The Journal of Reliability, Maintainability & Supportability *in* Systems Engineering

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RMS Reliability, Maintainability and Supportability Partnership

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Introduction

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We know reliability engineering (RE) is all about identifying and managing asset reliability risks that could adversely affect a product, the manufacturing environment in which the product is designed and produced and/or customer use, cost and satisfaction. Additionally, reliability and the associated risk(s) must be managed and tools utilized by reliability engineers to identify and reduce risk include:

- PHA – Preliminary hazards analysis
- FMEA – Failure modes and effects analysis
- CA – Criticality analysis
- SFMEA – Simplified failure modes and effects analysis
- MI – Maintainability information
- FTA – Fault tree analysis
- ETA – Event tree analysis
- RCA – Root Cause Analysis

During my tenure as this Journal's editor I've seen beaucoup articles on the above mentioned tools, reliability growth management as well as non-traditional solutions for current Reliability, Maintainability, and Supportability problems cross my untidy desk. We've published all of them because they continue to be timely and, with new approaches to their use—the focus of many—the stakeholders enjoy more reliable products and we, the reader(s), gain insight in to new methodologies. However, I would like to see the Journal's offerings branch out more to include a decided focus on Systems Engineering processes, moving the context up a level to discussions across *The Enterprise*. Fortunately, an increasing number of what I'll call "non-traditional treatments of reliability" articles are showing up. For instance, the 2012 Spring Journal contained two such articles: *Stakeholder Reevaluation, Through the Application of Salience Principles and China's Growing Presence in Africa: The Impact on the U.S. Supply Chain and National Security*. The "Stakeholder Reevaluation" article focused on identifying, interviewing and assessing system stakeholders in terms of their power, legitimacy, and urgency. The "China Presence in Africa" article examined long-term implications the Chinese presence could have on weapons proliferation and commercial supply chain interests of the U.S. and its allies.

Each article contains a "here are considerations from a reliability across the Enterprise perspective"; in short, an Enterprise perspective without the need for a trip down "here is how we'll address, specifically, risk(s) and reliability concerns from a systems approach." Put another way, reliability and risk(s) discussions could be initiated easily around the water cooler due to the article's makeup and focus, while specific "techniques" or an approach to resolving identified problems is/are left to the reader to pursue.

This Journal edition continues down that path—offering several articles that brush across "time honored" reliability tools and task management topics while embarking on discussions related to processes and "non-traditional reliability considerations."

Why mention any of this? Well, in the March, 2014 National Defense Magazine I came across an op/ed piece by the editor, Sandra Erwin, titled "Acquisition Business Reaches Inflection Point" (inflection point being that point on a curve at which the curvature or concavity changes sign from plus to minus or from minus to plus). Ms. Erwin points out that following a military mishap, e.g., airplane crash, an independent investigation is commissioned to find out what went wrong and similar "probes, occasionally, are done with acquisition programs after they implode."

As I perused Ms. Erwin's article I kept thinking, "Gosh, the reliability and Probability of Failure (Pf) of these DoD acquisition programs is terrible"; programs such as the Air Force' Expeditionary Combat Support System (ECSS), the Army's Future Combat System and the Joint Tactical Radio System are three of the more high profile instances. The ECSS program, the latest program to lose funding and be terminated, took on a "whipping boy" role in Ms. Erwin's article 'cuz it was the latest to be "probed," due mainly to TONs of funding being identified as wasted with zero hope of "fixing it;" the program was terminated in 2013. As a result and emphasized by Ms. Erwin, in a contextual sort of way, "Big-ticket acquisition flops over the past decade have put the fear of God into Pentagon leaders."

Some of the "reasons" for these flops include:

a) the Pentagon is still operating in a Cold War, Industrial Age mindset that served it well in the past but is now inhibiting technological innovation efficiency (Ed: not to mention the promotion of unreliable ACAT-1 programs of record).

b) the Pentagon continues to apply "brute force and buckets of money to acquire things."

c) according to Tom Captain, vice president of Deloitte's aerospace and defense sector, a "flawed down-select process has led to all-time record protests. We have flawed requirements, poor relationships and mistrust between acquisition officials and industry."

d) the latest acquisition-improvement initiative, Better Buying Power 2.0, echoes "good intentions but is catching flack for being ineffective."

In short, a + b + c + d + other 'reasons' is causing an inflection point swing towards a negative, signaling an unreliable acquisition business and program management approach within DoD. Frank Kendall, the Pentagon's top acquisition official, acknowledges they are at a crossroads—Ms. Erwin's inflection point. He agrees there has to be change, but there is no consensus on specifics. He states, "I am on a long quest to make improvements in the efficiency and effectiveness of our acquisition process. I think there have been a lot of attempts to solve acquisition problems with silver bullets, and none of them has worked."

Now, any discussion(s) on how to proceed and right the ship are far beyond my expertise. However, it seems to me, getting a couple of Enterprise-wide thinking reliability engineers in the room couldn't hurt. Some treatment and analysis of the program management approach, a carefully constructed model of the way the program looks today, along with a critical analysis from an "across the Enterprise" perspective that employs the process(es) found in some of those reliability tools—FMEA, CA, FTA and ETA—might be the ticket to improving things. Hopefully, the articles chosen for this and subsequent Journals will continue to expand our reliability thinking and apply some of the tried and proven RE tools across the Enterprise.

So, on to the "introduction section" where we highlight the four articles selected for your perusal. First up is an article on System(s) Integration by Curt Wann. Curt, through his work experiences as a systems integrator, has observed fellow workers' reluctance, when faced with implementing or working within the System(s) Development Life Cycle (SDLC) model or its variations, e.g., DoD 5000.2, to employ it for being "too rigid of a process." [Note: The systems development life cycle (SDLC), is also referred to as the application development life-cycle. It is a term used in systems engineering, information systems and software engineering to describe a process for planning, creating, testing, and deploying an information system]. Curt points out people view SDLC as unrealistic because it is a stepped process. They then go off, invent and utilize less rigid processes with names such as Rational Unified Process (RUP), Agile and others.

The fact is, new terms get invented all the time, while people like Curt are out there managing a project within the constraints of processes like SLDC. Thus, Curt's purpose, in authoring this article, is to provide some real world experience of how SLDC does "work," along with an occasional vagary or two, perhaps. As you peruse his offering you'll see his experiences show SDLC can be an iterative process, with steps that do over-lap; in short, it's not rigid; i.e., when there are problems that come up during the life cycle, one must return to the previous step(s) (within the process) to fix it. Curt doesn't delve in to the impact SDLC has on, or the impact of reliability, maintainability and supportability—that's not the focus—but, hopefully, others will pick up the RMS gauntlet and run with it. I see value in perusing the views of a system(s) developer/program manager—a "practitioner"—with an emphasis on the effects SDLC has on the Enterprise, customer and stakeholders; in that context, I expect you'll find his article interesting.

The second article, *Maintainability In The Context Of Systems Engineering: Some Challenges For The Future*, by Dr. Benjamin Blanchard, walks us through the evolution of the design and engineering of System Maintainability. Dr. Blanchard points out that, initially, there were two sides of the maintainability spectrum—the "prime" elements of a system and the various elements of its logistic support, system maintenance and the supporting infrastructure. Today, however, "design foci" includes design for maintainability, design for supportability, design for operability (or human factors), design for system availability, etc. In this article, Dr. Blanchard discusses the value of Systems Engineering in getting all of that to "gel" plus some challenges for the future. We are pleased Dr. Blanchard submitted this article as well as excited to know he'll be providing a second article for our 2014 Winter Journal on Life Cycle Costs.

The third article, *Developing Reliability Requirements for Potable Water Solutions in Politically Discontinuous Areas*, is authored by Katherine (Kate) Pratt. Kate is the RMSP's Coordinator of Environmental Affairs and, after a "Hey, Kate, ya wanna gen up an environmentally flavored article for the Journal" email from me, she produced a "doozy," in length and content. We've parsed the original in to two focal areas. The first article focuses on the current potable water situation today in the Middle East and what can/should be done to ensure sustainable and reliable potable water for the future. Kate will provide a second article, hopefully for the Winter, 2014 edition that will center in on the effects of hydro politics in that same region of the world. An aside note: after reading Kate's article I have been "googling away;" the subject is interesting and germane to us all across our good Earth! Here's some of what I found:

- There are knowledgeable scientists predicting that clean water will become the "next oil"; making countries like Canada, Chile, Norway, Colombia and Peru, with that resource in abundance, the water-rich countries in the world.
- The UN World Water Development Report (WWDR, 2003) from the World Water Assessment Program indicates that, in the next 20 years, the quantity of water available to everyone is predicted to decrease by 30%.
- Forty percent of the world's inhabitants are unable to access sufficient fresh water for minimal hygiene.

With all of that "going on," this and a future article by Kate go beyond "of topical interest"—how about salient and germane?

Our fourth article, *Field Data Collection*, by Eugene Cottle dives in to reliability assessments and the challenges reliability engineers face when collecting and analyzing field failure data.

Mr. Cottle is an ASQ Certified Reliability Engineer and, during his varied work assignments, has remained focused on product life cycle quality and reliability in commercial manufacturing and life-cycle sustainment settings. The analysis of product performance data is one part of a reliability engineer's focus—as large a part of his/her time is invested in developing sources for the data as well as gathering, parsing, cleaning and preparing the data for analyses. Eugene shares lessons learned regarding it all, discusses some of the elements of data tools and posits general rules that can make data collection successful.

The four authors are "first time submitters" and I couldn't be more pleased about the variety of subjects and the varying levels of detail—from the grass roots of reliability to trans-boundary, culturally diverse views, treatments and considerations of "problems" with a reliability focus. Enjoy them all!

System(s) Integration

Curt Wann

Introduction

The purpose of this document is to describe the process to perform a system integration project. The description will be generic and not focused on a specific type of system.

System(s) integration is defined as the bringing together of component subsystems into one system, ensuring the subsystems function together as a system. It involves integrating either existing subsystems or new systems developed under the aegis of the system integration process. The key attribute to system integration is the definition of the interfaces between the component subsystems. The resulting feature of system integration is the value added because of the interactions between the subsystems.

The system integration process follows a series of phases commonly referred to as the System Development Life Cycle (SDLC). Software development projects also refer to SDLC as the Software Development Life Cycle. SDLC is a methodology (or process) applied to creating systems, subsystems, and products, either hardware or software or a combination thereof. The development life cycle is comprised of seven discrete phases:

1. Feasibility Analysis
2. Requirements Definition
3. Design
4. Development
5. Test
6. Delivery
7. Maintenance

The adaptation of these phases is dependent upon the development strategy and the environment: market, customer, price, cost, schedule, and resources.

Some sources tend to point out the SDLC is a step process and not representative of the real world. However, SDLC is a framework for describing the activities in a development project. The actual development process is an overlapping of the various activities described in the discrete phases, dictated by the project scheduling activities.

System Integration Process

Figure 1 shows a serial process however, in reality the phases overlap with feedback to previous phases during the integration project. The results of each are contained in deliverables: hardware, software, and documents. Documents contain requirements definition, financial analyses, specifications, design, training material, maintenance manuals, and marketing and sales material.

