APPLICATION OF SOFTWARE QUALITY ASSURANCE CONCEPTS AND PROCEDURES TO ENVIRONMENTAL RESEARCH INVOLVING SOFTWARE DEVELOPMENT

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As EPA's environmental research expands into new areas that involve the development of software, quality assurance concepts and procedures that were originally developed for environmental data collection may not be appropriate. Fortunately, software quality assurance is a well-developed technical field in software engineering and its concepts and principles can be applied to software that is developed for environmental research. There are significant parallels between the two types of quality assurance and it should not be difficult to incorporate software quality assurance concepts and procedures into the EPA Quality System. This paper compares these two types of quality assurance and highlights their similarities and differences. Even readers who are not familiar with software quality assurance can use the concepts and procedures described in this paper to improve the quality of software developed for environmental research.

INTRODUCTION

EPA Order 5360.1 A2 establishes policy and program requirements for the mandatory Agency-wide quality system. Its scope includes the collection, evaluation, and use of environmental data as well as the design, construction, and operation of environmental technology. In the past, EPA's quality assurance activities have focused largely on environmental data collection. Increasingly, the uses of environmental data in databases and other information systems have become an area of concern. Quality assurance principles and procedures are needed for these information systems. The concepts and procedures that have been developed for environmental data collection do not apply well to information systems. Software quality assurance has developed in parallel with EPA's quality system and can be applied in those instances in which environmental research includes the development of software. This paper describes software quality assurance concepts and procedures that can be useful in those instances.

SYSTEMATIC PLANNING

The development of software begins with the systems analysis and design process, which is analogous to the systematic project planning process (see Table 1). This process is a direct application of the Shewhart cycle (plan-do-check-act). In broad terms, problems and solutions are identified, goals are established, software quality criteria (metrics) are set to gauge performance, software development is implemented, and progress is assessed during development and at its completion. The software is documented during the analysis phase in

software requirements, which describe the purpose and desired functions of the software, and in functional specifications, which are a formal description of the software and which is the blueprint for developing the software. Based on these documents, the design phase establishes the proposed structure of the software, which is documented in a high-level, architectural design for the overall system structure and in a detailed design that includes the design of specific program details. During this phase, testing procedures are developed to determine if quality metrics are being attained. During the development phase, testing and corrective action occur as needed. Additionally, the software is assessed in informal and formal reviews.

A software quality plan is prepared to document how quality assurance activities support the development and to answer questions such as: what are the quality metrics?; what testing and assessment will be done?; and how are uncovered problems corrected? The plan may contain the following sections: purpose; reference documents; management; documentation; standards, practices, conventions, and metrics; assessments; software configuration management; problem reporting and corrective action; tools, techniques, and methodologies; code control; media control; supplier control; records collection, maintenance, and retention; and testing methods.

THE GRADED APPROACH

Some software quality assurance procedures may not be appropriate for a specific software development project. As is the case for environmental data collection projects, a graded approach can be used to apply an appropriate level of software quality assurance for a project. Argonne National Laboratory's Decision and Information Sciences Division (ANL DISD) has three quality levels for its software development projects (see Table 2). The quality assurance procedures that must be followed at each level are dependent on factors such as criticality, external impact, development effort, security impact, and cost of failure.

QUALITY METRICS

Quality metrics, such as reliability, usability, maintainability, and adaptability, are more appropriate for software development projects than are the data quality indicators applicable to environmental measurements, such as precision, bias, and representativeness (see Table 3). Quality metrics can be divided into (1) process metrics which are used to improve the software development and maintenance process, (2) product metrics which describe the characteristics of the software itself, and (3) project metrics which describe the project and its execution (Ginac, 1998). There should be a correlation between the product metrics and the software requirements.

SOFTWARE TESTING

Software testing procedures fill the same role in software development projects as quality control checks do in environmental data collection projects. Various manual and automated techniques are available to test software inputs and outputs (black box testing) or to test the internal structure of software (white box testing) at various stages of its development. One model of software testing is a "V" in which software requirements, functional specifications, architectural

design, and detailed design move down the left side while unit testing, integration testing, system testing, and acceptance testing move up the right side. The expected output or result of each stage of the testing is defined in the documentation that is opposite it on the "V." Testing should not be done by the individual who prepared the software and, where feasible or necessary, an organization should not test its own software (Myers et al., 2004).

Independent verification and validation of software is a quite formal testing process that reserved for important, large, and complex projects, such as in the aerospace industry, for which it is critical that the software perform successfully. It is performed by an organization not involved in developing the software. The purpose of independent verification and validation is to ensure that the software design, implementation, and documentation meet requirements. Verification addresses "Am I building the product right?" and validation addresses "Am I building the right product?" The expected benefits are increased objectivity, earlier detection of errors, reduced effort and costs of removing detected errors, enhanced operational correctness, and a more consistent testing. It establishes traceability between the software and the requirements.

