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RELIABILITY, MAINTAINABILITY & SUPPORTABILITY *in* SYSTEMS ENGINEERING

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RMS Reliability, Maintainability and Supportability PARTNERSHIP

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INTRODUCTION

James Rodenkirch

I continue to focus on collecting Journal articles that embrace or touch tangentially the management, improvement(s) and/or sustainment of reliability, maintainability and supportability processes and/or products, throughout "the Enterprise." Enterprise entity descriptors include: public and private sector organizations, any business or corporation and collaborating public and/or private organizations in multiple countries as well as any complex, socio-technical system(s), e.g., people, information, processes and technologies. We can roll all of that up into this descriptor for the Enterprise—a broad brushstroke of entities that affect our daily lives, at work and at home.

"Leveraging off" an article in the National Defense Industry Association's October magazine by Sandra Erwin, "Golden Age of Federal Contracting is Over," one finds powerful cause and effect linkages to how public efforts and politics, e.g., Government and DoD, can influence the way we treat and/or focus our attention on reliability, at work or home. Ms. Erwin points out, "the political paralysis in Washington has resulted in gridlock" and a "resulting policy vacuum, not just in defense but also in energy, immigration and other key areas. This in turn has upended deeply held assumptions of the government-industrial complex." During an interview with Michael A. Daniels, long-time entrepreneur and chairman of LMI, Ms. Erwin uncovered this "predictor," by Mr. Daniels, "if the political morass is here to stay, it will be up to the private sector to take control of its destiny by becoming more entrepreneurial and innovative," and that's what caught my eye, from a "reliability-focused view across the Enterprise." Note: The remainder of the article provides cogent, germane examples of why our country is where it is, or isn't, in terms of the "policy vacuum" and the efficacy of the government-industrial complex and can be perused here:

http://www.nationaldefensemagazine.org/archive/2014/October/Pages/GoldenAgeofFederalContractingIsOver.aspx

While ruminating over the state of the Enterprise and its myriad influencers via some pointed "Internet googling" I stumbled across an article in the Midwest Energy News that focused on what midwestern Colleges and Universities are undertaking to ensure reliable electric power. In that article, Peter Strazdas, associate vice president of facilities management at Western Michigan University, stated, "Higher education facilities…really need to have reliable power (in order to maintain operations at laboratories, hospitals, etc.) and, unfortunately, the United States' electrical grid is less reliable now than it was in the past." The electric grid unreliable? Now, that will have an impact on reliability across the Enterprise! Further "noodling" and "googling" turned up a plethora of articles and papers on the causes and influencers of the grid's decreased reliability.

As an example, regulatory/political influencers gleaned from a report by The Energy Collective, a think tank on energy and the climate, include:

- The EPA plans to address carbon emissions by phasing out the usage of coal, replacing it with natural gas, renewables, nuclear power, and increasing efficiencies in power generation and usage. They may also implement carbon capture and sequestration (CCS) technologies. The risk with this somewhat arbitrary "shutdown of most conventional Coal Power" approach is the EPA is potentially putting future U.S. Power Grids at risk and elevating the cost(s) of doing business dramatically. For example, there will be an enormous cost to change to natural gas or alternative energy sources, current and proposed regulations can be ambiguous and at odds with each other and risky assumptions are being made that wind/solar energy generation will mature sufficiently enough to replace existing shuttered coal-fired plants. Equally importantly, any rapid changeover from one fuel source to another requires enormous amounts of time. In any of the perceived scenarios, the time required to accomplish these sorts of dramatic fuel source changes means less capacity or reserve margins; reserve margins are mandated by the various Public Service Commissions in case of power plant failure(s) or damage from severe weather.
- With the average rail tank car holding around 700 barrels of crude oil, about 759,000 barrels of crude oil per day were moved by rail during the first seven months of 2014, equal to 8% of U.S. oil production," according to the U.S. Energy Information Administration (EIA). Recent deadly accidents involving crude oil tank cars as well as the sheer increased volume of crude oil traveling through communities has prompted calls for tighter crude-by-rail regulation. However, some power generating and fuel transportation businesses are pushing back against increased safety standards. Examples on the non-policy side of electric grid "influencers" include:

- Amortization and depreciation rates have exceeded utility construction expenditures; i.e., for the past 15 years, utilities have harvested more than they have planted and the result is an increasingly stressed power grid.
- R&D spending for the electric power sector dropped 74 percent, from a high in 1993 of US $741 million to $193 million in 2000. R&D represented a meager 0.3 percent of revenue in the six-year period from 1995 to 2000, before declining even further to 0.17 percent from 2001 to 2006. (Note: to be fair, R&D spending may have improved since 2000….but, has any improvement in R&D expenditures over the past ten years "caught up" with the earlier years of declining R&D expenditures? One sorta doubts that.

So, Mr. Strazdas' assessment of the U.S. power grid—less reliable now than it was in the past—is easily validated, in terms of a mishmash of governmental regulatory policies, reduced R&D efforts and, quite simply, an aging power grid…much like our country's bridges and water supply systems.

The Midwest Energy News article goes on to describe the efforts of several Universities to develop their own micro-grids; i.e., if the U.S. power grid fails, they become power generating islands. Western Michigan University in Kalamazoo converted an aging coal-fired steam plant in the 1990s to a co-generating natural gas facility that produces both heat and electricity. It has continued to make investments since then in controls that improve its ability to manage both generation and consumption of energy on campus and paid off in better reliability, Strazdas said. As an example, when snow storms knocked out power for days to much of the city this past winter, Western Michigan's 150-building campus was "like this one light in the middle of our city," he said. Western Michigan is a little ahead of the pack in the Midwest, though several other schools have built or announced microgrid projects in the region, including the Illinois Institute of Technology, the Missouri University of Science and Technology, and the University of Wisconsin-Milwaukee. Note: A poster child for all of this is the U.S. Food and Drug Administration's White Oak campus in Silver Springs, Maryland, which kept power on during Hurricane Sandy by switching its Honeywell-built microgrid to "island mode."

"Microgrids are a good potential fit for colleges and universities for a couple of reasons," according to Michael Burr, director of the Microgrid Institute, a Minnesota-based think tank. "One, they're a defined space with a single utility customer, which simplifies the contractual issues. [that certainly works to reduce the impact of delayed, ambiguous or "one size fits all" government contractual policies – Ed.] Secondly, many schools already own on-site generation, which is by far the most expensive component of a microgrid system."

It's rewarding to see private sector entities, having been impacted negatively by government policy and non-policy influencers that have degraded and created an unreliable power grid infrastructure, doing something about it. They have become reliable power generating islands when the current Enterprise electric grid infrastructure fails. Increased reliability of one's power source, thanks to one's own power grid, with zero impact from negative power grid influencers. What's not to like about that?

The articles selected for this Winter Journal certainly cross many RMS boundaries throughout the Enterprise. Our first offering, "Life-Cycle Costing: An Effective Tool for Total Asset Management," was submitted by Dr. Ben Blanchard. I had contacted Ben last fall regarding an article for our Journal with an Enterprise focus and his offering—shifting from short-term to long-term life-cycle thinking when it comes to system design—will resonate with us all. Given reduced resource across the Enterprise these days, Ben's emphasis on life-cycle costing methods is timely.

The second article, "Application of Lean Principles in "White Collar" Areas of Product Development," was written by Dr. Nancy Moulton while earning her PhD. Dr. Moulton walks us through the process and methodology undertaken to craft a 2006 paper, "State-of-the-Art in Lean Design Engineering: A Literature Review on White-Collar Lean" Given the always present reminder(s) on limited resources, any focus on introducing or improving/leaning current processes is a good thing and I appreciate Ms. Moulton providing this article for re-publication.

Our third offering, "Overview of Design for Reliability and the New Era of Reliability 3.0," was submitted by Athanasios Gerokostopoulos. Mr. Gerokostopoulos takes us through a short history of reliability engineering, provides an overview of the Design for Reliabilty (DFR) process and focuses in on the latest version of DFR, what he likes to call version 3.0. Mr. Gerokostopoulos has been challenged with a demanding workload and completing this article in time for the Winter Journal was a struggle. I appreciate his efforts and hope he'll consider contributing more articles in the future.

Our fourth paper, "Developing Reliability Requirements for Potable Water Solutions in Politically Discontinuous Areas: Part 2 of 3 Watercourse Stewardship," by Katherine Pratt, is the second of a three part series on the problems associated with delivering reliable, safe water throughout third world countries in the Middle East. Kate has done her homework and the results of her research lead to a voluminous article she sent to me, initially, last year. That paper would have filled three—no, make that seven—Journals so she and I have worked long and hard at cutting it all down to three sections. Why was the initial paper so large? Well, the problem being addressed is complicated and complex. Competing cultures, varying degrees of technological prowess amongst the many countries involved and harsh, varying climates are prime influencers. Toss in some legal wrangling over dams and water rights and you have a recipe for, in my words, "a real mess to be sorted out." I kept enjoining Kate to reduce the length of this section and, fortunately, she kept resisting. Most notably, my wife, at one point said, "why are you trying to cut the article back? If it's interesting, leave it be." Well, it all *is* interesting and informative. Kate interleaves an RMS and system(s) foci that keeps me true regarding an editorial comment I made early on—I promised to ferret out articles that deliver RMS treatments and views across the Enterprise. This series by Kate and the contributions of the other authors helps me meet that goal.

There you have it. Four articles that span a bit of the breadth of RMS considerations across the Enterprise and three new contributing authors. We appreciate their efforts, hope they consider submitting articles for future Journals and look forward to the membership enjoying their offerings. Good reading to all and best wishes to you and your families during this holiday season.

LIFE-CYCLE COSTING: AN EFFECTIVE TOOL FOR TOTAL ASSET MANAGEMENT

Benjamin S. Blanchard

Abstract

Our decision-making processes through the years have been based primarily on the "short-term," and the design, development, and production (or construction) of new systems have considered the initial procurement and acquisition costs only. The consequences of this approach have been rather costly, since experience has indicated that many of the engineering and management decisions made in the early phases of the system life cycle have had a great impact on the sustaining operation and maintenance support of that system later on. Further, these "downstream" activities often constitute a large percentage of the total cost of a system. Thus, it is essential that we extend our planning horizon and decision-making to address system requirements from a total life-cycle perspective. The purpose here is to identify the need for and applications of life-cycle costing, describe the life-cycle cost analysis process, and to discuss some of the benefits from its application.

The Need for Life-Cycle Costing

Do you know the actual true cost of your system? Can you identify the cost of each functional element or activity? Are you aware of the high-cost contributors? Can you identify the causes for these high-cost areas? Can you truly assess the risks associated with the development, production, operation, support, and retirement of your system and its components? The answer to these and many questions of a related nature is a definite, "NO!"