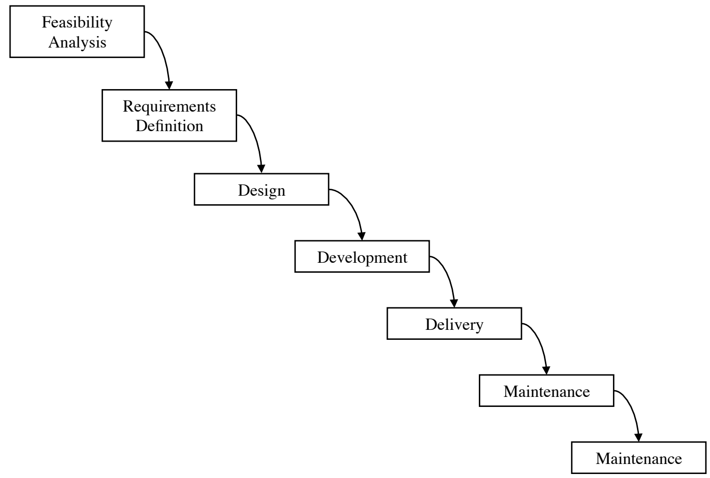

FIGURE 1 - THE SERIAL PROCESS

Deliverables are necessary because they provide the impetus or reason to begin the next phase of the process. In the process world, deliverables ARE the entrance and EXIT criteria between processes. In practice, individuals involved in the next process phase review/test the deliverables to determine if they are sufficient to begin the next process phase. For example, before a specification can be written requirements shall be defined. If the specification review finds the requirements are not clear or something is missing, the requirements are revised. Preparing documentation is an iterative process and similar interactions will occur throughout the project life cycle. Similarly, if hardware does not perform adequately to begin test, then it is returned to development for change.

Feasibility Analysis

The initiation of a system (or project) begins when a business need or opportunity is identified. Once a business need is approved, the approaches for accomplishing the project are reviewed for feasibility and appropriateness. The outcome of the feasibility analysis describes how the business will operate once the new system is implemented and an assessment of how the system will impact employee and customer privacy.

Once there is a clear definition of the opportunity, there are questions to be answered:

- What resources, other than financial, are needed (people, skills, material, space to build, etc.)?
- What is the schedule for the project?
- What is the market for the system?

- Is there a need for a pricing strategy and if yes, what is the strategy?
- What is/are the life cycle cost(s) (development, maintenance, etc.)?
- What are the financial objectives (earned value, return on investment, etc.)?
- What are the risks?
- What is the strategy for development, marketing, and maintenance?
- Can we do it?

Answers to these questions are high-level estimates and plans; they will be refined at periodic intervals throughout the project life cycle. Depending upon the answers to these questions it may be necessary to bring in partner organizations and a potential customer to add credibility to the project and provide a "reference sell" later on. Senior-level personnel perform this phase and if necessary, an outside consultant may be needed to coordinate this planning and strategizing effort.

The deliverables from this phase consist of:

- A statement of the opportunity that will be clearly understood by all personnel who are to be involved in the project, including any partner organizations and customers.
- A high-level description of the plans, strategies, and schedule for the project and a financial analysis (including an ROI analysis).
- Signed memorandums of understanding (MOUs) with partner organizations and internal organizations regarding their Identification of the project team and personnel to participate in Requirements Definition.

Requirements Definition

The Requirements Definition phase sets the stage/direction for the remainder of the project. The deliverables, contained in documentation, are key to defining the processes, plans, and schedules.

The main objective of the Requirements Definition phase is to define "what" is required for the system to function and be delivered to satisfy the needs of the user. Joint Application Development (JAD) sessions are conducted to obtain requirements. Stakeholders, people who will be affected by the system (users, recipients of reports, maintenance, installers, etc.), participate in this phase.

The JAD is lead by a facilitator who has the responsibility for establishing the ground rules for conducting the JAD as well as managing and providing unbiased direction while the objectives are fulfilled.

This phase focuses on "what" is wanted for the system to do and not "how' the system is to do the "what"; "how" the system is to look and perform is defined during the design phase. It is very easy during the Requirements Definition phase to fall into the trap of deciding "how" the system is to work without a definition of "what" is wanted because human nature says we should decide first off how something is suppose to operate. A reminder: this trap results in spending time on the "how(s)" and not on the "what(s)" and a challenge for the facilitator as he/she manages and orchestrates the team within the time constraints of the Requirements Definition phase.

For an Information Technology (IT) project the JAD should consider defining the reports needed to manage and administer the project because the reports define the data to be gathered and entered into the system. Once these requirements are defined the functional requirements can be identified. Using this technique tends to force the process to define "what" is required in terms of the required data.

There are different kinds of requirements, all of which need definition:

- Functional – *requirements that define the functions to be performed by the system. A functional requirement must stand the test of this question: Can the requirement be tested or verified? If the answer is no, the requirement cannot be verified or met.*
- User – *defines who the users are and their abilities necessary to use the system.*
- Test – *at a high level defines what kind of tests will be performed.*
- Environmental – *defines the environment in which the system will operate (temperature, humidity, dust/particles, vibration, pressure it needs to withstand, etc.).*
- Maintenance – *personnel and tools*
- Reliability
- Maintainability – *the ease with which maintenance of a functional unit can be performed in accordance with prescribed requirements.*
- Availability – *the proportion of time a system is in a functioning condition, including, possibly, degraded modes of operation.*
- Training
- Installation
- Documentation
- Promotion/Advertising

Requirements are reviewed, analyzed for consistency and completeness, validated for correctness and formally approved by the customer (or user) before proceeding to the Design Phase.

Collecting, organizing, and documenting the requirements is key to the success of the project. The requirements definition document will be used and referenced throughout the project as the basis to account for where the requirements are reflected in the design and tested to assure that the system performs as required. There are software tools (e.g., CASE – Computer Aided System/Software Engineering) available that provide a repository for requirements. These tools will support the remaining project phases and will make managing and doing the project much easier for everyone. Ensuring accountability of/for the requirements will be "the message" throughout the subsequent phases.

Prototypes of key components (e.g., user interface and function navigation in software applications, critical hardware functions such as beam forming) of the system are often developed to address critical or complex functions and to flush out perceptions about their operation. The results of prototyping may require changes to requirements. This process, sometimes referred to as "build a little, test a little," will continue until there is agreement among the stakeholders that the requirements are defined sufficiently. Prototyping sometimes can tend to increase scope once stakeholders see the potential to incorporate additional capabilities outside the scope of work and will be the challenge for the project team to manage.

Other activities in this phase include:

- Identification of critical items and areas of risk affecting schedule, requirements, or cost
- Preparation of project plans such as:
  - Risk identification and mitigation
  - Work Break-down Structure (WBS), staffing and budgets
  - Project communication and action item tracking
  - Change control
  - Statements of work for in-house departments and subcontractors
  - Style guides for documentation (engineering and textual)
  - Training plan (high-level)
  - Development – *defines the development tools and environment and plans the sequence of development activities*
  - Test Plan (high-level) – *planning for integration test starts in this phase (see the Test phase description later in this document for more detail)*
  - Promotion plan
  - Preparation of statements of work for subcontractors/ partners
  - Preparation and sign-off (acceptance) of documentation
  - Schedules
  - Requirements definition documents for the types of requirements
  - Functional descriptions for the system operation

If the project is to replace the current software system, a major activity in the development of a new software system is the need to transfer/migrate data from legacy systems—systems that will no longer be used or supported after the acceptance of the new system. Experience has shown that the most senior and experienced software developer must be assigned to this task. The reasoning is:

- The need to identify all applications providing data to migrate
- Migrated data can be corrupted (for example, wrong type of data in fields)
- Migration rules to handle corrupted data
- Planning and developing the capability to migrate data over a phased installation
- Testing for migrated data

With all that is defined and agreed to, across the Enterprise during this phase we can appreciate the criticality of and the need to have a single focus on defining requirements before subsequent processes/phases are initiated.

Design

The Design phase begins with establishing the development environment—identifying and obtaining the tools needed to develop the system, managing the development process, insuring quality assurance and providing for configuration management throughout the remaining project phases. In parallel there is the laying out/partitioning of the system into components. The requirements are first divided into two groups: functional requirements to be performed by the system (hardware and software) and non-functional requirements that support the system (test, training, maintenance, and documentation).

The first part of this phase is to partition the functional requirements into a layout of the system and into component subsystems. Crucial consideration is given to how the human will interface with the system in laying out the components. No more than three or four senior level people perform this layout in such a way that it shows a big picture of the system to the rest of the design team. An often-used method to develop the layout is on a large sheet of paper hanging on a wall that is easy to understand and visualize the system with notations of requirements functionality for the various component subsystems. Here decisions are made regarding what components are purchased and components that will need development, often known as "make or buy" decisions. Once the layout is solidified, it is documented and used as a reference in developing a more detailed design.

Next is to detail the design of the component subsystems. The components to be developed are documented in detailed functional descriptions and specifications. The functional descriptions give the developers guidance by describing how the component(s) will function correctly (i.e., to meet the requirement(s) including the user interface. The specification defines the parameters and accuracies the design shall meet. Both the functional descriptions and the specifications contain matrices listing the requirements and cross-references to the places (paragraphs) in the document where the requirements are satisfied.

If the component is an "off-the- shelf" item, a functional description and specification should be available from the vendor. The design team will need to incorporate functional descriptions and specifications cross-reference matrices (for traceability) and define the interface(s) between the purchased component and other system components.

Similar to the functional requirements design activity, non-functional requirements, e.g., test equipment, test fixtures, training material and promotional material will be designed as well.

An often-overlooked key feature of the system during the design phase is the incorporation of maintenance capabilities; adding them in later will be costly.

As the design activity evolves there will be requirement changes and refinement, new requirements added, and requirements that are deleted.

Development

The Development phase, sometimes called "crunch time," begins with approved functional descriptions and specifications. The development of test equipment, training material, and other items occurs along with the incorporation of the capability to support troubleshooting and maintenance.

Managing the development effort requires careful attention to minimizing outside distractions including the incorporation of out-of-scope changes. To ensure all components are accounted for and tested, quality assurance and configuration management and control are critical during this phase. A part of configuration management accounts for the requirements and software code comments and hardware drawings shall contain a cross-reference to the requirements.

Development testing, distinct from integration testing, is at the component, unit, module, and chassis level. The developers should prepare their own test specs and procedures for development testing. A quality assurance tool should be used for tracing the development status and testing down to the component level. Senior developers should review all development test procedures.

Examples of development tests are:

- White-box, black-box, and gray-box tests
- Analyze mathematical algorithms
- Visual inspections (type of material, color of paint, etc.)
- Environment (vibration, temperature, humidity, drop/shock, etc.)
- Electromagnetic interference (RFI)

If there is data to be transferred the development of the data migration capability occurs. The process to perform data conversion is developed and tested and will involve the participation of customer personnel in the review of the processes and sample data. Experience is that this is a very iterative and intensive process as increasing amounts of old data are processed and the results reviewed by the customer. Critical to this process is the measurement of the amount of time it takes to migrate the data needed to support the later installation process(es).

Integration Test

The Integration Test phase brings together the component subsystems culminating in a systems acceptance test. Planning and scheduling the integration sequence of the component subsystems is crucial for a successful integration test. Other tests performed during this phase are backup and recovery, regression and environmental (when new hardware is involved). Test specifications and test procedures are prepared and a "dry run" is conducted. A requirements cross-reference-to-test specification paragraph and procedure(s) steps is necessary to support accounting for requirements.

Once integration tests are completed, there shall be a User Acceptance Test (UAT) conducted by an organization independent of the development team. The UAT procedures may be written by this independent organization or they may want to use procedures from integration testing.

