | | | | | | P |
| OLEA | SHELL | BALL SYS ENG DI | SAN DIEGO CA | | | | | | |
| OLEA | SHELL | PROD SYS TECH I | PITTSBURGH PA | V | S | A | | | |
| OLEA | SHELL | NEURON DATA | PALO ALTO CA | I | V | S | A | | M |
| OLEA | SHELL | MCGRAW HILL BOO | NEW YORK NY | | | | | | P |
| OLEA | SHELL | COGNTRON TECH | CAMBRIDGE MA | | | | | | |
| OLEA | SHELL | ENVOIS | ARLINGTON VA | | | S | | | |
| OLEA | SHELL | LEVEL 5 RESEARC | INDIALANTIC FL | I | V | | | | M |
| OLEA | SHELL | KNOWLEDGE GARDE | NASSAU NY | | | | | | |
| OLEA | SHELL | KNOWLEDGE CR | PITTSBURGH PA | V | | S | | | P |
| OLEA | SHELL | KEYSTONE TECH | JACKSONVILLE FL | | | | | | |
| OLEA | SHELL | SW ARCH & ENGI | ARLINGTON VA | V | S | A | | | P |
| OLEA | SHELL | SW ARCH. & ENG | ARLINGTON VA | V | S | A | | | P |
| OLEA | SHELL | INTELLICORP | IRVING TX | I | V | S | A | | M |
| OLEA | SHELL | KDS CORP. | WILMITTE IL | | | | | | P |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|-------------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| OLEA SHELL | KDS2 | KDS CORP | WILMITTE IL | | | | | | P |
| OLEA SHELL | KBVISION | AMERINEX AI | AMHERST MA | | | | | | |
| OLEA SHELL | KBMS | AI CORP | WALTHAM MA | I | S | | | | |
| OLEA SHELL | JOSHUA | SYMBOLICS | MOUNTAINVIEW CA | | | | | | |
| OLEA SHELL | INTELLIGENCE | INTELLIGENCE WA | LOS ANGELES CA | | | | | | P |
| OLEA SHELL | ICAT | AUTOMATED REASO | ROSLYN NY | V | S | | | | M |
| OLEA SHELL | IBIS PLUS | INTELLIGENCE MF | | | | | | | P |
| OLEA SHELL | IBIS | INTELLIGENCE MF | WEST SACRAMEN CA | | | | | | P |
| OLEA SHELL | HUMBLE | XEROX CORP. | PASADENA CA | | S | A | | | M |
| OLEA SHELL | GURU | MICRO DATABASE | LAFAYETTE IN | V | S | | | | P |
| OLEA SHELL | GOLDWORKS | GOLDHILL COMPUT | CAMBRIDGE MA | | S | | | | P |
| OLEA SHELL | GEST | GA TECH RESEARC | ATLANTA GA | V | | | | | M |
| OLEA SHELL | GEN-X | GENERAL ELECTRI | SCHENECTADY NY | | | | | | P |
| OLEA SHELL | G2 | GENSYM CORP | CAMBRIDGE MA | V | S | A | | | M |
| OLEA SHELL | FORTH EXPERT | MOUNTAIN VIEW | MOUNTAIN VIEW CA | | | | | | |
| OLEA SHELL | FLOP | KEMP CARAWAY HE | BIRMINGHAM AL | | | | | | P |
| OLEA SHELL | EXSYS PROFES | EXSYS INC | ALBURQUERQUE NM | V | S | | | | P |
| OLEA SHELL | EXSYS | EXSYS INC. | ALBURQUERQUE NM | V | S | | | | P |
| OLEA SHELL | EXPERT-2 | MILLER MICROCOM | NATICK MA | | | | | | P |
| OLEA SHELL | EXPERT THINK | TRANSPower CORP | | | | | | | |
| OLEA SHELL | EXPERT SYS | COSMIC | ATHENS GA | | | | | | |
| OLEA SHELL | EXPERT R | COYNE KALA INC | ARLINGTON VA | | | | | | |
| OLEA SHELL | EXPERT EDGE | JEFFREY PERRON | SAN FRANCISCO CA | | | | | | P |
| OLEA SHELL | EXPERT EASE | JEFFREY PERRON | SAN FRANCISCO CA | | | | | | P |
| OLEA SHELL | EXPERT CONTR | UMECORP | LARKSPUR CA | | | | | | |
| OLEA SHELL | EXPERT CHOIC | DECISION SUPPOR | MCLEAN VA | | | | | | P |
| OLEA SHELL | EXPERT 87 | MAGIC 7 SAW | LOS ALTOS CA | | | | | | P |
| OLEA SHELL | EXPER OPS5+ | EXPERTELLIGENCE | SANTA BARBARA CA | | | | | | M |
| OLEA SHELL | EXPER OPS5 | EXPERTELLIGENCE | SANTA BARBARA CA | | | | | | M |
| OLEA SHELL | EXPER FACTS | EXPERTELLIGENCE | SANTA BARBARA CA | | | | | | M |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|-------|--------------|-----------------|------------------|-----|-----|-----|--------|-----|-----|
| OLEA | SHELL | EXADS | COSMIC | ATHENS GA | | V | | | P | |
| OLEA | SHELL | EST | MIND PATH TECH | DALLAS TX | | | | | P | |
| OLEA | SHELL | ESP FRAME EN | EXPERT SYS INTE | PHILADELPHIA PA | | | | | P | |
| OLEA | SHELL | ELOQUENT | ELOQUENT SYS CO | MANCHESTER NH | | | | | P | M |
| OLEA | SHELL | EASY EXPERT | PARK ROW S/W | SAN DIEGO CA | | | | | P | |
| OLEA | SHELL | DEV 2.0 | LEVEL 5 RESEARC | INDIALANTIC FL | I | V | | | | M |
| OLEA | SHELL | COGNATE | PERIDOM INC | BOWIE MD | | | | | | M |
| OLEA | SHELL | CLIPS | COSMIC | ATHENS GA | | V | | | P | M |
| OLEA | SHELL | CERBERUS | COSMIC | ATHENS GA | | V | | | | |
| OLEA | SHELL | C EXPERT | SW PLUS | CROFTON MD | | | | | P | |
| OLEA | SHELL | ART | INFERENCE CO. | LOS ANGELES CA | I | V | S | A | P | |
| OLEA | SHELL | ARITY/ES | ARITY CORP. | CONCORD MA | | | | | P | |
| OLEA | SHELL | APPL EXPERT | CULLINET S/W IN | HOUSTON TX | I | V | | | | |
| OLEA | SHELL | ALEX | HARRIS & HALL | PORT ANGELES WA | | | | | P | |
| OLEA | SHELL | AESOP EXPERT | COSMIC | ATHENS GA | | V | | | | |
| OLEA | SHELL | AES | AION DEV SYSTEM | DALLAS TX | I | | | | P | |
| OLEA | SHELL | ADVISOR 2 | EXPERT SYS INTE | PHILADELPHIA PA | | V | | | P | |
| OLEA | SHELL | ADS | AION DEV SYSTEM | DALLAS TX | I | | | | P | |
| OLEA | SHELL | 1XL | INTELLIGENCE WA | LOS ANGELES CA | | | | | P | |
| OLEA | SHELL | 1ST CLASS FU | 1ST CLASS EXPR | WAYLAND MA | | | | | P | |
| OLEA | SHELL | 1ST CLASS | 1ST CLASS EXPR | WAYLAND MA | | | | | P | |
| OLEA | SST | TABLET | C A INTELLEGEN | SAN FRANCISCO CA | | V | S | | P | |
| OLEA | SST | SIMKIT | INTELLICORP | IRVING TX | I | V | S | A | P | M |
| OLEA | SST | ROOMS | ENVOS | ARLINGTON VA | | | S | | | |
| OLEA | SST | REALM | KEYSTONE TECH | JACKSONVILLE FL | | | | | | |
| OLEA | SST | PLEXI | SYMBOLICS | CAMBRIDGE MA | | | | | | |
| OLEA | SST | NOTECARD | ENVOS | ARLINGTON VA | | | S | | | |
| OLEA | SST | MEDLEY | ENVOS | ARLINGTON VA | | | S | | | |
| OLEA | SST | KNW PRO GRPH | KNOWLEDGE GARDE | | | | | | P | |
| OLEA | SST | KNOWLEDGEMAK | KNOWLEDGE GARDE | NASSAU NY | | | | | P | |