A system in this instance constitutes a complex combination of resources in the form of materials, equipment, software, facilities, humans, computer resources, data and information, integrated in such a manner in order to accomplish some designated function in response to an identified need. There are many categories of systems to include electrical and electronic systems, transportation systems, communication systems, production or manufacturing systems, information processing systems, and the like. Included within the structure of these "systems" are not only those elements that are directly involved in the accomplishment of a given mission scenario, but the maintenance and support infrastructure that is necessary to ensure that the system will be able to successfully meet its objectives. If one is to manage all assets in an effective and efficient manner, then it is necessary to view these assets in the context of a system and in terms of its life cycle. [1]

Experience in recent years has indicated that the complexity and the costs of systems, in general, have been increasing! A combination of introducing new technologies in response to a constantly changing set of performance requirements, the increased external social and political pressures associated with environmental issues, the requirements to reduce the time that it takes to design and produce a new system, and the requirement to extend the life cycle of systems already in operation constitutes a major challenge! Further, many of the systems currently in use today are not adequately responding to the needs of the consumer, nor are they cost-effective in terms of their operation and support. This is occurring at a time when available resources are dwindling and international competition is increasing worldwide.

In addressing the issue of cost-effectiveness, one often finds that there is a lack of total cost visibility, as illustrated by the "iceberg" effect in Figure 1. For many systems, the costs associated with design,

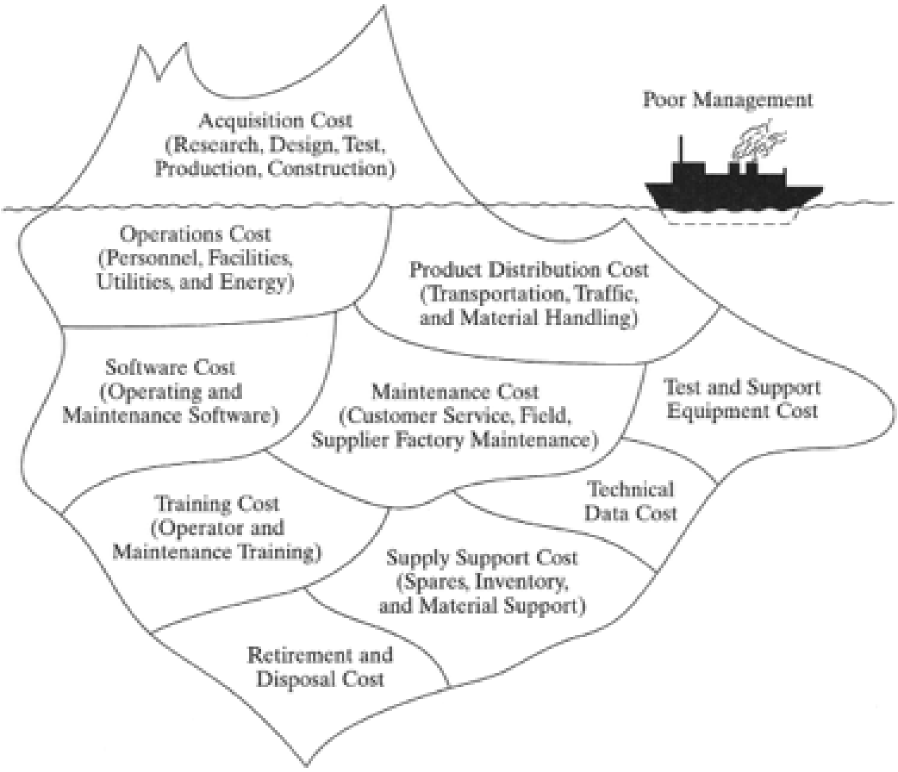


FIGURE 1 — TOTAL COST VISIBILITY

production, the initial procurement of capital items, etc., are relatively well known. We deal with, and make decisions based on, these costs on a regular basis. However, the costs associated with utilization and the maintenance and support of the system throughout its planned life cycle are somewhat hidden. In essence, we have been successful in addressing the short-term aspects of cost, but have not been very responsive to the long-term effects.

At the same time, experience has indicated that a large percentage of the total life-cycle cost for a given system is attributed to operating and maintenance activities (e.g., up to 70%–75% for some systems). When looking at "cause-and-effect" relationships, one often finds that a significant portion of this cost stems from the consequences of decisions made during the early phases of advance planning and conceptual design. Decisions pertaining to the design of a process, the selection of a technology, the selection of materials, the selection of an item of capital equipment, equipment packaging schemes, decisions pertaining to the use of humans versus the incorporation of automation, etc., have a great impact on the "downstream" costs and, thus, life-cycle cost. Additionally, the ultimate maintenance and support infrastructure selected for a system throughout its period of utilization can significantly impact the overall cost-effectiveness of that system. There are many interactions that can occur when dealing with systems and their respective elements. As illustrated in Figure 2, it is at the early stages in a program where the greatest gains can be realized in terms of the ultimate life-cycle cost of a given system.

Given these relationships in today's environment where available resources are dwindling and international competition is increasing, there is a need to re-evaluate our methods used not only in the design, development, and production of new systems but in the sustaining operation and maintenance of existing systems that are currently in use. Addressing system requirements from a total life-cycle perspective is essential, and the application of life-cycle cost analysis methods can be highly beneficial in facilitating this objective.

Application of Life-Cycle Costing Methods

The application of life-cycle costing methods can be effectively implemented in:

1. The design, development, and production (or construction) of a new system. Every time that there is a newly identified need, there is a new system requirement. Further, there are a series of top-down steps required in evolving from the identified need to the delivery of the ultimate system for operational use (i.e., definition of system requirements, functional analysis and requirements allocation, trade-off studies and design optimization, synthesis, and test and evaluation). The objective is to establish, from a top-down perspective, a quantitative "design-to-life-cycle-cost" requirement, and then design, build, and operate to meet this requirement. This must be accomplished from the beginning as illustrated in Figure 2.
2. The evaluation of an existing system capability, with the objective of implementing a "continuous-product/process-improvement" approach to increase the effectiveness while reducing the life-cycle cost of that system. This involves the initial determination of some quantitative goal(s) based on a defined need (i.e., the establishment of some "metric" for benchmarking purposes), describing the system and its processes in functional terms, collecting the appropriate data and identifying the resources being consumed in accomplishing the various functions, identifying the high-cost contributors and determining the cause-and-effect relationships, and initiating the necessary recommendation(s) for improvement of the system and its operation. This is an on-going iterative process.

The process recommended for both applications is illustrated in Figure 3. One would commence with the establishment of some initially-specified system requirement and then proceed through the steps shown, "tailored" to the requirements of the specific system evaluation effort.

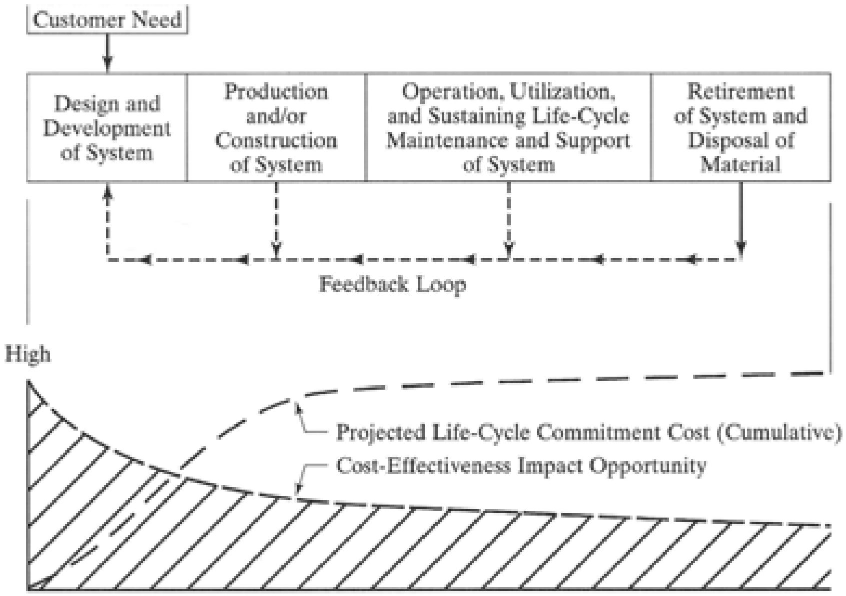


FIGURE 2 – OPPORTUNITY FOR IMPACTING TOTAL SYSTEM LIFE-CYCLE COST

The Life-Cycle Cost Analysis Process

The application of life-cycle cost analysis methods (see Figure 3) and the steps in accomplishing such an effort are identified in Figure 4. System requirements are initially defined, the system is described in functional terms, activities are identified by function for each phase of the life cycle, costs are estimated, high-cost contributors are noted, "cause-and-effect" relationships are determined, the applicable "causes" are analyzed, and recommendations for modification are presented for the purposes of system improvement. A continuing and iterative application of this process should not only improve the overall cost-effectiveness of the system but should result in lower overall operating and maintenance costs and, hence, costs to the user (consumer).