Delivery

Depending upon the type of system or product, there are two types of delivery: phased or one time. Planning for delivery should begin during the development phase and consider:

- Purchase and installation of supporting activities such as networking equipment, design and construction of facilities
- Involving the recipients/users and customer support personnel of the product in the schedule planning
- Execution of training plans (manuals and online versus classroom training)
- Pilot test installation locations and field support during installation
- Project closure report and recommendations
- Establishing help desk support

Installing at pilot locations tests the usability and support capabilities (documentation, user manuals, failures, recovery, Help Desk, etc.). This is also called a "Beta test."

During installation, periodic review of "Lessons Learned" is necessary to determine if there needs to be adjustments made to the schedule and supporting activities. Once installation has completed, a formal review with vendor and customer management is necessary to provide guidance for correction of deficiencies and recommendations of future enhancements.

Maintenance

The Maintenance phase continues for the life of the system and consists of performing changes or additions, corrections and upgrades. Major activities during this phase include:

- Operations Support – *operations manuals identifying personnel and processes to conduct backup, maintain equipment, maintain software and databases*
- Performance measurements
- Escalation of problems
- Disaster recovery/contingency planning
- Scheduled outages
- Acquisition of supplies/consumables
- Modifications to user documentation

Other Considerations

Defining requirements requires strict adherence to the use of language. Defining requirements for a system whether in a requirements document or an RFP, the verb "shall" is the only verb used. Oftentimes in RFPs the verbs "can," "must," "will," "should," and "may be," are used making it difficult for bidders to ascertain if a need is a requirement or not.

When responding to an RFP, there are tools to select requirements making it easy to identify what is required to address in a proposal. This is why it is very important *that* RFPs identify requirements using the "shall" verb.

When writing proposals, using the verb "will" is used to describe what the bidder will do with respect to a requirement and makes it easy for the reviewer to understand if a requirement is addressed or not.

Summary

SDLC is a methodology for a project regardless of the type of project. As with any methodology or process it is customized to support the development of a product for a set of users, whether the use is internal to the organization or a deliverable to a customer. Products can consist of consumables, software applications, defense systems, hardware/software systems, health care systems, logistic systems, financial systems, ad infinitum.

This paper describes the application of SDLC to system integration for software and hardware systems. The author includes lessons learned about key activities associated with these phases: requirements definition, design, development, and test. It is important to note that the SDLC is not a rigid, step-by-step process, nor does this paper cover every possible activity during the project lifecycle. However, SDLC does provide a framework for activities to be accomplished and deliverables to be developed, approved, and delivered throughout the project. The emphasis here is that every project plan must follow a rigid deliverable and approval process with traceability of the requirements throughout the project.

About the Author

Curt Wann, retired from IBM, held positions in systems engineering, business development, and project management. The majority of his IBM career involved the development of digital sonar systems for the Los Angeles and Trident class submarines. Prior to joining IBM he was a Naval Flight Officer in VAW-11, flew in the first operational detachment of the E-2A aircraft and served as the detachment's avionics division officer during a deployment to Vietnam. After retiring from IBM he was an adjunct professor in computer engineering at the University of New Mexico and later developed healthcare applications for state governments. Currently he is a consulting project manager for information technology applications. He has BS and MS degrees in Electrical Engineering. His hobbies are amateur radio and woodworking.

Maintainability In The Context Of Systems Engineering: Some Challenges For The Future

Benjamin S. Blanchard

1) Background

Maintainability is a characteristic of design that can be expressed in terms of the ease and economy in the performance of system maintenance and support. The objective is to design and develop systems that can be maintained in the least amount of time, at the least cost, and with a minimum expenditure of supporting resources (e.g., people, material, equipment and software, facilities, data, etc.), without adversely affecting the overall performance of the system in question. Maintainability is the *ability* of a system to be maintained, whereas maintenance constitutes those actions taken to restore a system to (or retain a system in) a specified operating condition. As such, maintainability (along with reliability and other related disciplines) is inherent within and a major contributing factor in the overall *availability* of a system.[1]

In the United States, the concept of maintainability, as a design discipline, was first formally recognized by the Department of Defense and the military services around the mid-1950s. The concept evolved from the results of reliability programs conducted in the late 1940s and early 1950s, which indicated that 100 percent reliability of systems was an unobtainable goal. Despite the fact that the reliability programs in being at the time were effective in prolonging the life of systems, it became evident that maintenance requirements could not be eliminated. With the increased size and complexity of defense systems, the maintenance costs for these systems approached one-third of all the operating costs. In addition, it was established that nearly one-third of all personnel were engaged in system maintenance and support functions. Maintainability was conceived to deal with these problems of maintenance and support, with an immediate objective to reduce the costs of sustaining those systems already in operational use.

Maintainability, as envisioned at that time, was intended to deal with "systems" in total, and to address *all* aspects of system support from a total *design* perspective. This included both: 1) design of the prime mission-related elements of a system such that they can be supported effectively and efficiently throughout the system life cycle; and 2) design of the system maintenance and support infrastructure to facilitate this objective. In other words, there were two sides of the spectrum that must be properly integrated in design, from the beginning, in order to meet the overall system objectives; i.e., the "prime" elements of a system and the various elements of its logistic support.[2]

To this day, the principles and concept(s) of maintainability continue to be important, and incorporation of the proper characteristics (attributes) into the *design-for-maintainability* is critical if the resultant system configurations are to ultimately perform their respective missions in a cost-effective manner. While specific definitions of "maintainability," and the overall spectrum of activity within a given maintainability program, have changed somewhat, the ultimate design-related objectives (as initially intended) basically remain the same. However, in our world today, many of these same objectives may be categorized within a broader spectrum of activity to include the *design for maintainability, design for supportability, design for operability (or human factors), design for system availability*, and so on. Further, many of these same requirements have been nicely combined and integrated within the overall requirements of systems engineering, and implementation of the *system engineering* process. This, of course, is not intended to diminish the importance of "maintainability in system design," but to place greater overall emphasis through the implementation of multiple approaches.[1]

2) The Current Environment

Having a good understanding of the overall *environment* in which we operate and sustain is certainly a pre-requisite to the successful implementation of maintainability principles and concepts. Although perceptions will differ, depending on what various individuals observe, there are a few trends that appear to be significant relative to the requirements for designing new systems and/or the modification and upgrade of those systems already in operational use. For instance, such trends include:

1. **Constantly changing requirements** – the requirements for new systems are frequently changing because of the dynamic conditions worldwide, changes in mission thrusts and priorities, and the continuous introduction of new technologies.
2. **Greater emphasis on "systems"** – there is a great degree of emphasis on total systems versus the components of systems. One must look at the system in "total," and throughout its entire life cycle, to ensure that the functions that need to be performed are being accomplished in an effective and efficient manner. Further, we are dealing more with systems within the context of some overall higher-level hierarchy, or the concept of *system-of-systems* (SOS).
3. **Increasing system complexities** – it appears that the structures of many systems are becoming more complex with the introduction of evolving new technologies. Further, the interaction effects between different systems, within a "SOS" configuration, often lead to added complexity.

4. **Extended "system" life cycles with shorter "technology" life cycles** – the life cycles of many systems in use today are being extended for one reason or another while, at the same time, the life cycles of various technologies are often much shorter. It will be necessary to design systems with an *open-architecture* approach in mind so that the incorporation of new technologies can be accomplished easily and efficiently without destroying the overall architectural configuration of the system in the process.
5. **Greater utilization of commercial off-the-shelf (COTS) products** – with current goals pertaining to lower initial costs and shorter and more efficient procurement and acquisition cycles, there has been a greater degree of emphasis on the utilization of best commercial practices, processes, and COTS equipment and software.
6. **Increased globalization and international competition** – the "world is becoming smaller" (as they say), and there is more trading and dependency on different countries (and manufacturers) throughout the world than ever before.

In addressing these and related trends, the overall requirements for *maintainability* still exist and are critical in design; that is, to reduce maintenance frequencies, downtimes, the consumption of supporting resources, and life-cycle cost for the system(s) overall. On the other hand, the emphasis has shifted more to the system and major subsystem level of design, versus the design of smaller modules and components. Design goals pertaining to accessibility, functional packaging and interchangeability, modularization, condition monitoring and diagnostics, etc., continue to be important and, when combined with reliability and other design requirements, are critical in meeting the overall *availability* goals for the system.

3) Increasing Emphasis On Systems Engineering

In response to some of these trends, there has been an increased degree of emphasis during the past several decades on *systems engineering*. Systems engineering may be described as *an engineering discipline whose responsibility is to create and execute an interdisciplinary process to ensure that the customer's needs (i.e., a system) are satisfied in a high-quality, trustworthy, and cost and schedule efficient manner throughout a system's entire life cycle. This process is usually comprised of the following seven tasks: state the problem, investigate alternatives, "model" the system, integrate, launch the system, assess performance, and re-evaluate.*[3]

While there are a variety of accepted definitions of "systems engineering," the basic thrust includes thinking in terms of total systems as an "entity," addressing systems from a total "life-cycle" perspective, and applying a total "integrated" top-down/bottom-up (versus just bottom-up only) approach to system design and development (Reference [1], Chapter 1). Of critical importance is an on-going iterative process which includes: 1) the initial establishment of system *requirements* (system needs and feasibility analysis, system operational requirements, development of the initial maintenance and support concept); 2) functional analysis and the allocation of these requirements downward to the subsystem level and below as required: 3) synthesis, analysis, and design optimization (accomplishment of design trade-off studies); system test and evaluation; and requirements validation. Inherent within this process is the integration of various design requirements (and associated programs) to include reliability, maintainability, human factors, safety, security, producibility, supportability, sustainability, disposability, quality, value/cost, and other related factors into the ultimate system design configuration.

4) Maintainability: A Major Requirement in Systems Engineering

Maintainability requirements, in the form of specific quantitative and qualitative "design-to" criteria (an *input* to the design process), must be included from the beginning during the conceptual design phase as system-level requirements are being initially defined. Such requirements may be specified in terms of (Reference [1], Chapter 13):

1. Maintenance frequency factors; *e.g., mean time between maintenance (MTBM);*
2. Maintenance time factors; *e.g., maintenance downtime (MDT), mean corrective maintenance time (Mct-bar), mean preventive maintenance time (Mpt-bar);*
3. Maintenance labor-hour factors; *e.g., maintenance labor hours per operating hour (MLH/OH);*
4. Maintenance cost factors; *e.g., cost per maintenance action (Money/MA);* and/or
5. Various combinations of these or some equivalent factors.

Maintainability requirements must, of course, be "tailored" to the system in question and must be mission-related; i.e., must make sense in terms of the mission or the functions that the system is to perform. Maintainability requirements must be integrated with the other system requirements (e.g., applicable reliability factors such as MTBF, failure rate, etc.); allocated to the subsystem level and below as appropriate; design analysis and trade-off studies are conducted; a maintenance task analysis (based on the system-level functional analysis) is accomplished; maintainability test and demonstration requirements are initiated; and the system maintainability requirements, as initially specified, are validated as part of the overall system validation effort.