SOFTWARE DOCUMENTATION

The documentation that is needed for a software development project should be defined in the design phase. It may be embedded in the software itself or it may be in hard-copy or on-line documents. The documentation requirements for ANL DISD projects include a software quality assurance plan, a configuration management plan, a test plan, and test documentation/results (see Table 4), which parallel EPA's documentation requirements. In addition to development-related documents, other documents that may be written for the software include code documentation, user documentation, and guides for installation, operation, and maintenance.

SOFTWARE ASSESSMENT

The assessment function can be performed by peer reviews that are performed at various stages of the development process and with various degrees of formality as follows (Wiegers, 2002):

- Inspection is the most systematic and rigorous of the assessments and it is the software industry's best practice. It has procedures that are similar to a technical systems audit. A group of people, including a moderator and a recorder, conduct an inspection to review a document, such as a functional specification or test plan. The goal is to find problems with the document, not to fix them. A formal report of the inspection will be prepared.
- Team review is planned and structured, but less formal and rigorous than inspections
- Walkthrough is an informal review in which the software author describes the software to a group of peers and solicits formal comments. The author takes the dominant role.
- Pair-programming is when two developers work on the same software simultaneously at the same workstation. The synergy of two focused minds creates superior software.
- Peer-deskcheck is a detailed self-review of software by the programmer to find errors.
- Passaround is when a programmer solicits informal comments from peers about software.
- Ad hoc review is a spur-of-the-moment review within the software team.

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BIOGRAPHICAL INFORMATION

Mr. Wright is a chemist in US EPA's Air Pollution Prevention and Control Division in Research Triangle Park, North Carolina. He provides quality assurance support to the researchers there, including document reviews and audits of technical and quality systems. He has 33 years' environmental science experience in a wide variety of technical areas, including quality assurance, environmental measurements, instrument evaluation, hazardous wastes, and atmospheric chemistry. His experience in quality assurance ranges from preparing guidance documents to conducting audits of gaseous calibration standards. Prior to coming to US EPA, he was an environmental scientist at RTI International where he conducted contract research for governmental and industrial clients. He was an engineering technician at the Ohio EPA where he worked with ambient air quality monitors. Additionally, he was a Peace Corps volunteer in Botswana where he taught science in a junior secondary school. Mr. Wright has a B.S. degree in physics and a M.S. degree in environmental science and engineering.

Table 1. Comparison of Systematic Planning Process and Software Analysis Process

Systematic Planning Process (after EPA, 2000)	Software Analysis Process (after Satzinger et al., 2004)
Step 1: identify project manager and staff	Step 1: research and understand problem
Step 2: identify project schedule, resources, milestones, and requirements	Step 2: verify that the benefits of solving the problem outweigh the costs of the solution
Step 3: describe the project goals and objectives	Step 3: define the requirements for solving the problem
Step 4: identify the types of data needed	Step 4: develop a set of possible solutions (alternatives)
Step 5: identify constraints to data collection	Step 5: decide which solution is best and make a recommendation
Step 6: determine the needed data quality	Step 6: define details of chosen solution
Step 7: describe how, when, and where the data will be obtained	Step 7: implement the solution
Step 8: specify QA and QC activities to assess the performance criteria	Step 8: monitor to make sure that you obtain the desired results
Step 9: describe methods for data analysis, evaluation, and assessment against the intended use of the data	

Table 2. Argonne National Laboratory Graded Approach to Software Quality Assurance

Quality level	Level C+ (low)	Level B (medium)	Level A (high)
Consequence of failure	Negligible	Moderate to severe	Unacceptable, major losses
External impact and visibility	Few external users, proof of concept	Limited distribution, prototype or beta	Wide distribution and visibility
Complexity and technical risk	Few modules, moderate complexity	Several modules and libraries	Many complex components
Development effort (person-years)	Less than 1	1 to 2.5	More than 2.5
Customization	Minimal	Moderate	Significant
Security impact and proprietary impact	None	Moderate	Significant
Cost of failure	Loss less than $100k	Loss $100k to $1m	Loss more than $1m

Table 3. Comparison of Quality Metrics for Data Collection and Software Development

Environmental Data Quality Indicators (after EPA, 2002)	Software Quality Metrics and Attributes (after Dunn, 1990)
Bias	Reliability (completeness, consistency and precision, robustness, simplicity, traceability)
Precision	Usability (accuracy, conformity, documentation accuracy/clarity, completeness, efficiency, testability)
Accuracy	Maintainability (documentation accuracy/clarity, modularity, readability, simplicity)
Representativeness	Adaptability (modifiability, expandability, portability)
Comparability	
Completeness	
Sensitivity	

Table 4. Argonne National Laboratory Requirements for Software Documentation

Quality level	Level C+ (low)	Level B (medium)	Level A (high)
Software QA plan	**X**	**X**	**X**
Configuration plan	**X**	**X**	**X**
Testing plan	**X**	**X**	**X**
Testing records	**X**	**X**	**X**
Requirements document		**X**	**X**
Design document		**X**	**X**
Design reviews			**X**
Code reviews			**X**
Documentation		**X**	**X**
External reviews			If more than 3 person-years