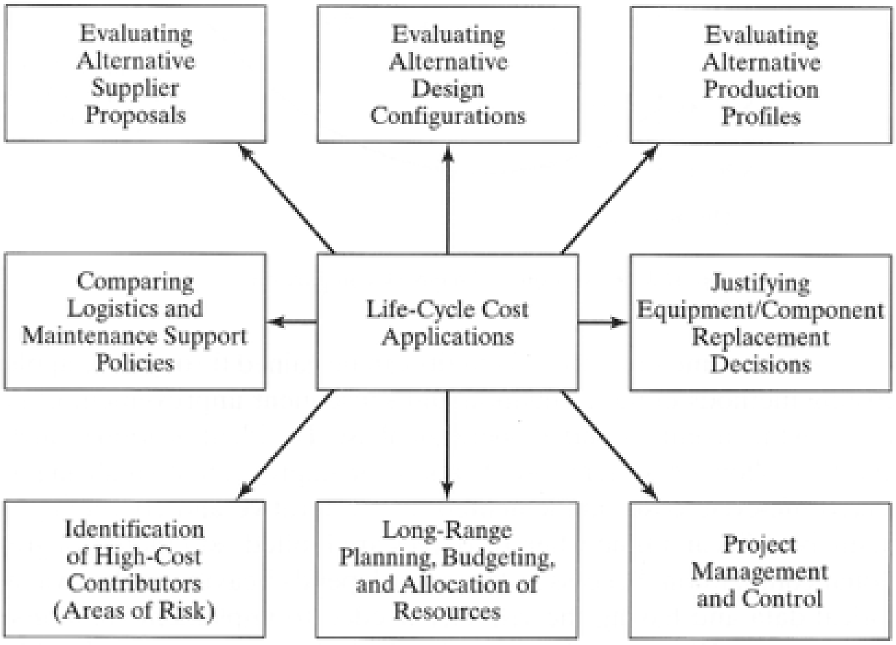


FIGURE 3 – LIFE-CYCLE COST APPLICATIONS

The Basic Steps in a Life-Cycle Cost Analysis

1. **Define System Requirements.**
   Define system operational requirements and the maintenance concept, identify the applicable technical performance measures (TPMs), and describe the system in functional terms (functional analysis at the system level).
2. **Describe the system lifecycle and identify the activities in each phase.**
   Establish a baseline for the development of a cost breakdown structure (CBS) and for the estimation of cost for each year of the projected lifecycle.
3. **Develop a CBS.**
   Provide a top-down/bottom-up structure, to include all categories of costs, for the purposes of the initial allocation of costs(top-down) and the subsequent collection and summarization of costs (bottom-up). All life-cycle activities must be covered within.
4. **Identify data input requirements.**
   Identify the input data requirements and their possible sources. The type in the amount of data will, of course, depend on the nature of the problem being addressed, the phase of the system life cycle, and on depth of analysis.
5. **Establish the costs for each category in the CBS.**
   Developed the appropriate cost-estimating relationships (CERs) an estimate the annual costs for each category in the CBS (using activity-based costing methods).
6. **Select a cost model for the purposes of analysis and evaluation.**
   Select (or develop) a computer-based model to facilitate the life-cycle cost analysis (LCCA) process. The model must, of course, be sensitive to the specific system being evaluated.
7. **Develop cost profiling summary.**
   Constructed cost profile (i.e., cost stream) showing the flow of costs over the entire life cycle, and the percent contribution in terms of the total.
8. **Identify high-cost contributors and establish cause-and-affect relationships.**
   Highlight those functions, elements of the system, or segments of a process that should be investigated for possible areas of design improvement.
9. **Conduct a sensitivity analysis.**
   Evaluate the model, input-output data relationships, and the results of the baseline analysis to ensure that (1) the overall LCC analysis approach is valid and (2) the model itself is well constructed and sensitive to the problem at hand. The sensitivity analysis can that's aid in identifying major areas of risk (as part of a risk analysis).
10. **Construct a Pareto diagram and identify priorities for problem resolution.**
    Conducted Pareto analysis, construct the Pareto diagram, and identify priorities for problem resolution (i.e., those problems that require the most management attention).
11. **Identify feasible alternatives for design evaluation.**
    Having developed an approach for the LCC evaluation given single design configuration, it is now appropriate to extend the LCC analysis through the evaluation of multiple design alternatives.

12. **Evaluate feasible alternatives and selecting the preferred approach.** Develop cost profile for each of the alternatives being evaluated, compare the alternatives considering the time-value of money, construct a break-even analysis, and selective preferred design approach.

Referring to Step 3 above, a key factor in conducting a life-cycle cost analysis is the initial development of the cost breakdown structure (CBS). The CBS constitutes a functional breakout of costs, covering all activities in the system life cycle and down to the depth required to provide the desired visibility relative to the true costs of the various processes and/or elements of the system. Figure 4 shows an example of a CBS. Costs may be initially allocated by "function" (for an early top-down "design-to-cost" requirement) and later determined for the various resources (materials, people, facilities, etc.) consumed in the accomplishment of the required functions (a bottom-up cost collection and integration approach). The CBS must be "tailored" to the specific system application. For example, it might be desirable to gain greater visibility of the life-cycle costs associated with system "support." Referring to the figure, it may be appropriate to break this item down into the various levels of support, the elements of spares and associated inventories, and the activities associated with the procurement and acquisition of spare parts. The CBS may be extended downward to provide visibility at each level of maintenance.

In accomplishing an analysis of this type, the estimation of costs often represents the most challenging task (see Step 5, above). The lack of good historical data upon which to base accurate cost estimates is a common problem, particularly with regard to those activities pertaining to the operation and maintenance of the system throughout its life cycle. While the more traditional short-term-oriented accounting data have been utilized as a source in many instances, a data collection capability enabling a long-

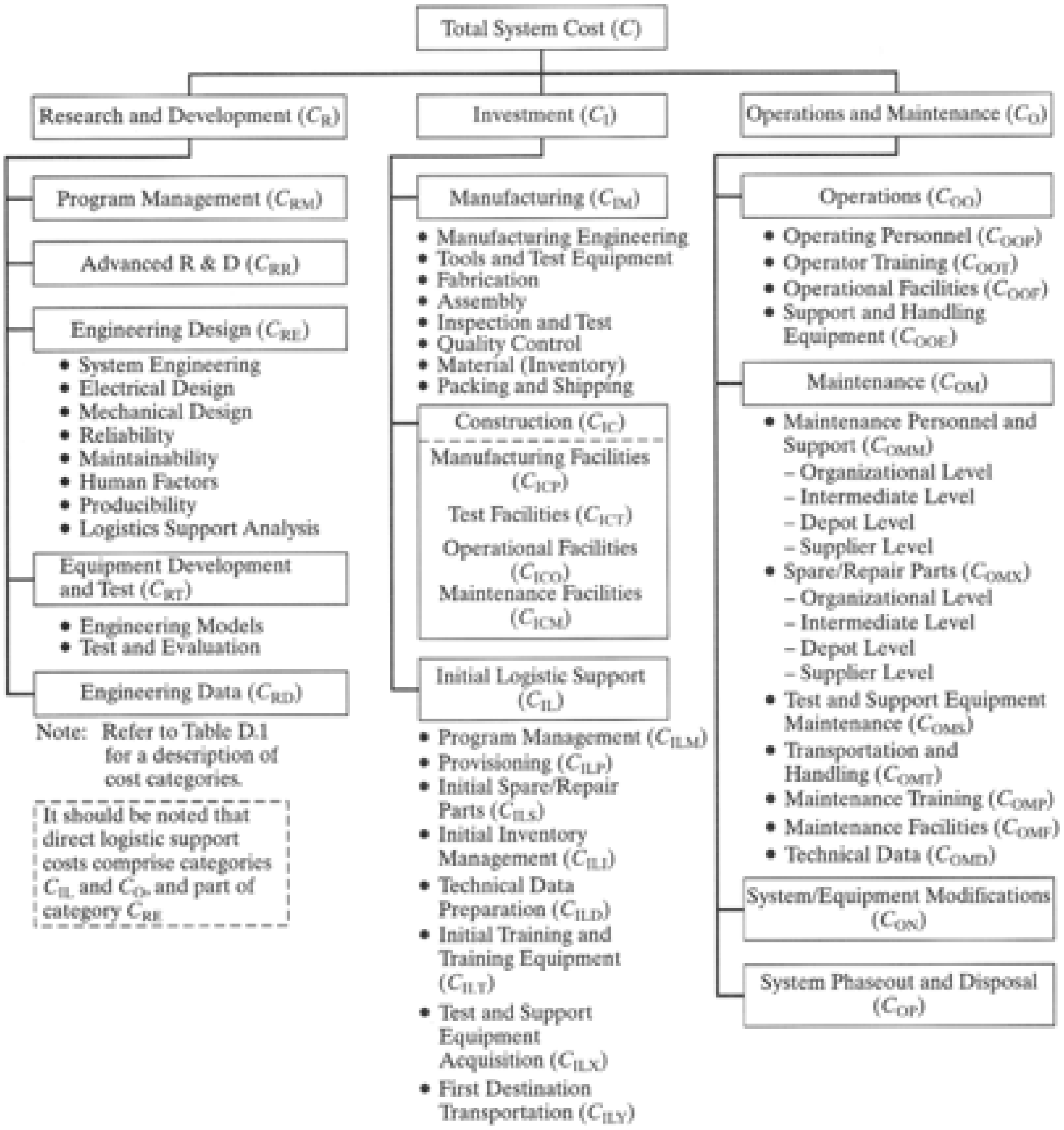
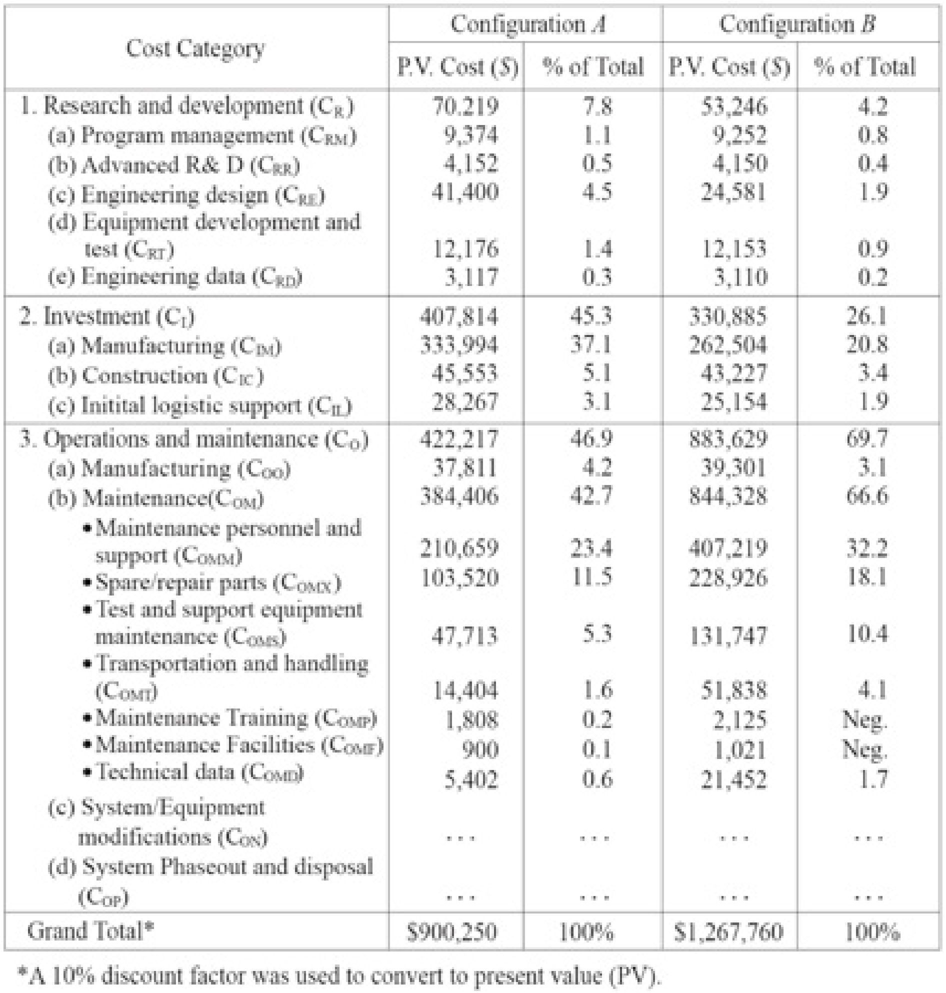


FIGURE 4 – EXAMPLE OF A CBS

term functionally-oriented cost evaluation is often not in place. Cost estimates are made based on a combination of using standard factors from the past, analogous approaches based on similarities, and/or parametric cost estimating methods. However, the establishment of a good comprehensive data collection, analysis, and reporting capability is necessary for greater visibility. Applying the principles and concepts of activity-based costing (ABC) is essential, as the application of such helps in the "tracing" of costs back to the various "causes" and the responsible functional elements of the system. Full-cost "traceability" is essential if one is to properly assess the risks associated with the day-to-day design and management decision-making.