In essence, the implementation of maintainability program requirements is accomplished as an integral part of the system engineering process. The appropriate analytical techniques, models, and tools are utilized as necessary to facilitate the system design process. This includes the accomplishment of maintainability prediction, failure-mode-effects-and-criticality analysis (FMECA), level-of-repair analysis (LORA), maintenance task analysis (MTA), life-cycle cost analysis (LCCA), and related analyses, as necessary. All of this must, of course, be planned and integrated in a timely and effective manner. As design changes are introduced throughout the system life cycle, the applicable maintainability requirements must be re-initiated to the extent and depth needed.

5) Some Challenges For The Future

One of the most significant requirements for an individual (or organization) responsible for the implementation of a maintainability program, and actual realization of the desired maintainability characteristics in system design, constitutes an "active" involvement in the system design process on a pro-active basis. While it is not uncommon to accomplish many of the individual required tasks such as maintainability prediction, maintenance task analysis, etc., these tasks have often been accomplished "after-the-fact" and have had little (if any) impact on the actual design process itself. Given the current trends, and the quick-reaction requirements in making design decisions, there are some additional challenges ahead if one is to be an effective participant in the design process. For example:

1. A familiarization with the overall environment in which the system is to be utilized is required; e.g., geographical location, country (or countries) where operational, language and culture for operation and maintenance support, etc. The design requirements for a given system may vary depending on where the system is to be operated and maintained (supported), and for its entire life cycle.
2. An in-depth knowledge of the system and its "technical" requirements, the technologies being utilized and incorporated, the functional interfaces both within a given system configuration and external between other systems in a "SOS" hierarchy, and the design process is essential.
3. An in-depth familiarization with the available design aids, tools, computerized models, and techniques that are utilized to facilitate the overall design process is necessary; e.g., computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided support (CAS), rapid-prototyping models for software development, or equivalent. Knowledge of model applications, the information acquired and conveyed, input-output requirements, etc., is desirable if one is to comprehend the processes being simulated.
4. A rapid and more comprehensive approach in the implementation of maintainability analysis tasks is necessary if one is to adequately respond to current design requirements and the shorter procurement and acquisition cycles in a timely manner; e.g., shorter turn-around times in the accomplishment of FMECA, LORA, MTA, LCCA, and related analyses.

While much of this is not new in terms of the desired results in the implementation of maintainability engineering requirements, the big question remains: are we truly having a significant impact on the overall system design process in continuing to function as we have in the past?

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About the Author

Benjamin S. Blanchard is a Professor of Engineering-Emeritus at Virginia Polytechnic Institute & State University and a consultant in such fields as systems engineering, reliability and maintainability, maintenance, logistics, and life-cycle costing. Before officially retiring, he served as Assistant Dean of Engineering for Public Service, College of Engineering (until June 1996), and as Chairman of the Systems Engineering Graduate Program, Virginia Tech (1979-1997). Earlier, he was employed in industry for 17 years where he served in the capacity of design engineer, field service engineer, staff engineer, and engineering manager (Boeing Airplane Co., Sanders Associates, Bendix Corp., and General Dynamics Corp.). In conjunction, he also served as an Adjunct Professor for several years at the Rochester Institute of Technology (1966-1969). Prior to his industry career, he was an electronics maintenance officer in the U.S. Air Force (during the Korean War timeframe).

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Developing Reliability Requirements for Potable Water Solutions in Politically Discontinuous Areas

Katherine Pratt

Abstract

The world is becoming more aware of the problems of potable water shortages in many countries, due mainly to scarcity. Even though over 75% of the world is covered in oceans, seas and other bodies of water, only 2.5% of this water is fresh water.[1] In countries such as China, poor resource management has resulted in their waterways becoming contaminated with toxic waste streams, which has aggravated the problem of obtaining potable water.[2] Africa and the Middle East are touted as the most pressing areas requiring remediation for water scarcity.[3] This paper will focus on the following Middle East countries: Jordan, Syria, Palestine (Gaza and the West Bank), and Israel.

Introduction

Water Scarcity

Water is a global and national security issue because many countries in the Middle East, and other parts of the world, face water shortages and rising tensions over water sources they must share. When two or more sovereign countries share a watercourse, which could be a river basin, lake, or aquifer, it is considered to be an international watercourse. The potential for conflict appears to be highest in the developing world, where much of the land is either semiarid or arid and most of the unexploited water resources are in international watercourses.[4] The majority of water in this dry region comes from three river basins: the Nile, the Jordan, and the Tigris-Euphrates.

Only about 0.024% of the world's water supply is available to us as liquid freshwater in accessible groundwater deposits, and in lakes, rivers and streams. The rest is in salty oceans or locked up in the polar icecaps and glaciers, or inaccessible because the groundwater is too deep or too salty.

This available supply is continuously collected, purified, recycled, and distributed as part of the earth's hydrologic cycle (the solar-powered movement of water between the sea, air and land). On a global level, we have plenty of freshwater, but differences in annual precipitation and economic resources ensure that freshwater is unevenly distributed when compared to population size.

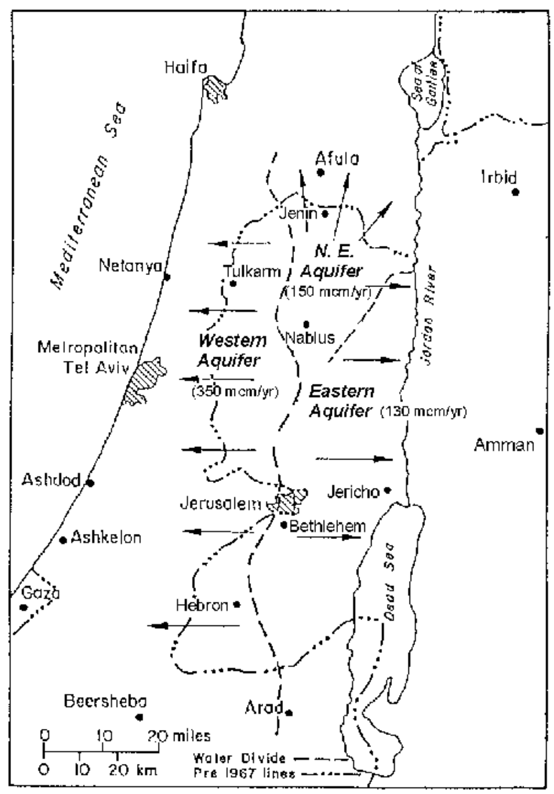
Natural Capital Shares Distribution[5]

	% Water Resources	% Population
Asia	36%	60.5%
Africa	10%	14%
Europe	8%	11.3%
N. & Central America	15%	7.3%
S. America & Caribbean	26%	6.4%
Oceania	5%	0.5%

Despite its importance, water is one of our most poorly managed resources. We waste it. We also charge too little for making it available. We do not assess enough reparation to those who pollute water systems. We do not pass strong enough legislation to act as a deterrent to those fail to accurately measure water quality to avoid being held accountable for their unplanned events and misadventures. This encourages still greater waste and pollution. This is a variable that must also be addressed quantitatively and planned for when managing the performance of a function over time such as reliable potable water products or systems.

The Jordan River Conflicts: Trans-Boundary and Political

The potential for conflict appears to be highest in the developing world, where much of the land is either semiarid or arid and most of the unexploited water resources are in international water courses.[6] The Jordan River is by far the most water-short region, with fierce competition for its water occurring between Jordan, Syria, Palestine (Gaza and the West Bank) and Israel. (See Figure 1)



Basing on: Assaf. Karen; al Khatib, Nader; Kally, Elisha; Shuval, Hillel: A Proposal for the Development of a Regional Water Master Plan. IPCRI: Jerusalem 1993.

Figure 1 - The Jordan River and Associated Aquifers

Israel has warned Syria that it may destroy any dams that may prevent their region from surviving and it has cooperated with Jordan and Palestine over shared water resources. Although used primarily for farming by Jordan, Israel and Syria, the Jordan River is littered with sewage and agricultural runoff. It is the water source for the Dead Sea, which has declined 70 percent in recent years, shrinking in size from 50 miles long 50 years ago to 31 miles today.

A particularly dramatic water situation has developed in the Gaza Strip. As a result of a large influx of refugees in the aftermath of the 1948 and 1967 wars and also very high birth rates, this very small area of 365 km2 became inhabited by around 850,000 people according to official Palestinian sources in 1994. Nearly 70% of them are registered as refugees.[7] With more than 2,000 persons per square kilometer, the Gaza Strip is among the most densely populated areas of the world. Rainfall occurs only in the winter months and averages between 400 mm/year in the North and 200 MM/year in the Southern part of the strip and is the sum total of all surface water. This area has no permanent rivers, but does share Israel's Coastal Aquifer. This aquifer is fed by irrigation returns and sewage on the order of 20 mcm per year. Despite the lack of potable water, water consumption in 1994 amounted to 100–110 mcm per year, which was 50 to 100 percent above the natural replenishment rate.[8]

This continuous drop in groundwater levels has allowed the seawater seepage to extend about 1.5 km into the fresh water aquifer. Worse, further to the East, a saline groundwater stratum, even more briny than seawater underlies the Gaza shallow aquifer. Digging into this layer has allowed the two aquifers to intermingle, increasing the brackish water concentrations.

Moreover, growing nitrate and chemical concentrations from fertilizers, microbial contamination, and pollution by heavy metals and fuels from sewage effluents are aggravating the hydrological situation. More than 60% of households lack any well-controlled and -organized sewer networks. Wastewater facilities are lacking or inoperable.

Since 1971 through 2012, more than half a billion Euros in assistance has been provided to the Palestinians by the European Community, leading them to question the viability of the Palestinian Authority (PA) also known as Hamas.[9] Hamas' dictatorship should have been empowered to be responsible for the infrastructure support and repair, however, the aid from international donors goes primarily into funding terrorist activities, as evidenced by the current meager water and sewage services. In the West Bank, there are complex issues with water resources, due in part to a challenging natural environment as well as mismanagement of water resources by the Palestinians themselves. Israel provides more water resources to them than the Oslo accords, and that amount is set to rise by another 50% in light of a deal struck between Palestine, Israel and Jordan.

Even the Palestinian Water Authority (PWA) estimates that at least 33% of its water is wasted through leakage, mismanagement, defective maintenance, and old infrastructure. According to the water agreement of 1995, the Palestinian Authority should be preventing and repairing leaks in domestic pipelines and recycling treated wastewater for agricultural irrigation, but it repeatedly refuses international funding packages to do so. In the past too, militants have diverted pipes intended for sewage/services towards groups skilled in fashioning basic missiles.

Gaza-Palestine offers many complications. Since the Egyptian and Israeli blockade, the entity has not had sufficient fuel to sustain its electricity supply and to keep its water and sewage facilities running. The Hamas Government refuses to buy alternative fuels, because the taxes would go to the rival Fatah-controlled Palestinian Authority. It also refuses to pay the Israel Electric Corporation, owing Israel millions of dollars. The end result is power shortage with water pumping stations ceasing operation…and Gazan streets that look like sewers. With the pumping stations out of action, fresh water no longer reaches taps. The infrastructure is there and the water is there; the issue is electricity, and the blame for that lies entirely on the shoulders of Hamas.

In the water agreement of 1995, both parties agreed to prevent any harm to, or pollution or deterioration of, the quality of all water resources, yet the Palestinians constantly breach the agreement by drilling 'pirate wells' in West Bank-Palestine and Gaza-Palestine, by not treating their sewage, by then contaminating the streams, and by not developing any new sewage treatment or desalination plants. The problem is not so much access to water but the willingness and ability to treat and distribute it effectively.