Technology for the Assessment of Software Quality "TASQ"

| APPL_N | TYPE | TOOL_NAME | COMPANY | CITY & STATE | IBM | VAX | SUN | APOLLO | IBM | MAC |
|--------|------|---------------|-----------------|---------------|------|-----|-----|--------|-----|-----|
| OLEA | SST | KNOWLEDGE DB | KNOWLEDGE GARDE | NASSAU | NY | | | | | P |
| OLEA | SST | KEE CONNECTI | INTELLICORP | IRVING | TX I | V | S | | | P M |
| OLEA | SST | HPO | AION DEV SYSTEM | DALLAS | TX I | | | | | P |
| OLEA | SST | GRAPHICS | C A INTELLEGEN | | | V | S | | | P |
| OLEA | SST | FRAME/DBFRAM | C A INTELLEGEN | SAN FRANCISCO | CA | V | S | | | P |
| OLEA | SST | EXPERTEACHII | INTELLIGENCE WA | LOS ANGELES | CA | | | | | P |
| OLEA | SST | EXCHANGE | C A INTELLEGEN | SAN FRANCISCO | CA | V | S | | | P |
| OLEA | SST | EX123 | C A INTELLEGEN | | | V | S | | | P |
| OLEA | SST | ES STARTER | MIND PATH TECH | DALLAS | TX | | | | | P |
| OLEA | SST | CONSULTANT | C A INTELLEGEN | SAN FRANCISCO | CA | V | S | | | P |
| OLEA | SST | CONSENSUS BLD | MAGIC 7 SW | LOS ALTOS | CA | | | | | P |
| OLEA | SST | AUTO INTELLI | INTELLIGENCE WA | LOS ANGELES | CA | | | | | P |

APPENDIX D

CLASSIFICATION TOOLS MATRIX

[A single copy of the composite classification matrix
used to subsequently categorize the tools/environment
of Appendix C is separately bound]

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