Cost Category	Configuration *A*		Configuration *B*	
	P.V. Cost ($)	% of Total	P.V. Cost ($)	% of Total
1. Research and development (C_{R})	70.219	7.8	53,246	4.2
(a) Program management (C_{RM})	9,374	1.1	9,252	0.8
(b) Advanced R& D (C_{RR})	4,152	0.5	4,150	0.4
(c) Engineering design (C_{RE})	41,400	4.5	24,581	1.9
(d) Equipment development and test (C_{RT})	12,176	1.4	12,153	0.9
(e) Engineering data (C_{RD})	3,117	0.3	3,110	0.2
2. Investment (C_{I})	407,814	45.3	330,885	26.1
(a) Manufacturing (C_{IM})	333,994	37.1	262,504	20.8
(b) Construction (C_{IC})	45,553	5.1	43,227	3.4
(c) Initital logistic support (C_{IL})	28,267	3.1	25,154	1.9
3. Operations and maintenance (C_{O})	422,217	46.9	883,629	69.7
(a) Manufacturing (C_{OO})	37,811	4.2	39,301	3.1
(b) Maintenance(C_{OM})	384,406	42.7	844,328	66.6
• Maintenance personnel and support (C_{OMM})	210,659	23.4	407,219	32.2
• Spare/repair parts (C_{OMX})	103,520	11.5	228,926	18.1
• Test and support equipment maintenance (C_{OMS})	47,713	5.3	131,747	10.4
• Transportation and handling (C_{OMT})	14,404	1.6	51,838	4.1
• Maintenance Training (C_{OMP})	1,808	0.2	2,125	Neg.
• Maintenance Facilities (C_{OMF})	900	0.1	1,021	Neg.
• Technical data (C_{OMD})	5,402	0.6	21,452	1.7
(c) System/Equipment modifications (C_{ON})	. . .	. . .	. . .	. . .
(d) System Phaseout and disposal (C_{OP})	. . .	. . .	. . .	. . .
Grand Total*	$900,250	100%	$1,267,760	100%

*A 10% discount factor was used to convert to present value (PV).

FIGURE 5 – LIFE-CYCLE COST ANALYSIS SUMMARY

Figure 5 presents a summary of the estimated life-cycle costs for each of two alternatives, including the identification of high-cost contributors (in terms of percent contribution of the total). The cost figures, derived from the cost profiles for each of the alternatives, are presented in terms of present value (considering the time value of money) for comparative purposes. Review of the results indicates that Configuration "A" may be preferable (as compared to Configuration "B"). However, prior to making a final decision, a break-even analysis needs to be accomplished to establish the point in time when "A" assumes a position of preference (refer to Step 12). Given that "A" is the preferred choice, the next step is to identify the high-cost contributors; i.e., maintenance personnel which represents 23.4% and spares/repair parts which represents 11.5% of the total under Item 3b. The question is—what are the "causes" leading to these high costs? The problem may point to an unreliable item of equipment, a high-cost periodic maintenance procedure, a faulty software module, or the requirement for multiple quantities of costly high-skilled personnel to accomplish specific inspection and test functions. Through this type of analysis, the high-cost "drivers" may be traced back to a specific function or to a particular component of the system.

Using a combination of such tools/techniques as the failure mode, effects, and criticality analysis (FMECA), an operator and/or maintenance task analysis (MTA), reliability and maintainability predictions, a reliability-centered maintenance analysis (RCM), a level of repair analysis (LORA), a Pareto analysis, or equivalent, "tailored" to the problem being addressed, can assist in assessing the various cause-and-effect relationships and in the prioritization of those areas where modifications for improvement can be incorporated. The objective is to enhance overall system effectiveness while at the same time, reducing life-cycle cost. Figure 7 illustrates the process and the interrelationships (in terms of input-output factors) of a few of the many tools that can be applied in this area. It should be noted that the specific sequence of activities will vary depend on the problem at hand. [2]

The Benefits of Life-Cycle Costing

The application of life-cycle cost analysis techniques offers numerous benefits. More specifically, the approach:

1. Forces long-range planning versus the more traditional short-term thinking applied in the current on-going decision-making processes. As a result, decisions can be based on more complete information with less risk involved.
2. Forces total cost visibility and the identification of high-cost system

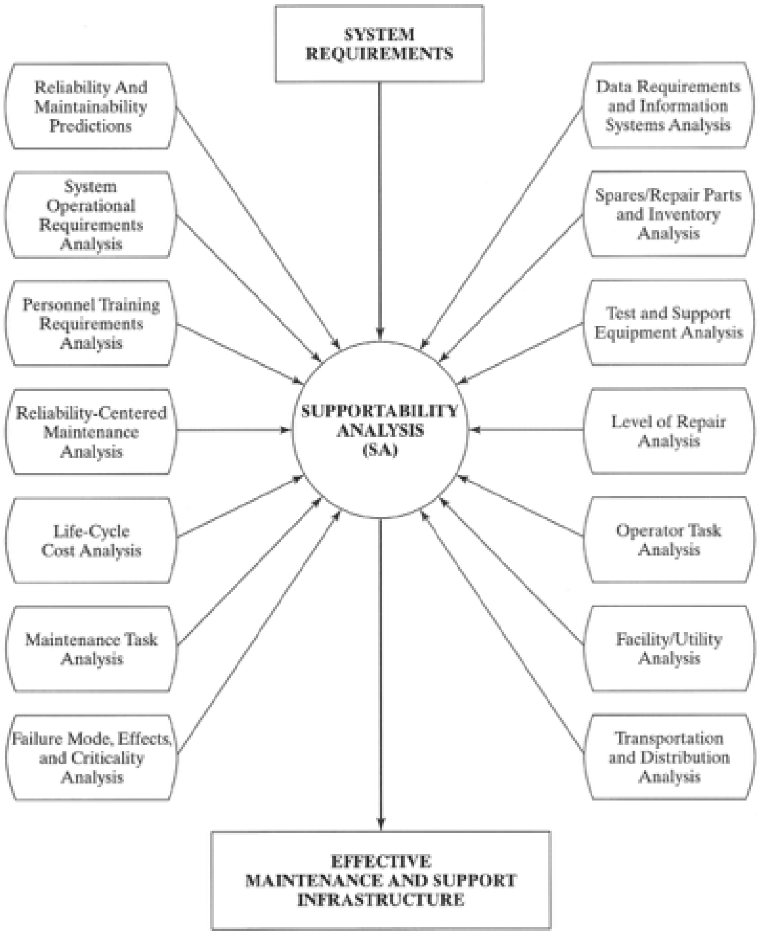


FIGURE 6 – SUPPLEMENTAL ANALYSIS MODELS (TOOLS)

elements, equipment, processes, and so on. This helps to "pinpoint" the specific functional areas where resource consumption is high and where there are opportunities to incorporate modifications for improvement.

3. Enables a better understanding of the interrelationships between different system components and the elements of cost. The applicable interaction effects become more visible through a life-cycle cost sensitivity analysis.
4. Aids in the early identification of high-cost areas, the quantification and magnitude of such and, hence, the high-areas of risk. Even if a decision is based on some smaller aspect of cost (e.g., the initial procurement price), the consequences of such should be viewed in terms of possible life-cycle implications.
5. Allows for better overall resource management because of the long-term visibility. Resource planning and budgeting can be accomplished for all activities within the system life cycle as desired.

Summary

While the benefits are numerous, there are also some major impediments. Our current thought processes, accounting practices, organizational objectives, and politically-driven activities are more oriented to the "short term!" To successfully implement the principles and concepts discussed herein requires a change in thinking and in our current ways of doing business; i.e., a "cultural" change is required. On the other hand, if our current objective is to remain competitive in today's international and resourced-constrained environment, we need to start thinking and acting with the "long-term" in mind. With this as an objective, the application of life-cycle cost methods can produce highly beneficial results and following the approach described herein is highly recommended.

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2. Blanchard, B.S. (2004). Logistics Engineering and Management. 6th Ed. Upper Saddle River, NJ: Prentice-Hall. All of the figures in this paper were taken from this text.

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).

Professor Blanchard's academic background includes a BS degree in Civil Engineering, graduate course work in Electrical Engineering, and a MBA degree (through an Executive Development Program at the University of Rochester). He has authored four textbooks, and has co-authored four additional texts. He has published numerous monographs and journal articles and has lectured extensively throughout Africa, Asia, Australia, Europe, and North America. Professor Blanchard is a Charter member, Fellow, CPL, member of the Board of Advisors (BOA), and past-president of the International Society of Logistics (SOLE); a Fellow of the International Council on Systems Engineering (INCOSE); and a member of some other professional organizations (ASEE, IIE, AFA, NDIA, and CLEP).

APPLICATION OF LEAN PRINCIPLES IN "WHITE COLLAR" AREAS OF PRODUCT DEVELOPMENT

Nancy A. Moulton, Ph.D.

Introduction

The article titled "State-of-the-art in lean design engineering: a literature review on white collar lean" (Baines, Lightfoot, Williams, & Greenough, 2006) explained that the concept of lean is normally applied to manufacturing operations and therefore little information is available pertaining to the application of lean to management processes. The authors of this grounded theory study investigated the application of lean principles to 'white collar' disciplines, in particular, product development (PD) processes. Themes emerged from the literature which confirmed that lean can be applied successfully outside the manufacturing area. Findings indicated that the definition of lean is one of the keys to success. The definition has changed over the last decade. Toyota's lean manufacturing methodology, based on the Shingo criteria, is the favored approach to lean that has emerged from the literature. In addition, organizations which implement lean in product development are advised to employ a strong leader with control over the total project and change organization-wide systems, processes and culture to support lean. The article concluded with recommendations to test the findings in future work.