The Israeli Water Council (IWC) currently sells desalinated water to Palestinian communities inland on the network of pipelines they built. The desalination prices are low for some areas (as low as U.S. $0.57/Cubic Meters [CM]), whereas villages in the West Bank are assessed substantially more than Israeli settlers. An IWC report published in 2004 estimated the transmission costs alone at $1.15/CM. Factoring in additional capital and investment costs, the price of water was estimated at $1.85/CM.[10]

Wastewater Re-use

In 2009, the Palestinian Water Authority (PWA) and the United Nations Development Programme of Assistance to the Palestinian People in partnership with the Government of Japan launched a cross boundary wastewater management project in the occupied Palestinian territory (oPt). The project included the construction of three wastewater collection systems in the Jenin, Tulkarem and Qalqylia Governorates [serving 16,500 people], in addition to building the capacities of the service providers and the PWA regarding waste management issues. This project brought new jobs to the Qalqylia, Jenin, and Tulkarem areas and created a platform for cross boundary cooperation between Palestinian and Israeli municipalities on environmental problems. In 2009, Israel reconfirmed its willingness to implement the decision of the Local Israeli Assembly for Organization and Building to use a piece of land in the Hadera area to build a desalination plant for the benefit of the Palestinian Authority, despite the PA's and or Hamas's objections.[11]

The PWA also put in place with the Israeli Authorities a coordination mechanism where the wastewater generated by these three governorates is treated by Israeli water systems inside the 1949 Jordanian-Israeli armistice/Green Line and are following up on it with the Joint Water Committee.

Approximately 35% of the population of the West Bank has access to wastewater network collection systems and there are only three treatment plants located in the Ramallah, Jenin, and Tulkarem districts. Due to an old infrastructure of collection systems, sewage leakage reaches up to 50% in the areas of Tulkarem and Qalqilyah. Only one sewage treatment plant has been built in West Bank-Palestine in the past 15 years, despite there being $500 million-worth of international donor funding available for that sole purpose.

Israel has more water because it developed desalination technology and it recycles household wastewater for agricultural use. Israel has stated clearly that it is happy to share expertise and is actually now providing training in both recycling and desalination to the Palestinians. Instead Palestinian Hamas leadership resists Israeli assistance, spending much of their energy and money building armaments, readying for their next confrontation.

Current Wastewater Management

Modern modeling techniques and a statistical tool known as Quantifiable Microbial Risk Assessment have shown that many wastewater management strategies can be applied to optimize health benefits to downstream populations. Wastewater treatment serves two main purposes; the removal of harmful pathogens from waste to protect health and the removal of nutrients (significant amongst which are Nitrogen and Phosphorous) from waste to protect the environment. Most high-energy processes focus on nutrient removal and rely on chlorination for pathogen removal. This focus on nutrient removal is significantly more costly to capture these valuable inputs of phosphorus and nitrogen for agricultural use while the reuse of treated wastewater, which is pathogen-free, has significant potential to increase agricultural productivity and reduce reliance on chemical fertilizers.

Decisions about wastewater management strategies are a process of balancing cost and effectiveness across these two objectives. Where reuse of wastewater is common, removal of pathogens is a priority.

In developing countries, many rural households have onsite sanitation effluent vaults, which are emptied between two and four times per month due to high water tables. A typical scenario for the delta region is that 88% of households use poorly functioning household facilities, known as bayaras or trenches, and the remaining 12% are connected to either a centralized oxidation ditch system or a centralized activated sludge system that typically is at 50% capacity. In Egypt, most of this effluent is either used directly on the fields, or discharged directly into agricultural drains and canals without treatment. Informal private operators provide emptying services and dispose of wastes in both irrigation channels and drainage canals. The Nile delta has a high prevalence of poorly managed onsite sanitation facilities, low rates of connectivity to wastewater treatment facilities and is crisscrossed by a network of agricultural canals and drains.

Reliable Water and Current Health Risks

Reliable water, i.e., with little health risk(s), in downstream areas is a function of water quality and farming practices. Diarrheal disease is caused by a wide range of pathogens, however, the most common organisms when considering risks associated with wastewater reuse in agriculture are: rotavirus, norovirus, Campylobacter, e-Coli, Cryptosporidium and Ascaris. Children under the age of five are most likely affected by the rotavirus, whereas adults more commonly are affected by the norovirus (acute gastroenteritis).

The resultant water quality in downstream channels depends upon:

- the baseline water quality and flow upstream of the sanitation system,
- the rate and quality of water discharging via sewerage and wastewater treatment system; and
- the rate and quality of water discharging outside the sewerage/wastewater treatment system (from domestic onsite systems and unregulated commercial discharges).

Reductions in risks associated with the reuse of wastewater can broadly be achieved by:

- diversion of wastewater flows from low-treatment to high-treatment facilities prior to discharge,
- improved levels of treatment in existing facilities; and
- improved on-farm and post-harvest practices.

The specific focus of current investment strategies include:

- rehabilitating existing treatment plants;
- commissioning new treatment plants;
- most importantly, construction of new sewer networks particularly in the rural areas. The most significant health risks are posed by un-regulated dumping of wastes from poorly performing household cesspits and septic tanks.

The most effective treatment intervention is the replacement of faulty household septic tanks/cesspits, with effective primary and secondary treatment. Even though centralized systems are the preferred long run improvement strategy, immediate onsite sanitation redress is an important and cost-effective short-term intervention that could have significant health implications. If households are offered more flexible approaches to finance with the households bearing a greater share of upfront costs, there might be a willingness to pay to reduce the inconvenience of the current system of bayaras, which need to be emptied frequently. Note: Waste stabilization ponds also provide good health protection and are not reliant on the operation of chlorinators for pathogen removal.[12]

Methods Available to Improve the Current Situation

Some available options for Egypt, Jordan, Palestine, Israel, and Iraq in their efforts to acquire more water include: slow their population growth or waste less water. Other options include importing more grain to reduce the need for irrigation water, establish water-sharing agreements with other countries, raise water prices to improve irrigation efficiency, use conservation-minded processes such as recycling and improved technologies associated with water use; if they don't agree on some combination(s) of the above, as none of them are easy to implement or manage, they will suffer the harsh human and economic consequences of "hydrological poverty."

Over the next few decades, global drivers such as population growth, climate change, and improving living standards will increase pressure on the quality, availability and water resource distribution systems. In order to make best use of available water resources, increased management and policy development of these global drivers will need to be in place at all levels of collection, production and distribution of water.

Currently too many legacy water policies, standards and usage parameters are relied upon to make short and long term decisions. Better data gathering surrounding water status, management and use is the first step to more effective planning and implementation. This will help determine if agricultural needs can be met from existing sources, and if so then improving agricultural water usage efficiency. If existing water sources for agricultural needs cannot be met, then determining alternative strategies will be needed for alternate food sources. Understanding effluent returns to water, groundwater and elsewhere is important when planning for the future in an arid environment.

In order to better serve urban populations with water supplies, accurate accounting for the numbers of users served from public water sources as well as assessing if those served from private sources will, with time, also need to be served by public supplies. An average daily consumption by these groups will need to be established and the current fee structures determined. The above holds true for wastewater collection as well. Understanding of how wastewater is treated, to what standards, and how much and under what conditions is released untreated will need to be assessed.

An important job of country, state, city, or town management is to reduce vulnerability of their populations to extreme events, such as droughts, floods and storms. To better understand the ramifications of these types of events, you have only to look at historical records of the economic performance consequences of failures to plan effectively. Even a rough estimate, determined by using a ratio of the past population numbers to current, will provide a realistic starting number regarding the risk(s) to the population and economy from extreme events.

Today, metrics accumulation processes have improved sufficiently to understand the impact of water abstraction and pollution on natural environments and ecosystems. Different types of data are needed for different purposes; e.g., near real-time data are used to determine operational-perspective requirements, whereas longer-term datasets and indicators are used as tools for policy development and evaluation. However, there is a lack of systematic data collection in most countries, which prevents regular reporting on water resources and water-use trends. There is also no agreed upon terminology, which leads to discrepancies in data definitions, compilation and analyses.[13] Terms such as "green economy," "sustainability," "green growth," "green jobs," and "environment sector" are often used, but are not rigorous enough for the concepts, terms and definitions to be measured consistently across countries and over time.[14]

Fortunately, the United Nations Statistical Commission (UNSC), which oversees the work of the United Nations Statistics Division, has adopted a conceptual framework for monitoring trends and the impact of economic and social development on the environment and, within this framework, a supplementary system has been devised specifically for water, SEEA-Water, launched in 2007. In 2010, the International Recommendations supplemented this system for Water Statistics.[15]

These are both compatible with, and enhancements to, the internationally used System of National Accounts (SNA), providing for data collection on natural, environmental water-related capital as a guide to the future sustainability of current economic and social activities and performance, as well as to water resource management needs. Although SEEA-Water and IRWS are relatively new, more than 50 countries are compiling or planning to compile water accounts. Improvements to SEEA-Water are ongoing.[16]

For more information on the Joint Monitoring Programme (JMP) for Water Supply and Sanitation provided by WHO/UNICEF, three tools are provided so you can dynamically build water supplies and or sanitation data in the form of maps, tables and graphs for a country, region or worldwide. *www.wssinfo.org/data-estimates/introduction*

To manage water footprints effectively, measurements of concentrates of pollution in key water bodies need to be established in order to determine the water pollution baseline and to measure against this baseline in outlying years to determine degree of progress in water quality; e.g., key markers, such as accounting for fish species and their estimated population number(s), help in determining trends.

Aquifers, an important source of water for many countries, need to be assessed to determine if there are trends related to water levels and increased or decreased contaminated. Current data on the availability and quality of surface water and groundwater are poor and can be difficult to summarize because of the variable nature of the resource across different segments of time (seasonal, inter-annual, decadal)—hence the need to report on trends. Even so, trends are hard to establish, because historical datasets are rare or often discontinuous, and the dates of statistics are not always given.

The following are abbreviated explanations of practical steps that should be considered and implemented on a case-by-case basis.

Intrastructure Support

In arid environments, getting the right equipment to enable potable water availability or developing and maintaining the removal of effluents in a manner so there are no leaks or cross contamination is critical.

Regardless if the current political situation appears to be stable, the risks to infrastructure must be assessed, planning and execution must be accomplished, all completed with caution. It may be that the wells, springs and streams are all that are immediately available; however, affording the local populace access to safe drinking water is a top priority. If the drinking water is not safe then it is also possible that there may be a high incidence of waterborne disease; water treatment plants and water distribution systems will need to be installed.

Education, Training and Human Capacity

Prepare an educational component in any plan for "infra-restructuring." Disseminating information, including health and hygiene education, is an excellent starting point when assessing the water and sanitation situation. Political strife is a factor that can be moderated with strategies such as providing goods and services to countries that share Israel's geographic region. For instance, Palestinian workers may benefit from labor and training opportunities supporting Israel's regional commercial potable water industries. In turn, the Israelis are afforded a less expensive labor force that is already located within regions targeted for new business expansion; Palestine is in a similar environmental area that may also benefit from using their products. Most importantly, steps such as these can help to align National political positions where there is a shared solution to a shared problem, there is the potential for peace.

Capacity building—understanding the obstacles that inhibit people, governments, international organizations and non-governmental organizations from realizing their developmental goals while enhancing the abilities that will allow them to achieve measurable and sustainable results—is important.