Description of Methodology

Baines et al. used a qualitative grounded theory research methodology, descriptive analysis and explanatory results to provide information pertaining to the use of lean techniques in a white collar environment. The author's research methodology included clear criteria for published articles that address product development, i.e., engineering, quality, construction. All others were excluded including other 'white collar' work. Research questions, developed and used to guide the search, were:

1. "What is commonly meant by the term Lean?"
2. "How is Lean commonly applied?"
3. "Are there any apparent limitations to the application?"
4. "Where are the best examples of good practice?"

A broad selection of databases were used to search literature published between 1999 and 2005. Key words were used and wildcard key words were added to capture papers that included information on coordination of cross-functional activities. Of the 550 publications that were retrieved, 24 were found suitable for this literature review within the time frame desired. A detailed review of the 24 articles was conducted in the United Kingdom (UK); however, the articles were not restricted to any particular region or originating country. The chosen articles were organized into two tables by author, title, source and chronological order.

Evaluation of Methodology

Baines et al. conducted an initial analysis which involved summarizing each article against the research questions. The result of this initial phase was a better understanding of the topics and emerging themes. Next the researchers combed through the articles in great detail and illustrated them with mind mapping techniques to capture and present the messages. When analyzing the mind maps, topics which found agreement among authors became findings and topics on which there was disagreement became issues. The last step in the analysis was to present the preliminary findings and issues to practitioners in order to test the interpretations for accuracy. The result of the research and analysis design provided excellent alignment and internal consistency among the findings, analysis and the research questions.

The process described above is very similar to the five step grounded theory research process published by Egan (Egan, 2002): 1) initiation; 2) selection of data; 3) collection; 4) analysis; and 5) conclusion. According to Egan, what differentiates grounded theory from other research is the iterative nature of the analysis and data collection. A process of constant comparison (Glaser & Straus, 1967; Y. S. Lincoln & Guba, 1985) is used starting with a small sample and then adding one set of data at a time to the analysis. This allows the data to be categorized and coded in a manageable way and for inferences to develop as the data begins to "speak" to the researcher (Straus & Corbin, 1990). Themes will emerge from the data and become the foundation for the new theory or decision-making model to develop (Golden-Biddle & Locke, 1997; Torraco, 1997).

Strong reliability in the study was demonstrated by the use of operational definitions and categorical definitions to ensure the categories or units of analysis were consistently recorded. Construct validity was demonstrated by using multiple sources of scholarly journals. External validity was enhanced by selecting a stratified sample of articles that studied similar size companies with similar experience in implementing LSS. The data analysis used was similar to the three step technique used by Miles and Huberman (Miles & Huberman, 1994). First, the articles representing the data were collected and divided into groups for analysis. Second, a subject matter was

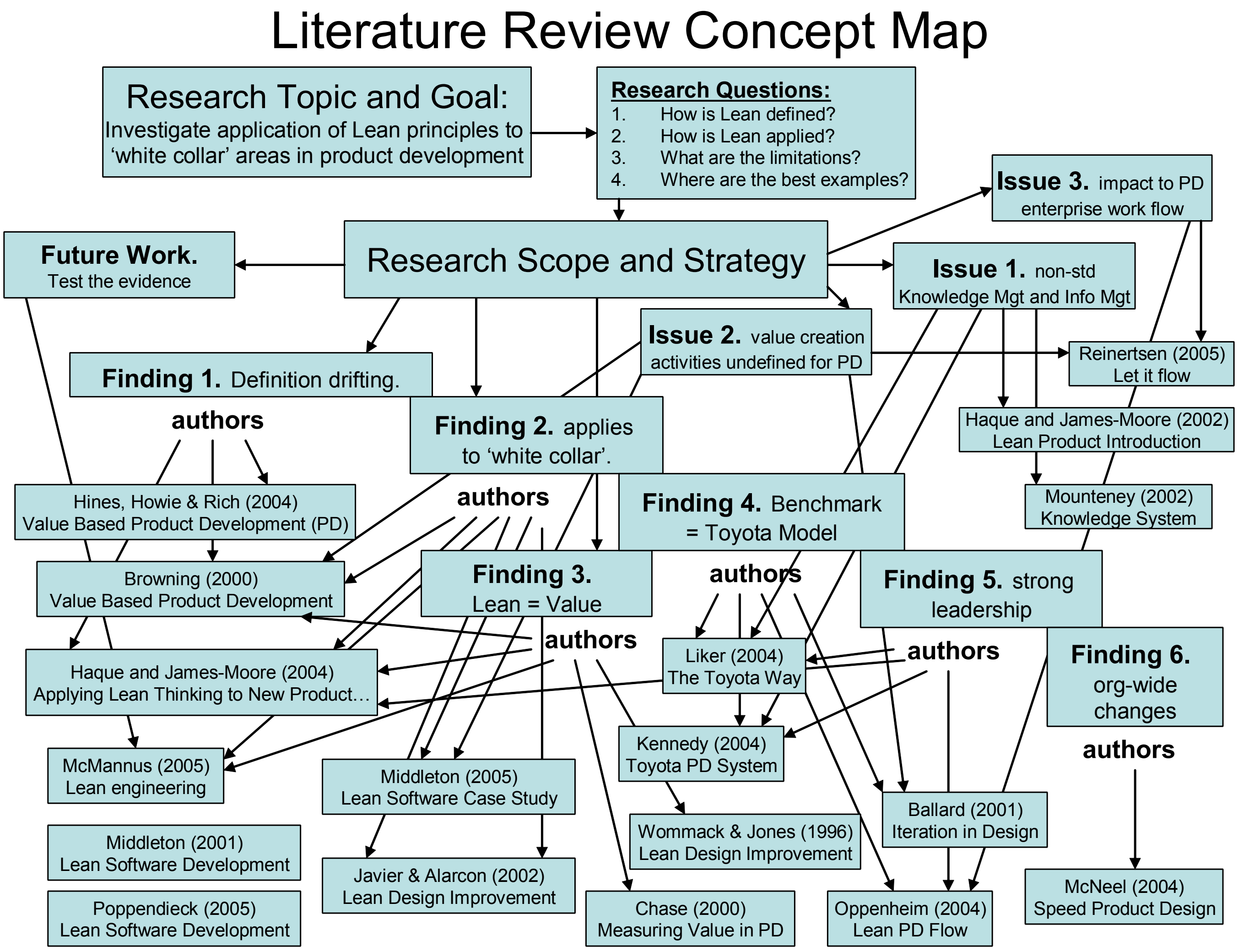

FIGURE 1 – CONCEPT MAP

categorized and labeled. Lastly, the third phase combines categories into a smaller number of core themes.

As Baines et al. developed their new theory from the emerging core themes, the authors ensured that the data emerging was linked to the literature (Golden-Biddle & Locke, 1997). The importance of the study, problems and gaps in the body of knowledge set the stage for suggesting new understandings, explanations or perhaps a new model or solution to the problem (Hansen, 2005). Based on the evaluation of the methodology above, the authors demonstrated a primary level presentation which assured both validity and reliability.

Six key findings or themes and three issues were developed from the data analysis and are also shown on the concept map in below. Finding 1: The definition of Lean has changed. While earlier papers saw Lean as a philosophy for waste reduction, the emerging view is now one of value creation. Finding 2: It is clear that Lean can be applied (although the extent is yet to be confirmed) to product design, engineering and development in the aerospace and other sectors. Finding 3: Value in the product development process needs to be defined precisely as it is not necessarily the same as value in production operations. Finding 4: The Toyota approach of applying set-based concurrent engineering with parallel evaluation of multiple subsystem alternatives and minimal design constraints provides an effective base for Lean design. Finding 5: Adoption of Lean requires the strong leadership of a chief engineer with responsibility for the total project. Finding 6: A truly successful application of Lean requires organization-wide changes in systems practices and behavior. Issue 1: The standardization of knowledge/information management processes that support the adoption of Lean in product development is yet to be defined. Issue 2: The key areas of value creation in the design process remain unresolved. Issue 3: The extent to which the entire product development workflow needs to be re-engineered, in the adoption of Lean, needs to be better understood.

The concept map (Cooper & Schindler, 2006), see Figure 1, illustrates the organizational strategy of the literature review and grounded theory method data analysis. The literature review began with clearly defining the topic and goal that the authors wanted to achieve. Based on the goal, four research questions were developed to guide the research.

Next the research scope and strategy were defined. As part of the strategy, the research was done and the analysis was conducted. This led to the six key findings, three issues and one recommendation for further work. The concept map shows the flow, just described in a pictorial form and shows the linkages between the findings and sources, issues and sources and among multiple sources, findings and issues. The concept map could be taken a step further and another dimension added to show the theoretical underpinnings of the various authors' concepts, i.e. ontology, epistemology, etc.

Author-Identified Limitations, Implications, and Recommendations

The basic constraint of this review is it is limited to the engineering discipline view point only vs. the broader 'white collar' area of concern. The review finds that although there is clear evidence lean can be applied to other than manufacturing organizations, the procedures are not well established. The authors believe that there are many opportunities in this area for further research; however, they only listed one. The recommendation for further research was to test the evidence gained from the literature review in a follow-on study.

Application of Methodology

Writing this paper has afforded the author a clear image of the process by which qualitative research, grounded theory research and new theory development are performed. The process of qualitative research stems from the research question as it organizes and sorts data (Ruona, 2005); uses an interpretive approach to search the data for deeper meanings (Schwandt, 1994), patterns and themes (Creswell, 2007); is reliant on the subjective judgment and interpretation of the researcher to create meaning from the data (Yvonna S. Lincoln, 2005); requires the researcher to become a "bricoleur" (p.234): very knowledgeable of the data contents and understanding what the participants or authors, in this case, mean by their comments; and finally, it requires an iterative approach to continuously comparing new data to the collected data to enhance the meanings as the analysis proceeds (Glaser & Straus, 1967).

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About the Author

Dr. Nancy Moulton has over 35 years of experience in technical, management, leadership and consulting fields. Her military career, civilian leadership positions, and advanced education have provided her with expert knowledge and skills in business operations, organizations and management. For example she received the Lean Six Sigma Excellence Award Program (LEAP) award for best organizational deployment in 2010 and 2011 from the Secretary of the Army. She directed a transformation program that produced over 23 billion dollars in benefits in under four years.

She has served as the Command Select List (CSL) Project Manager (PM) for Light Tactical Vehicles (LTV) and has been responsible for a $1.2B budget and successfully leading teams, for as many as 23 programs simultaneously. Under her leadership, her teams have enabled the Army's largest fleet of over 104,000 trucks to function during war, peace, crisis, and stability operations by sustaining high fleet readiness (93% Army-wide) at low cost (45 cents per mile) to the user. Her extensive leadership experience as a senior management official, principal Army spokesperson on critical issues, leader of Department-level policy formulation and director of enterprise-wide performance improvement has well equipped her for even more significant challenges in the future.