Developing the human and technical capacity, through staff-training, technical assistance and institutional support, to generate and analyze data is necessary to enable water management institutions in the formulation of water management plans. Technical infrastructure that manages water use and is understood and bought in to by all stakeholders can contribute to conflict resolution. Building human and administrative capacity to develop sustainable water management plans and implement them is necessary to prevent long-running water related disputes. Capacity building via conflict management techniques (such as mediation and facilitation) and stakeholder participation helps prevent dispute and mitigate emerging conflicts. Capacity building in conflict management should target groups such as water management institutions, local non-government organizations, water user associations, or religious groups, each of which could play a specific role in mitigating water-related conflicts.[17]

Capacity is also needed to mitigate contested water issues. On the local level, strengthening the human capacity of excluded, marginalized, or weaker groups so they can articulate and negotiate their interests helps prevent them from developing grievances. On the international level, disparities in capacity and knowledge have often led to mistrust between riparian countries and hindered cooperative action. Strengthening negotiating skills of less powerful riparians is conducive to prevention of conflict, as is strengthening their capacities to generate and authorize relevant data.[18]

Data

Having a reliable database including meteorological, hydrological, and socioeconomic data is a fundamental tool for deliberate and farsighted management of water resources. However, it may be difficult for developing countries to obtain reliable information. The lack of a common database can cause tensions between water-sharing parties, as different assumptions regarding the characteristics of a resource can lead to controversial management decisions. Sharing information increases in importance as the scope of the water management unit grows and becomes more difficult, and the number of parties sharing water increases. Downstream water managers need hydrological and meteorological data collected upstream to plan water use and development. Information on emergencies, such as floods and contamination, is crucial to protect human and environmental health. Tensions between states emerge when data and information are not shared. Cooperative action is hindered by inability to generate, interpret and legitimize data.

One resource, the Regional Water Data Banks Project (WDBP), was launched in 1995 to exchange consistent, compatible and reliable water data information among Israel, Jordan and Palestine to support decision making both at the local and regional levels. The project is managed and coordinated by an Executive Action Team (EXACT) comprised by two representatives from each of the three countries, as well as from the donor countries (United States, European Union, Canada, France, Canada, and the Netherlands). For more information see *http://www.exact-me.org*

Organizational Management Structure

It should not be taken for granted that there will be a centralized group, or specific part of the ministry that is responsible for the problem(s) requiring mitigation. Water management in many countries is characterized by duplicate responsibilities and it is not uncommon, in third world countries, for nepotism to run rampant; the person with the correct title may know very little about the actual job they are expected to manage or oversee but happens to be the cousin of the man who did the hiring. Equally confusing, the actual decisions may be made by a variety of non-related or institutions with bifurcated responsibilities, e.g., agriculture, fisheries, water supply, regional development, tourism, transportation, conservation and/or "the environment."

This disaggregated decision-making approach, seen frequently in developing countries, often produces divergent management approaches serving contradictory objectives, leads to competing claims from different sectors and enables powerful water users to supersede water use rights of less powerful, local communities. These competing claims are even more likely to contribute to disputes in countries where there is no formal system of water use permits, or where enforcement and monitoring are inadequate.

Water resources management is highly complex and extremely political. Balancing competing interests over water allocation and managing water scarcity requires strong institutions. In developing countries, water management institutions often lack the human and administrative capacity needed to develop adequate, comprehensive management plans and to implement them. If water resources are not managed properly, tensions over water access are likely to arise and can contribute to conflict without an institutional framework for settling disputes. Managing water is even more complicated when it is scarce, while scarcity is often due to previous mismanagement. Lack of institutional and social capacity to adapt to water scarcity (known as adaptive capacity) can lead to environmental and, consequently, economic collapse which leads to social instability.[19]

Record Management

There may not be any physical maintenance, or maintainability records, so one should be prepared to develop these as best as practical.

If the customer's maintenance capability is limited, or if distribution of high-cost spares is limited by inadequate transport capability, then it stands to reason that more spares will be required. This pre-supposes that there is enough information to evaluate supply maintenance and distribution capability.

Failure Data Management

Feedback in equipment failure data is essential, to wit: what parts, how often, how many, and for more sophisticated equipment, under what conditions. It is essential that a database or log book, representing all of the customer's sites captures legacy information identifying how well past maintenance, supply and distribution problems were addressed for each of their separate support problems.

Materiel Management

If forecasting is done in each functional area, then a formal requirements documentation process should be in place. This should address how each customer appropriates materiel, and how the materiel is apportioned to each of the customer's sites.

Spares and Repair Parts Management

It will be necessary for multiple sources for spares and repairs parts to be established. If there is a requirement to sustain customers during times of combat situations, then there will also need to be a level of sustainment established.

Repair and Support Personnel

Consideration should be given to determining the number and levels of trained repair and support personnel needed, and how their skills will be utilized.

Logistics

All active participants should review the existing logistics system regularly, and changes should generally be evolutionary in nature.

When possible, maximum advantage should be taken to standardize the logistics used with all customers. This will enable the failsafe of using an alternate supply from another customer co-located in the same region, which can lessen procurement lead times during critical periods. Procurement lead times can be reduced by planning for alternate sources of supply whenever possible.

In order to improve readiness rates, the resupplying of repair parts and accompanying maintenance channels should be moved to regional logistics locations rather than a centralized warehouse. By integrating repair parts and maintenance support system channels, down times can be reduced.

Inventory Management

Developing and implementing strict inventory management accounting systems saves money and improves readiness.

Although resupply and maintenance may be done at a regional level, the overall logistics support oversight should be centralized to include control of all supply and service units, including a materiel management center, thereby creating a good organizational-level tool.

Limiting the number of potable water major end item equipment types will simplify maintainability issues and repair parts inventory management; as always, preventive maintenance is essential.

Systematic approaches evaluating the "health" of a customers' military logistics support system, is worth taking the time to understand. If problems start at the top, then it follows; solutions may also start there, too.[20] Cooperation begins, with team building, and shared good working knowledge.

Conclusions

Agriculture is the single largest source of livelihood, particularly in developing countries, where large portions of the population depend upon subsistence farming. Without this livelihood, people are often forced to migrate to urban areas with already stressed water resources. This exacerbates other tensions linked to rapid urbanization, e.g., turning to illicit ways to make a living. Poverty due to livelihood loss has been identified as the common denominator of the varied causes of conflict in most civil wars that emerged in Africa, South Asia and Latin America during the last decade.[21]

The implementation of joint water-related projects with funding contingent upon trans-boundary cooperation may be a method to begin to bring countries to put aside past grievances and to work towards a mutually beneficial goal of reliable, disease free water. Theoretically, the idea that cooperation over water resources could act as a pathway for building peace is feasible if it focuses on the design and implementation of cooperative processes, as both the content and form of cooperation are critical for peace building. The key to successful trans-boundary cooperation is to tie external opportunities to internal strengths linked with objectives. Improve human capacity and utilize clear policies and objectives to ensure conflicts are minimized.

Sustainable water management, regardless if the context is social, environmental or economic, can help prevent potentially related conflicts and is a prerequisite for establishing the socio-economic foundations for peace. Conflict-sensitive approaches to balancing competing interests and inequalities related to water could help prevent conflicts from arising in the future. Cooperative water management mechanisms offer the most advanced approach because they can anticipate and mediate water-related conflict, provided that all stakeholders are included in decision-making processes and given the means (information, trained staff and financial support) to act as equal partners.

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About the Author

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Field Data Collection

Eugene Cottle

Abstract

Reliability assessments based exclusively on a single source, whether laboratory testing, development testing or sustainment field failure performance will be incomplete. While analysis of test data is straightforward, collection and analysis of field failure data is fraught with challenges. A reliability engineer responsible for analysis of field data generally spends more time developing sources and parsing and cleansing data than on analysis. This paper presents some lessons learned for design of data collection tools and for population performance data analysis. Some general rules are presented for the design of a successful FRACAS/DCACAS database and for the forms and tools to be used by maintainers and field service representatives. Some common traps and potential error sources are discussed, as well as methods for avoiding them. Recommendations are made for managers, system developers and reliability engineers that can help make meaningful field performance a reality.

Introduction

Any Reliability Engineer responsible for the analysis of product performance data will soon discover that analysis is only a small part of the job. The bulk of his or her time will likely be spent on developing data sources, gathering data, cleansing data, parsing data and preparing it for analysis. This is due partly to the fact that systems designed for the collection and analysis of performance data fall short of the mark. Decades after the fundamental principles of reliability were first developed the application of those principles is still immature in many industries.

This article shares some lessons learned about effective field failure data collection. I first make the case for true end user, entire product life data collection, and discuss the role it can play in customer support, logistics, sustainment and design. I discuss some of the elements of effective data tools, and some general rules for making a data collection effort successful.

Why Field Data Collection

Field Data Versus Laboratory Data

Field data collection is crucial to the accurate assessment of product reliability.

One of the crucial functions of Reliability Engineering is the collection and analysis of system or product performance data. The results of that analysis is then used to predict or anticipate future performance, to drive engineering, logistics support, warranty and other management decisions.

There are two fundamental ways of directly measuring the reliability characteristics and performance of a product or system:

- Laboratory testing and
- Field data collection, directly measuring the end user experience.

Analytical modeling and simulation are important predictive tools, but do not directly measure actual reliability. Reliability models must be based on direct measurements of component or subsystem reliability. Any model or simulation must be continually checked against the real world, and refined to ensure that it is an accurate, realistic representation.

<u>Advantages and Disadvantages of Laboratory Testing</u>

The benefits of laboratory testing are that the products can be observed under carefully controlled conditions, where it is easy to gather and analyze the data. The primary disadvantage is that it may not always adequately represent real world conditions, and therefore may not accurately predict actual performance.

The only true measure of the reliability of a product is the end user experience. The only way to know the true long-term end user experience is to gather true end user field data.

<u>Advantages and Disadvantages of Field Data Collection</u>

There is a disconnect often between what the end user experiences and what engineers believe the end users experience. In some cases it may even be difficult to convince the engineers of what the end user is experiencing. On one occasion I visited a customer to explore the possibility of gathering data on our products that were being used in their facility. They led me to a section of the facility where they had been seeing a high failure rate on our components. They had begun collecting boxes of our failed products for disposal. They were in the process of switching over to our competitor's products because they lasted longer. They had been working with our Engineers, but the Engineers had attributed the failures to environmental factors. But no one had yet begun to quantify the life of either our components or our competitors', so it was difficult to convince the engineers of the severity of the problem. Most importantly, we were going to lose the business. The solution to the problem began with data collection: "Speak with data, act on fact."

Field data collection is far more difficult than laboratory testing. In many applications it is impossible to collect data from the entire population. In those cases it is challenging to structure samples representative of the entire population. Warranty returns do not provide complete data for the entire product life. Failures after the end of the warranty period go unreported. Even in applications where data can be collected on an entire captive population, failure and population data is notoriously incomplete or inaccurate.

It is impossible to completely characterize the operating conditions, one of the crucial elements in the definition of reliability. For all of these reasons, engineers sometimes conclude that field data cannot be used to quantify expected life of a component or system.