She is currently retired from federal service and is the CEO of Mainely Education, Inc. In this capacity she leads enterprise-wide transformation programs, strategic planning, management planning, performance improvement programs, organizational assessments, process improvement workshops, program management projects and educational seminars.

Dr. Moulton's educational degrees include: Doctorate of Philosophy (Ph.D.) in Organizations and Management; Master of Systems Management and Information Technology; Master of National Resource Strategy; and Bachelor of Organization and Management. Certifications include: Lean Six Sigma Master Black Belt, Level III Program Management and Life-Cycle Logistics from the Department of the Army Acquisition Corps, Program Management Professional (PMP) and Fiduciary training.

Dr Moulton is an active citizen of Bahama Village, Key West, Florida who gets involved and inspires others to be involved in continually improving the community. She is currently serving as a member of the Bahama Village Redevelopment Advisory Committee, Waterfront Playhouse Board of Directors, Key West Business Guild, Florida Equality and the American Legion Post 28.

OVERVIEW OF DESIGN FOR RELIABILITY AND THE NEW ERA OF RELIABILITY 3.0

Athanasios Gerokostopoulos

Introduction

Today's global competitive markets and customers' demand for highly reliable products has led to an increasing attention to reliability engineering processes and tools. The common challenge that many companies face is implementing a reliability program that can achieve the specified reliability goals in a cost-efficient and timely manner. In this paper, we provide a short history of reliability engineering and an overview of the widely used Design for Reliability (DFR) process. We then present a process that is based on the DFR principles and aims to increase efficiency and reduce development costs by leveraging knowledge gained throughout the lifecycle of a product. This process is illustrated through an example using ReliaSoft's Synthesis Platform.

A Short History of Reliability Engineering

Reliability engineering is a fairly new engineering discipline. Although the reliability of products and structures has been of concern to designers for centuries, the term reliability as known today was first introduced due to the needs of World War II whenmany new electronic products were introduced in the military and it was quickly found that they were not meeting operational requirements. For example, 50% of the spares and equipment in storage became unserviceable before use; electronic gear on bombers gave no more than 20 hours of failure-free operation and 60% to 75% of radio vacuum tubes in communications equipment were failing [1]. These failings led to the creation of an Ad Hoc group on reliability in 1950 by the Department of Defense which in 1952 became the Advisory Group on the Reliability of Electronic Equipment (AGREE) and is often considered as the turning point in modern reliability engineering [2]. At the same time, Waloddi Weibull published the paper titled "A Statistical Distribution Function of Wide Applicability" [Weibull paper] which introduced the Weibull distribution; one of the most commonly used distributions for reliability data analysis even today. The next two decades introduced a number of standards and handbooks on reliability originating either from the Department of Defense or from Aerospace (especially after the efforts on space exploration began). During this first era of reliability, which we will refer to as Reliability 1.0, reliability engineering was formalized as a discipline and the first tools, methodologies, standards and processes were established.

The 1970s brought an increase in the use and variety of ICs and by the 1980s many consumer products were heavily using semiconductors [3]. These advancements in technology led to the expansion of reliability principles in many other industries. For example, Bellcore issued the first consumer prediction methodology and similar documents were produced for the automotive industry [3]. These developments along with an increased consumer awareness of reliability led to reliability engineering becoming a widely used discipline over the next decades. The emergence of computers and the introduction of software packages to easily perform reliability analyses greatly assisted in this development. Methodologies like Accelerated Life Testing Analysis (ALTA) and physics of failure modeling became widely used. This era in reliability, which we will refer to as Reliability 2.0, saw the adoption, evolution and expansion of many individual reliability engineering tools and methodologies. Reliability engineering became more institutionalized and processes like DFR provided the vision and roadmap of how reliability engineering methodologies should be applied during the development of a product.

The next logical progression, especially in today's information age where data is in abundance, is to build upon the existing processes, tools and methodologies and create a process that effectively manages and leverages information and knowledge gained throughout the lifecycle of a product while following the best practices of a reliability program. We will refer to this new era as Reliability 3.0. The following section provides an overview of the DRR process which lies at the heart of Reliability 3.0.

Overview of the Design for Reliability Process

Starting from the last quarter of the 20th century with the emergence of a prevalent global economy, companies began facing an unprecedented worldwide competition that resulted in the following challenges:

- Mandate to reduce costs.
- Faster development times.
- High customer expectations with regards to product reliability.

The need to address those challenges brought up the need for an efficient reliability program. In addition, and given the increasing need for cost reduction, companies began to realize that the later a reliability issue is identified and addressed in a product's lifecycle, the more costly its resolution will be. This notion is summarized by the "Factor of 10 Rule" [4] indicating that the cost of fixing a reliability problem increases tenfold as one moves through the product's lifecycle

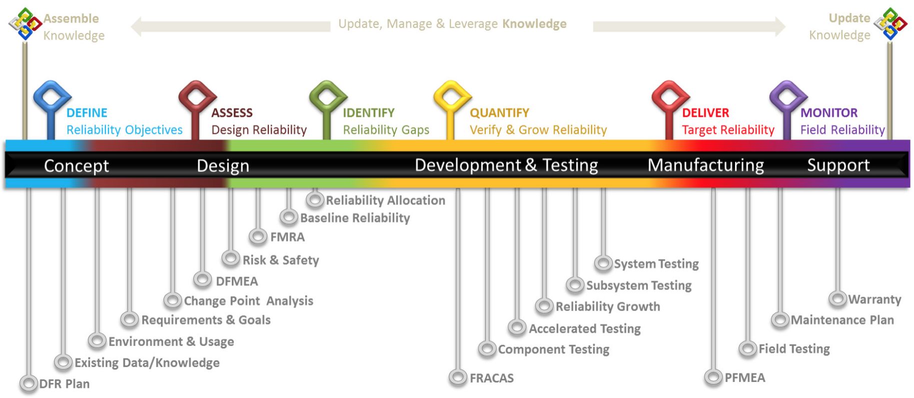


Figure 1 – The DFR Process

stages. This realization led to a shift in how many companies approach reliability. Instead of operating in a reactive mode where reliability issues are dealt with after they appear in the field and reliability is something that only needs to be measured through testing, companies began to operate in a proactive mode with respect to reliability. As a best practice, reliability activities began taking place early in a product's lifecycle with reliability teams working more closely with design teams. This paradigm shift led to the introduction of the DFR process, which has been widely accepted and implemented in companies across different industries over the last two decades.

Although the manner at which the DFR process is implemented across different companies or industries may vary, in its core, the DFR best practice philosophy can be summarized in the following three statements [5]:

- Reliability must be designed into products and processes, using the best available science-based methods.
- Knowing how to calculate reliability is important, but knowing how to achieve reliability is equally, if not more, important.
- Reliability practices must begin early in the design process and be well integrated into the overall product development cycle.

The DFR process describes the entire set of tools that support product and process design throughout its lifecycle to ensure that customer expectations for reliability are fully met. Figure 1 presents a generic reliability program plan. This roadmap aligns the DFR phases with the product lifecycle phases and lists typical activities that can be performed at each stage. Not all activities will be relevant or applicable to every company. It is in the hands of the reliability team to identify those activities that can have a significant impact on reliability and eliminate those that don't add value. It should be noted that although the activities here are presented in a linear fashion, a great deal of overlap could occur in reality. Similar stage gate DFR processes have been proposed in [6] and [7].

Define Phase

This first phase typically takes place prior to the initial product design and sets the stage for all reliability activities that will occur during the development of the product. Initially, a DFR plan or otherwise referred to as a Reliability Program plan is created. Then, any existing data or knowledge is gathered in order to have a full understanding of the environmental and usage conditions that the product will be subjected to and define system level reliability requirements. These requirements need to be clearly defined quantitative metrics that are tied back to customer requirements ("voice of the customer" tools can be used) and existing financial goals (warranty costs, maintenance costs, etc.).

Assess Phase

During this phase the initial design of the product is assessed. If the design is an evolution of an existing product, change point analysis can be implemented in order to identify and document all changes made in the product's design, manufacturing, supplier selection, usage environment, etc.[8]. Another activity of this phase is Failure Modes and Effects Analysis (FMEA) which plays a crucial role in any reliability program. The role of an FMEA is to identify potential failure modes, assess risk and ultimately improve the design of a product. The results of an FMEA can also drive reliability testing that is performed in later stages.

Identify Phase

During this phase an initial estimate of the product's reliability is sought in order to identify gaps between system requirements and current state of the product. Physics of failure techniques andStandards Based reliability predictions can be utilized along with any existing field data from similar designs in order to estimate a baseline reliability of the product. Ultimately, reliability allocation techniques can be used in order to translate system level reliability requirements into subsystem and component requirements.

Quantify Phase

When initial product prototypes become available, reliability testing is performed during this phase. This typically involves an iterative process where tests are performed, results are analyzed and any necessary design changes are implemented. Initial HALT tests can be performed to identify design weaknesses. Life testing or accelerated testing can be performed at the component level to quantify reliability while reliability growth testing can be performed at the system level.

Deliver Phase

During this phase the product design has reached a mature state and the product is ready for manufacturing. Reliability demonstration tests are typically performed at this stage to assure that the product has reached the specified reliability requirements. The possible effect of manufacturing on the product's reliability should not be ignored. Process FMEAs can be performed to evaluate the manufacturing process and reliability tests on samples out of manufacturing can be performed to assure that reliability has not deteriorated.

Monitor Phase

Once the product reaches the hands of the customer continuous monitoring is necessary to gain knowledge regarding the actual use conditions and reliability of the product. An effective warranty system should be put in place to collect any relevant reliability information from field failures. A tool such as a Failure Reporting, Analysis and Corrective Action System (FRACAS) can assist in gathering field failures and initiating problem resolution processes to identify the root cause of observed failures and implement corrective actions to contain and resolve the problem.

Reliability 3.0

The DFR process and an effective reliability program plan can provide the roadmap to achieving reliable products and processes. However, the ultimate goal is to achieve reliability in a cost effective and timely manner. As stated in a previous section, the era of Reliability 2.0, saw a great development in the tools and science behind the different reliability activities. This has laid the groundwork for increasingly successful reliability programs. The next step is to build upon the existing processes (like the DFR process) and tools in an effort to increase the efficiency of achieving high reliability. We will refer to this progression in reliability analysis and processes as Reliability 3.0.

What we have observed through our experience and interaction with companies across many different industries is that although expertise on individual activities has continuously grown over the years, many companies are still operating under a silo mentality. In other words, knowledge gained from one activity is not always transferred to other activities while many activities are oftentimes performed in order to satisfy a checklist without necessarily adding sufficient value to the product's reliability. The ability to manage knowledge is critical, especially in today's information age where data is becoming abundant, while the ability to leverage this knowledge across many different activities will lead to more efficient processes. Today's computer technology offers the opportunities to begin breaking those silos and effectively manage the knowledge gained from each reliability activity, which forms the basis of Reliability 3.0.

The core philosophy of Reliability 3.0 is:

- No reliability activity is an island as it is tightly interwoven with every other activity and all activities follow a holistic closed-loop process.
- Information drives activities and information is continuously updated as new and better information is obtained.
- Each and every activity both leverages from other activities and contributes to other activities.

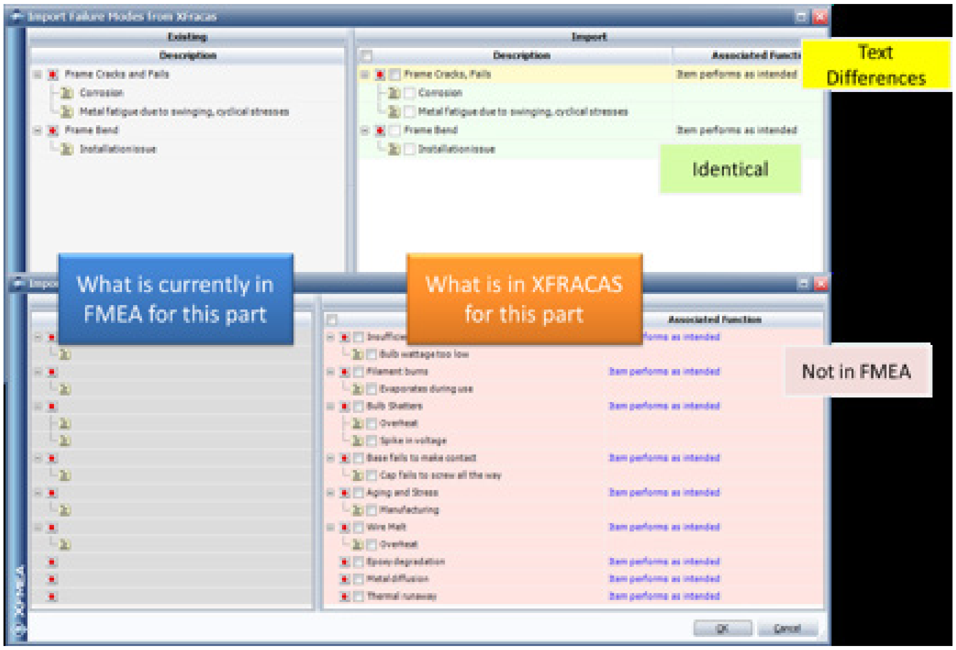
The Reliability 3.0 philosophy attempts to address the challenges that companies face by achieving the following goals:

- *Faster* through a streamlined and structured process that eliminates activity overlaps.
- *Better* through synthesizing the program's activities into a single continuous self-improving process that leverages work and knowledge from the combined whole, while simultaneously addressing existing gaps and shortcomings.
- *Cheaper* through the reduction of both direct costs (time and effort expended during the development process), as well as collateral, operating and maintenance costs throughout the product's life cycle.

There are two factors that play a predominant role in achieving those goals within a company. The first is building a reliability culture that provides the support and resources to implement a reliability program that follows best practices. The second is the technology and software tools that enable knowledge management and reuse of information throughout a reliability program. One such tool is ReliaSoft's Synthesis Platform which was built based on the Reliability 3.0 philosophy. The following section will present the architecture behind the Synthesis Platform and provide an application example.

Reliability 3.0 in Action

To illustrate the concepts discussed in previous sections we will begin with the FMEA activity of a DFR process and show how the analysis performed at this stage can be leveraged by other activities. When performing an FMEA, companies have relied on spreadsheets claiming familiarity or ease of use. However, relational database software provides numerous advantages and can prove essential in performing an effective FMEA. Some of those advantages include the capability for multi-user collaboration with different security permissions, the ability to query functions, failure modes and causes from existing FMEAs, the ability to easily reuse past FMEAs or insert generic FMEAs, the ability to manage generated actions through notifications in order to assure that they have been implemented and the ability to leverage existing knowledge. For example, a common mistake when performing FMEAs is not considering all major "lessons learned" from past product use when identifying failure modes [9]. To avoid such a mistake, an FMEA



Existing: Description	Import: Description	Associated Function
Frame Cracks and Fails	Frame Cracks, Fails	Item performs as intended
Corrosion	Corrosion	
Metal fatigue due to swinging, cyclical stresses	Metal fatigue due to swinging, cyclical stresses	
Frame Bend	Frame Bend	Item performs as intended
Installation issue	Installation issue	

Description	Associated Function
Insufficie…	…forms as intended
Bulb wattage too low	
Filament burns	Item performs as intended
Evaporates during use	
Bulb Shatters	Item performs as intended
Overheat	
Spike in voltage	
Base fails to make contact	Item performs as intended
Cap fails to screw all the way	
Aging and Stress	Item performs as intended
Manufacturing	
Wire Melt	Item performs as intended
Overheat	
Epoxy degradation	Item performs as intended
Metal diffusion	Item performs as intended
Thermal runaway	Item performs as intended

FIGURE 2 – IMPORTING FAILURE MODES FROM A FRACAS SYSTEM

team needs to have readily available all major field problems that have occurred in the past. To assist with this process, a relational database software can provide the interface to import existing incidents from a FRACAS system that contains field data and allow the user to identify which failure modes have not yet been addressed in the FMEA. Figure 2 shows the import utility between ReliaSoft's XFRACAS and XFMEA that provides the FMEA practitioner with a list of failure modes and causes within the FRACAS system that are not part of the existing FMEA and gives her the opportunity to select which ones to import.

Once completed, the FMEA activity in itself, and assuming that it has been executed effectively, accomplishes its primary objective which is identifying potential failure modes and their causes early in development and implementing actions to improve the system design. However, the FMEA produces a wealth of information that can also be used as input to other activities. As an example, and early on in the development cycle, a baseline estimate of the design's reliability is sought as part of the DFR process. The FMEA can serve as a starting point for computing such an estimate. What can be leveraged at this point is the system hierarchy used in the FMEA along with the identified causes of failure and their corresponding occurrence rankings. This analysis is called Failure Modes and Reliability Analysis (FMRA) [10]. Figure 3 shows the FMRA of a simple chandelier system that includes the frame, wiring, bulb and socket subsystems along with the identified failure modes and causes.

Assuming that no reliability data is available at this point, the occurrence ranking of each cause can be converted to a failure rate in order to be used as the reliability model of that cause (a simple assumption of an exponential distribution is necessary when no other information is available). For example, if the occurrence ranking of a cause corresponds to 1 in 10,000 (typical criteria for occurrence scales) then the probability of failure is. The failure rate can be calculated for any operating time, by:

$$\lambda = \frac{-ln(1 - Q(t))}{t}$$

Using this approach, the reliability of each cause can be calculated at any operating time. Then, assuming that if any cause occurs the component fails (reliability-wise in series) the cause reliability can be rolled up to the component level, then the subsystem level and ultimately to the system level. This can be seen in Figure 3, where the system reliability of 84.9% at 5,000 hours is calculated by multiplying the reliabilities of each cause. Component and cause reliabilities are color-coded to

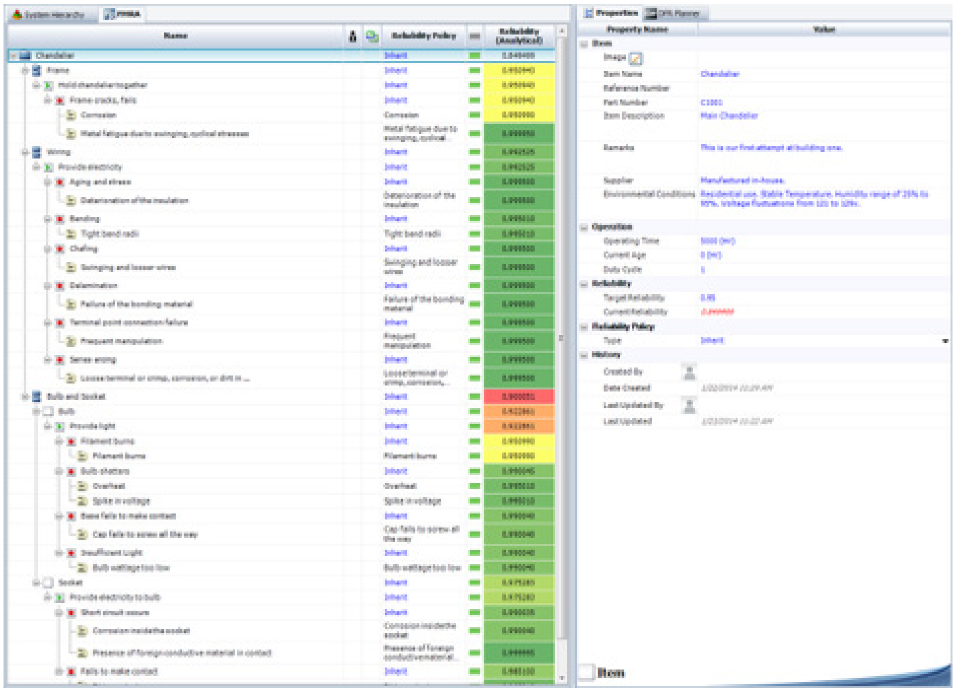


FIGURE 3 – FMRA OF CHANDELIER SYSTEM

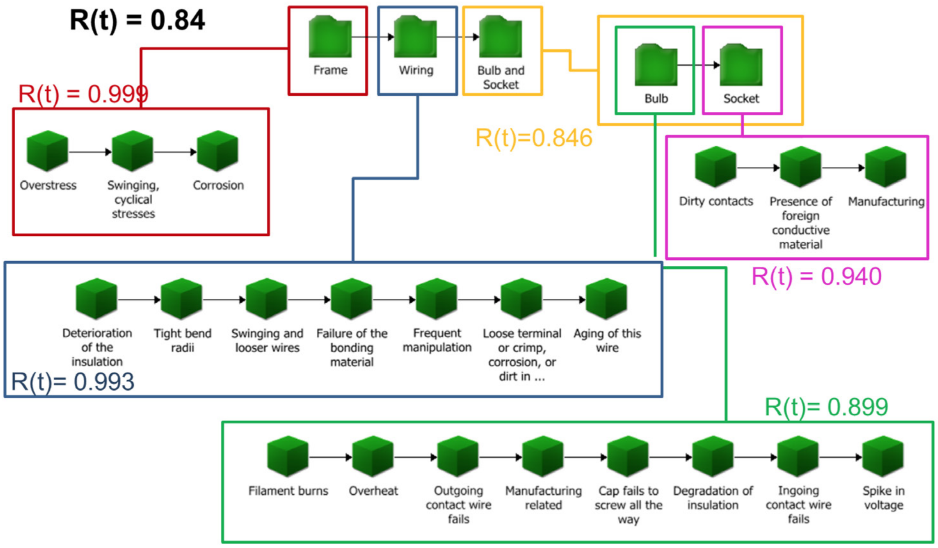


FIGURE 4 – RBD CHANDELIER SYSTEM

easily identify the less reliable components and subsystems.It should be noted that the baseline reliability calculated at this point provides a rough estimate of the system's reliability since no actual failure has been used.If reliability information for a specific cause or component is available through existing field data, past tests, standards based predictions analysis or supplier information, then it can replace the simplified reliability model that was estimated using the occurrence ranking.