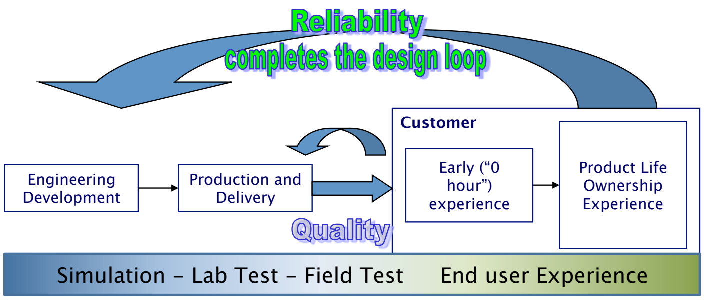

FIGURE 1

Figure 1 illustrates the role of field data collection in the product life cycle. A product life cycle is often represented as a single linear process, starting with concept and development and ending with product sustainment and finally disposal. The quality feedback loop is often relatively short-term looking primarily at workmanship and manufacturing defects. As-designed product life is not usually included in the purview of the quality department, and even warranty returns look only at the early part of the product life. Reliability is concerned with the long-term product life. Simulation and laboratory testing are intended to represent the end user experience, and field data collection provides the truth of what the end user actually experienced.

Some of the difficulties of field data collection are exacerbated by the design of data collection systems. They are not always designed with the needs of the Reliability Engineer in mind.

The next section describes the requirements of a successful field data collection process.

Basic Requirements

In this section we will look at the basic requirements of the data collection system, the objectives that must be met, and some of the scenarios in which the data collection system must operate.

Objectives

Field data collection and analysis meets four basic objectives:

1. Customer support
2. Manufacturing reliability
3. Population sustainment
4. Estimating design parameters

<u>Customer Support</u>

Credible reliability parameters calculated from "ground truth" customer experience can be valuable in RCCA (Root Cause and Corrective Action) investigations, and in resolving issues for specific customers.

<u>Manufacturing Reliability</u>

Plant Reliability Engineering could be considered a special case of field data collection. Manufacturing equipment is a captive population, and lends itself to gathering actual performance data. A plant reliability engineer has the luxury of working all the time with actual performance data. This data can also be used to compare performance between locations within a plant, or between plants.

For suppliers of manufacturing equipment, or components used on manufacturing equipment, field data collection becomes more difficult. For them, their products are a dispersed population. Actual data can be invaluable in identifying performance differences under different scenarios, or in resolving quality or life issues.

<u>Population Sustainment</u>

Actual performance data is often collected as part of a long-term logistics, population sustainment effort. The data is used to estimate spares requirements, and to anticipate and sometimes eliminate frequent failure modes. Root Cause and Corrective Action initiatives may be triggered by frequent or costly failure modes. In a mature sustainment effort, the data can be used in Reliability Centered Maintenance.

<u>Estimating Design Parameters</u>

Design tools used to predict product reliability depend on good initial estimates of component reliabilities. Reliability allocation has traditionally been done based on constant failure rate estimates and product structure complexity, but it can now be done with reliability analysis software. The software can take into account initial estimates of component failure probability distributions and improvement difficulty factors to optimize the allocation. These initial design parameters are based, in turn, on either laboratory or field data. Reliability Block Diagrams also require component reliability models based on test or field data.

Population Analysis versus Failure Analysis

We have all seen the insurance company commercials that tout "drivers who switched saved an average of $500" (or some number) on their auto insurance. The message is clear, but the hidden assumption is not; at least not to the statistically uninitiated. The message being conveyed is that you can expect to save a bunch of money if you switch from your current insurance to the insurance being advertised. The hidden assumption is that the population of interest includes only those drivers who switched, and excludes drivers who discovered that they wouldn't be able to save money on their premiums.

The same faulty assumption is often made in the design of field data collection systems. The implicit objective is to record "failure" data, with no attempt to gather "success" data, that is, data on the members of the population that have not failed.

The term "Failure Reporting, Analysis and Corrective Action System" (FRACAS) is often used to describe the database and associated tools that facilitate corrective actions. The term is also used more broadly to describe the corrective action process itself. The term FRACAS itself illustrates this hidden, faulty assumption. The system is usually designed to collect only failure data. Like the insurance commercial, it implicitly omits a crucial part of the population.

One of the first challenges a Reliability Engineer faces at the outset of any analysis is finding data on the un-failed members of the population. In the case of warranty data this takes the form of sales or delivery quantities over time. In the other scenarios it takes the form of system or component ages over time. If age is a function of calendar time it can be easily estimated if manufacture or delivery dates are known. But this is seldom the case. Most systems or components age by something other than calendar time. In those cases it is necessary to either routinely gather life data on all systems, or gather data on a large enough sample that ages can be estimated with some degree of confidence.

Life Events

Reliability Analysis is not just failure analysis, but *population analysis*, and the data system should not be designed to collect failure reports, but to record life events. A life event can be anything that is germane to Reliability Analysis. Life events include:

1. Preventive maintenance,
2. Corrective maintenance
3. A record of cycles to date for any member of the population,
4. Etc.

This is much easier in a manufacturing scenario than a fielded scenario. For a sample population it is also not too difficult, although the sampling usually starts at some time after the systems have been fielded, leaving a gap in data in the early part of their lives. It should be easy in a captive population, but data quality is often an issue. In those scenarios it is important to record data at every "touch" of every member of the population.

MTBF versus Reliability

Field data collection systems are usually designed based on an assumption that the primary measure of merit will be either Mean Time Between Failure (MTBF) or Mean Time To Failure (MTTF). These have traditionally been the most frequently used measures of "reliability." They are familiar, easy to calculate and easy to use. Because they are so familiar they have been vastly over-used and often misused. Analysts or decision makers are not always familiar with the ramifications of the constant-failure-rate assumption and when it does or doesn't apply. Reliability is defined as a probability of failure.[1] MTBF and MTTF are expressed in units of time or cycles. There is not universal agreement among Reliability Engineers about when or in what situations they should be used. Some tools and techniques are based exclusively on MTBF as the primary measure of merit, such as the AMSAA-CROW Reliability Growth techniques.[2] Others argue that they should seldom be used.[3]

Reliability software tools facilitate the use of more accurate failure distributions, and there is no longer a need to use the constant failure rate simplification where it is not applicable, inaccurate or possibly even misleading. But more accurate failure distributions require changes in the design of data collection systems. Traditional data collection does not generally provide enough information to calculate more accurate distributions. The change in mind-set requires a change in data collection.

The following are some of the scenarios in which reliability field data are collected.

Scenarios

<u>Disperse Population – Warranty Data</u>

Warranty data is used in the case of a consumer or other broadly fielded product, in which it is impossible to gather data on an entire population.

The data element typically collected in warranty returns is the total number of returns in a given time period, returns per week or returns per month. It is also common to quantify returns in returns per 1000 units sold. There are three crucial data elements typically missing from warranty return data, which are required to do accurate Reliability Analyses.

1. Total quantities sold in a given time period.
2. Reason for return, at a minimum failed or not failed.
3. Time or date sold, if age is quantified by calendar time. If age is quantified by operating hours, then operating hours at return is required. Additionally, if using operating hours, a 4th element is required:
4. Population operating hours over time. In a military application this is usually termed operational tempo, or OPTEMPO.

A warranty return matrix, or Nevada chart, Figure 2, lists date or time period sold down the left-most column, quantities sold in the 2nd column, date or time period returned along the top-most row, and quantities in the matrix.

Probability of failure, or probability of return, is quantified as the percentage of products of a particular vintage, or sold during a given time period, returned at a given point in the products' life. Probability is calculated as the percentage of product returned at a particular age in service.

Date	Deliveries	Jan-1998	Feb-1998	Mar-1998	Apr-1998	May-1998	Jun-1998	Jul-1998	Aug-1998	Sep-1998	Oct-1998	Nov-1998	Dec-1998	Jan-1999	Feb-1999	Mar-1999	Apr-1999	May-1999	Jun-1999	Jul-1999	Aug-1999	Sep-1999
Jan-1998	237					1															1	
Feb-1998	203					1		1														
Mar-1998	486						1											1	1			
Apr-1998	287					1					1		1						1			
May-1998	435								1				1									
Jun-1998	255										1											
Jul-1998	396															1						
Aug-1998	463																				1	
Sep-1998	292																1		1			
Oct-1998	718															1						
Nov-1998	540																				1	1
Dec-1998	177													1	1							1
Jan-1999	299																		1		1	
Feb-1999	549																					
Mar-1999	677																					
Apr-1999	516																			1	1	
May-1999	413																					
Jun-1999	592																			1		
Jul-1999	631																					1
Aug-1999	524																					
Sep-1999	541																					

FIGURE 2

There are several assumptions inherent in using warranty returns for reliability analysis. The first is that all failed products are returned. Of course this is never really the case. Unreturned product will result in understating the probability of failure, and overstating the reliability, of a product.

One way to overcome this difficulty is to work with a captive subpopulation. This can be done by working out agreements with a subpopulation of customers. It is also possible to incentivize returns. It has been said that the Reliability Engineer is the only one in the organization who gets excited by a failure. Testing can have either a success oriented or a failure oriented mindset. The objective of a success oriented test is to complete testing without a failure. The objective of a failure oriented test is to determine when and how the product fails. The objective is to break the product. Reliability Analysis using warranty return data is analogous to a failure oriented test. If failed product is not returned then the true life, or the true probability of failure at a given time in service, cannot be accurately calculated.

Another assumption is that all products returned have, in fact, failed. This is also not true in general. Products are returned for many reasons, but true failure is only one reason. This is why it is crucial to record, as a minimum, whether a returned product has actually failed. This can only be done effectively at the point of return, when the data collector interfaces directly with the user. A free text description of the reason for return is good, but a simple check box, "failed Y/N" is better. Another reason product can be returned without failure is with recalls, proactive or forced replacement of a population or components.

Captive Populations

There are some cases in which it is possible to gather data from the entire population. There are two criteria that characterize a captive population:

1. It is possible to capture data for all life events from the entire population "of interest." That is, there is no need to learn about or compare with components or systems outside the population of interest,
2. It is possible to control or influence the data gathering people and mechanisms,

A third criteria determines whether traditional statistical analyses will be meaningful:

3. The population is large enough to produce statistically significant results from the analysis.

This is possible in a manufacturing setting where the population is defined as all of the machines at a facility. Of course, a larger population yields better results. If a company is able to combine the data from all facilities at all locations the results will be better.

The captive population scenario also applies in many situations where a company is managing an entire fleet of airframes or vehicles. This is often the case in military or government situations.

In a captive population it is at least theoretically possible to capture data for the entire life cycle of components and systems, something that is not possible in warranty analysis.

Since it is possible to collect information on all systems in the captive population, it is important to collect a few crucial elements on every system at every opportunity. Reliability analysis is not failure analysis, it is population analysis. It is impossible to calculate even the most basic elements of reliability without time or cycles in service for the portion of the population that didn't fail.

Disperse Population – Subpopulation

A subpopulation is a sample and is similar to a captive population from a data collection perspective. It is theoretically possible to collect data on all life events for the entire population of interest. From an analysis perspective, a sample population must follow all the rules for sample data collection4. The primary analytical challenge is ensuring that the sample is representative of the entire population. The data collection challenges are the same as the captive population scenario.

Data Collection System

In this section we look at some general principles that will facilitate a successful field data collection system. The design of the system is driven by the needs of competing stake-holders. Understanding these sometimes conflicting interests will maximize the value of the data collected.

Reliability Engineer's (RE) Perspective

Reliability calculations are based on probabilities and statistics, which typically require the RE to look back through history at a large population of interest. This can typically involve a large body of data, sometimes thousands or 10's of thousands of individual records. While free text fields may contain all the information the RE needs to parse and categorize an individual record, the time required to parse, format and interpret all of the data is often prohibitive. Free text fields are crucial, but the RE also needs data broken out into standardized, restricted fields that capture key elements of a record. The RE may puzzle over individual records that the data collector could easily have recorded very clearly.

Data Collectors' Perspective

From the data collectors' perspective, data collection is seldom a top priority. If their primary job is maintenance, the top priority is getting the work done as quickly and efficiently as possible, and getting the system turned-around and out the door. In a manufacturing setting lost time can cost hundreds of thousands of dollars and they understandably have very little patience for recording pages of redundant information.

General Principles for a Successful Data Collection System

Following some basic rules and principles will help mediate the various competing interests, maximize the value and accuracy of the data and minimize wasted effort.

Some Basic Rules:

1. Treat data collection as a production process and apply six sigma principles just as in any other production process. Identify sources of variation and error, make the process robust.
2. Respect the effort of the people recording the data. The front line troops in data collection are often the end users or maintainers. Your data is not their top priority. To that end:
   - Don't ask for more than you need.
   - Never collect the same data twice, unless a few key elements are needed for redundancy. The forms you fill out at the Doctor's office are a good illustration of this principle. You are usually asked to fill out your name and contact information multiple times. Your insurance information may also be recorded on more than one page. Several things happen. After a few pages you begin thinking "they already have this, from the previous page." The receptionist may tell you that you only need to fill out certain fields. You may begin leaving things out, filling out only what you believe is really necessary. The end result: it creates opportunities for errors or discrepancies.
   - Prioritize the data elements. If you ask for too much data, the data collector will begin censoring and will leave out information. Ensure it is clear to the person entering data which elements are crucial and which are just "nice to have."
3. Use your information systems to link data and fill in missing elements, don't ask your data collectors to do it. For example, if you ask for a part number and serial number, there is no need to ask for the other characteristics of the part. If they record a VIN (Vehicle Identification Number) correctly, the data system can fill in vehicle characteristics. The VIN is a good candidate for redundancy and error checking. Verify the accuracy of the VIN rather than asking for additional characteristics.
4. Automate the recording of common or known failure modes. Use the information system to fill in pertinent details, require the maintainer to fill in only details specific to that event.
5. Record information at the lowest applicable level, use information systems to roll the failure data up.

For example, if the alternator fails, record a failure for the alternator part (by S/N if possible) rather than recording an alternator failure at the vehicle level. This minimizes parsing time. An information system can roll the data up to the system level, but it often requires human "eyes-on" the data to roll the data down.

Design of the FRACAS/DCACAS System

The traditional function of the Failure Reporting, Analysis and Corrective Action System (FRACAS) is to record failures and track corrective action activity. As noted earlier, recording only failures excludes a large body of crucial data, information about members of the population which have not failed. A more appropriate designation would be a DCACAS, with the broader emphasis of Data Collection etc. than simply Failure Reporting.

The emphasis of the DCACAS should be on recording life events. Every "touch" of a member of the population is recorded as a life event. Current time or cycles for all members of the population must be taken into account in the statistical analysis. Omitting current life of those members that didn't fail results in an overestimation of the failure rate, or underestimation of life.

An effective DCACAS database includes, as a minimum, the following tables:

- *Repairable systems* – these will normally be serialized systems, and the unique instances of the non-repairable components are linked to the repairable system by install and removal dates and or ages.
- *Life events of repairable systems* – A life event could be preventive maintenance, inspection, repair, or operational check. At every life event, the date and age of the system is recorded.
- *Non-repairable components* – This table contains a record for each uniquely identified instance of every component whose life will be characterized. These need not be serialized, as it is possible to track each components' life by recording install and removal cycles on the parent system.
- *Life events of non-repairable components* – Each non-repairable component will have a life begin and life end event. They will also have preventive maintenance, inspection, repair, or operational check events. As with repairable systems, the date and age of the system is recorded at every event.
- *Event Actions* – Each life event could be associated with multiple actions, that is, the event table will have a one-to-many relationship with the actions table.
- *Event components* – Each life event can be associated with multiple subcomponents or parts, that is, it will be in a one-to-many relationship with affected components.
- *Failure categorization* – Each life event for each hardware system or component can have any or all of the following associated failure elements. These do not need to be identified every time, since many events are known; repeats of previous events. New failure modes would include the following information:
  - Known failure. If this is a known failure mode, all other data elements should be filled in automatically by the system, simply by identifying the known failure.
  - Failure mode or symptom
  - Failure mechanism
  - Presumed cause. The root cause for a newly identified item should be determined by a rigorous root cause and corrective action investigation.

The system will also include look-up tables of standard values.

<u>Example: How this data is used in Reliability Analysis</u>

The following example illustrates how this data is collected and used in the analysis of the failure probability distribution of a non-repairable component.

Consider a population of hydraulic presses in a manufacturing facility. Each press is uniquely identified by serial number, and its age is tracked by cycles. When the machine is checked, maintained or repaired, a work order records the details of the action.

If a valve failure causes the machine to break down, the repair record is recorded in the database. This repair action creates a life event record in the life event table. In the component table it updates one record and creates a new one. There is already a record in the table for the valve instance that was removed. That record gets updated with the date and cycles at end of life. A new record is created for the new instance of the valve, its date of installation and cycles of install is noted in the new record.

When the Reliability Engineer analyzes the life distribution for that part number valve, he gathers the following subpopulations:

- All valves that have never failed. The current cycles for every press that has this valve installed is used as the current age of those valves. These are suspensions.
- All valves that have failed. The cycles at install and cycles at failure are used to determine the age at failure.
- All valves that have been removed prior to failure, such as proactive replacements during an overhaul. These are also suspensions.
- All valves that have been installed as replacements since the last failure. The current machine cycles are used to determine the age of currently installed valves. These are also suspensions.

All of these subpopulations are then collected and used as data points in the statistical analysis.

The failure categorization elements, identification data and other information from the database can be used to divide the data into sub-populations for comparison. If enough data is available, it might be possible to compare the life data from one manufacturing plant with another, to see if there are statistically significant differences in their failure distributions. This type of analysis can be used in root cause investigations.

Another element of the DCACAS system is the failure categorization. We address that next.

Failure Categorization

Failure categorization is a perpetual challenge, and most categorization schemes share some common shortcomings.

Common Shortcomings

Every record of a life event is precipitated by a trigger. A trigger may be a failure, scheduled maintenance, or required maintenance.

If the event trigger is a failure there will be a top level failure and failure characterization. A typical failure report form includes at least one field for the failure. Sometimes the field is a free text field, sometimes it is standardized. The following are common errors on failure report forms:

1. They may conflate different types of information,
2. Standard values are not mutually exclusive and independent,
3. They require all information from a single event to be distilled into a single characterization at the event level.

Conflation

Consider a case where a fleet vehicle comes into the shop with the complaint that the Air Conditioner is blowing warm air. The mechanic finds that the compressor is failing, so they replace the compressor and the belt. How should this event be categorized? The FRACAS system includes standardized codes the maintainer can choose from, such as:

- A/C Compressor
- Replaced A/C Compressor
- Belt
- Blowing warm air
- Re-charged A/C

Any or all of these could apply in this situation. These codes include a mixture of components, actions, symptoms or failure modes and failure mechanisms.

A failure categorization scheme may rely on a FGC5 (Functional Group Code) or something similar as the description or categorization of the failure. While an FGC identifies the hardware involved, it does not identify the reason for replacement. A FGC may include symptoms, functions and hardware in the same category list.

Categories are Not Mutually Exclusive and Independent

When standardized failure modes are used, it is not uncommon to see categories overlap. For example, consider a case where a temperature sensor is giving a faulty reading. After troubleshooting, the mechanic replaces the temperature sensor.

In the A/C compressor example above, the symptom could be described in different ways. It could be described as "blowing warm air," or as "A/C doesn't work." If both symptoms are included in a standard symptom list the maintainer, when recording the failure, must choose one or the other.

When analyzing this data, the RE or analyst must consider every possible way a particular problem could have been recorded, then parse the data looking for each one.

Data Prioritization

It was mentioned earlier that the required data should be prioritized to ensure that the front line data collector knows which the most crucial elements are. This can be done in the design of the data collection form. The form can take the form of a failure tag, a computerized work order, a survey sheet, or a number of other tools.

The design of the data collection forms will vary depending on the scenario in which it is used. The case of warranty sales and returns was treated earlier. The following apply to some of the other scenarios.

In a plant engineering scenario, the population hours or cycles are or can be collected almost continuously. Cycles on individual components could theoretically be tracked continually, but it is not always done. As mentioned earlier, population life is required for life analysis.

In a logistics or long term population sustainment scenario, with a captive population, this would happen each time a system is checked. It could happen daily for members of fleet vehicles. Again, the piece of information that is usually most difficult to obtain is population life or cycles.

Whether it is a failure tag, work order, daily check sheet or any other record, the following are the most crucial elements that should be collected at the event level:

1. **Date**
2. **Identification** – This should be an accurate unique S/N of the system, or, if a non-repairable, non-serialized component, of the parent system.
3. **Life or Cycles** – This would be of the system itself, or of the parent system.
4. **Trigger** – Why did this "touch" take place. This is important to distinguish between latent failures discovered during routine maintenance, and failures that cause the system to go down.
5. **Failure Y/N** – Again, this distinguishes system failures from routine maintenance, for the purpose of segregating latent failures from system critical failures. This is also a departure point for all other data collected on the form or WO. It is also surprising how often this simple flag is omitted. The end user or maintainer is in the best position to determine whether a system or component has failed, but this distinction is often left to the analyst. The definition of a failure is sometimes complicated, spelled out in great detail in a Failure Definition and Scoring

Criteria (FDSC). But in simple terms, if the system or component stops performing as required or expected, it can be considered failed for the purposes of the front line data collector. The analyst can change that determination later if required, but it saves a lot of time and effort if a determination is made up-front.

Even if no other data is collected, those five elements would enable calculation of some of the commonly used measures of merit. If those elements are missing or if the data is not usable, even the most basic measures of merit cannot be calculated. Yet, it is surprising how often that data is unavailable or how often data systems omit one of them.

The next data elements will depend on whether or not the event trigger is a failure. If yes, the next most important event level question is probably:

6. **Failure categorization**

The program may want to permit the assignment of more than one category. This will be further segregated into failure mode, mechanism, etc. as described above.

Below the event level, the data collected can be broadly broken down into actions and components. Each component will then trigger its own set of similar data. Since each system level event can also represent a life event for the components, the same questions should be answered for them as well. If a valve is removed, the valve event record should require

1. (date comes from top level event)
2. Identification
3. (life or cycles comes from the system level event)
4. Trigger may or may not be different
5. Failure Y/N for this component.
6. Etc.

Note: For the data collection rules mentioned in "General Principles," fields are automated wherever possible to minimize entering unnecessary or duplicate data.

Conclusion

While this has certainly not been exhaustive, an attempt has been made to share some lessons learned about how to make field population data collection and analysis more effective. An attempt has been made to illustrate the need for a robust program of data collection directly from end users, for the entire product life cycle. The general requirements of a field data collection system have been described, and some of the scenarios in which they are used. Elements of a well designed FRACAS/DCACAS have been presented. We looked at some of the common problems to be avoided in categorizing failures. Finally, a priority approach was suggested for the fields to be included on a data collection form. Following these guidelines could help make any Reliability Engineering program more successful.

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