At this point the FMRA has allowed us to leverage information from the FMEA activity in order to obtain a first estimate of a system's baseline reliability. Following the Reliability 3.0 process where information is passed from one activity to the other, this structure can now be automatically converted into a Reliability Block Diagram (RBD) or a Fault Tree in order to begin the process of a formal system reliability analysis. Using an RBD one can consider more complex component configurations (such as redundancies or standby scenarios), identify high criticality components with respect to reliability and investigate the effect of different design options on system reliability. Figure 4 shows the RBD of the chandelier system that was generated using the existing FMRA.

Once the initial RBD of the system is created, the system level reliability requirements can be translated into subsystem and component requirements. This can be done using reliability allocation techniques. A number of different allocation techniques are available to perform reliability allocation. One is the optimum reliability allocation that considers the cost or difficulty of making design improvements in components. Following this approach, the system level reliability requirements flow down to components while the cost of making improvements is minimized [11].

As the product moves into development and testing, actual failure data from different tests and analyses can be used to update the initial component reliability estimates and as a result update the baseline system reliability. From a technical standpoint, this ability to share information among different analyses can be achieved using a methodology called Object Based Reliability Modeling (OBRM). A brief description of this concept follows next.

Object Based Reliability Modeling

In order to allow for different types of reliability analyses to be combined and different subject matter experts to share information, ReliaSoft's Synthesis Platform has introduced the Object Based Reliability Modeling (OBRM) methodology. Object-oriented methodologies are by no means new. They have been extensively used in computer programming as an extremely powerful way to analyze, design, implement, evolve and maintain complex systems. The objective of OBRM is to provide the structure that can encapsulate the complexity of the analysis performed in one application (i.e., Life Data Analysis, Accelerated Life Testing Analysis) while maintaining external simplicity with respect to other applications. This is achieved by encapsulating the results of an analysis in an object. All applications can extract relevant information from that object, such as reliability at a given time or B10 life, without having to carry over the complexity behind the analysis.

To illustrate this concept, consider the chandelier example and assume that testing of the frame has produced corrosion failures that were used by a life data analysis expert to fit a Weibull distribution in Weibull++. The generated Weibull model is then encapsulated into an object within Synthesis, which contains the analysis outputs that can now be used by a different subject matter expert in a different activity without her needing to have knowledge of the data or the methods used to build the object. In this case, the object can be used by the system reliability expert in the generated RBD in order to update the chandelier's baseline reliability with more accurate information. Anytime new information becomes available (i.e. new test data) the original analysis can be updated and the new analysis outputs are automatically pushed to all other applications that use this object.

Analysis from other activities within the DFR process such as Accelerated Life Testing, Degradation Analysis, Reliability Growth Testing or Standards Based Predictions can be encapsulated into objects in the same manner and all those objects can be pushed to the RBD, continuously updating the system reliability and eventually, as all reliability testing and analysis is concluded, producing a final estimate of the chandelier's reliability.

Conclusions

In this paper, we presented Reliability 3.0, a process based on Design for Reliability principles, that aims to reduce development costs and time through effective knowledge management and sharing of information across different reliability activities. The example that used ReliaSoft's Synthesis Platform has shown how one can use the FMEA activity as the starting point in order to compute the system's baseline reliability and then automatically generate a Reliability Block Diagram to perform reliability allocation. Once reliability data becomes available through testing,different subject matter experts can encapsulate their analyses into objects that can be combined to update the system reliability estimate. As new data becomes available throughout development, these analyses can be updated and the new information will automatically be pushed to all applications that use them. Finally, once the product is fielded, a FRACAS system can be used to capture warranty information that can be utilized in future product development, therefore providing a closed-loop process.

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About the Author

Athanasios Gerokostopoulos is a Reliability Engineer at ReliaSoft Corporation. He is involved in the development of ReliaSoft's software products and the delivery of training seminars and consulting projects in the field of Reliability and Quality Engineering. His areas of interest include Reliability Program Plans, Design for Reliability, System Reliability and Reliability Growth Analysis. Mr. Gerokostopoulos holds an M.S. degree in Reliability Engineering from the University of Arizona and an MBA from Eller College of Management at the University of Arizona. He is a Certified Reliability Professional (CRP) and an ASQ Certified Reliability Engineer and Certified Quality Engineer.

DEVELOPING RELIABILITY REQUIREMENTS FOR POTABLE WATER SOLUTIONS IN POLITICALLY DISCONTINUOUS AREAS – PART 2 OF 3 WATERCOURSE STEWARDSHIP

Katherine Pratt

Abstract

The United Nations Watercourses Convention, adopted in May 1997, is a global framework agreement with the goal of ensuring optimal and sustainable use, development, conservation, management and protection of international watercourses for present and future generations. This is accomplished by individual States/Countries exercising due diligence with their rights and duties associated with watercourse management, so as not to cause significant harm to other watercourse States [1]. Albeit not as rigorous as an ecosystem-oriented instrument, the Convention requires a State or Country, when using a watercourse, to consider obtaining optimal and sustainable amounts of water, not just from their perspective and benefit, but also from the cumulative user(s) view of all the other watercourses as well, with a focus on long-term protection of that watercourse itself. Watercourse ecosystem stewardship expands "optimal and sustainable use" to include flora, fauna, sediment, aquatic, aerobic and anaerobic considerations, as well as pollution prevention, and environmental protection. Given the fragility of relations amongst Middle Eastern States, compliance with the Convention is currently daunting enough without introducing the myriad legal influencers associated with the ecosystem community. This paper will focus on the Blue and White Nile River tributaries with its multiple riparian regions and the struggle to manage this common resource reliably, via Convention goals, amongst politically discontinuous Middle Eastern States.

Water Scarcity

Three countries—Ethiopia, Sudan, and Egypt—use most of the water that flows in Africa's Nile River. Egypt, where it rarely rains, gets more than 97% of its freshwater from the Nile and is the last in line to tap this North-flowing river. The Nile River watercourse flows north as this is the path of least resistance, and therefore downhill. It is a confluence of two separate river systems (tributaries); the White Nile River and the Blue Nile River. The source of the confluence is at Khartoum, Sudan. There is still debate as to the exact source of the White Nile River, as there are many smaller tributaries, streams and lakes, as one approaches the source [2]. Whether it's the Kagera River, the Ruvyironza River or the Nyabarongo River, the Nile ends its journey in northern Egypt where it flows into the Mediterranean Sea. To meet their water and food needs of their rapidly growing populations, both Ethiopia and the Sudan plan to divert more water from the Nile. These upriver diversions will reduce the amount of water available to Egypt, which cannot exist with the current and planned infrastructure demands for water and irrigation water from the Nile upriver watercourse.

Ethiopia

The 1959 Nile Waters Agreement between the Sudan and Egypt did not include the upriver states: Ethiopia, Kenya, Uganda, Rwanda, Burundi and Tanzania, which so offended the Emperor of Ethiopia, he began building several dams on the Blue Nile and its tributaries. Nasser of Egypt, in turn, encouraged Muslims in Eritrea that had reunified with Ethiopia after World War II, to secede from Ethiopia and persuaded Muslim Somalis to fight for the liberation of Ethiopia's Ogaden region. Although Ethiopia won the war with Somalia in 1977–1978, Eritrea won independence in 1993.

After Egypt built their Toshka Canal, the Ethiopian Prime Minister Meles Zenawi in anger and disbelief, protested: "While Egypt is taking the Nile water to transform the Sahara Desert into something green, we in Ethiopia—who are the source of 85% of that water—are denied the possibility of using it to feed ourselves." Although late to mega-dam building, Ethiopia is now making up for lost time. One of the tallest dams in the world was completed in 2009 on the Tekeze River in northern Ethiopia. Three major dams on the Omo and Gibe Rivers in southern Ethiopia are either completed or nearly so, and a new mega dam, the Grand Renaissance Dam, is in early stages of development.

In May of 2013, Ethiopia began diverting the Blue Nile to begin building The Grand Renaissance Dam, a giant hydroelectric dam. It will have a reservoir holding 67 billion cubic meters of water—twice the water held in Lake Tana, Ethiopia's largest lake—and is expected to generate 6000 megawatts of electricity [3]. This action raised tensions with Egypt and the Sudan, both of which are currently grappling with major internal political and economic crises.

Ethiopia's options for economic development are limited. With nearly 90 million people it is the most populous landlocked country in the world. It is also one of the world's poorest countries—174 on the list of 187 countries in the United Nations Human Development Index for 2012. (Sudan is 169 and Egypt 113.) This index rates countries based on life expectancy, education, and income, among other criteria. Part of Ethiopia's challenge is that 85% of the workforce is in agricultural commodities, an industry that brings in low profits. Ethiopia is already leasing land in its southern regions to Saudi Arabia, India, and China for large irrigated water projects—despite severe land shortage in its northern regions—because it does not have the funds to develop this land on its own.

The state-owned Ethiopian Electric Power Corporation optimistically reports that the Grand Renaissance Dam will be completed in 2015 at a cost of nearly 5 billion dollars. As of 2013, the project is 13% complete, suggesting that it may be many more years and billions of additional dollars before the dam is finished. The Tekeze Dam was completed well over its predicted budget and years behind schedule when it was in development, as well. The World Bank, the European Investment Bank, the Chinese Import-Export Bank, and the African Development Bank provided financing for some of the other dams; but concerns about the environmental and political impact of this latest dam have discouraged lenders from continuing financial support. The International Monetary Fund suggested that Ethiopia put the dam on a slow track, arguing that the project will absorb 10% of Ethiopia's Gross Domestic Product, thus displacing other necessary infrastructure development. Nevertheless the Ethiopian government insists that it will stick with its schedule and finance the project domestically. It probably will secure more help from China, a loyal ally and the world's major developer of hydroelectric power [4].

Thus, the development and sustainment of reliable water resources for Ethiopia hinge on the availability of solid resources and continued support via alliances with countries such as China.

Sudan

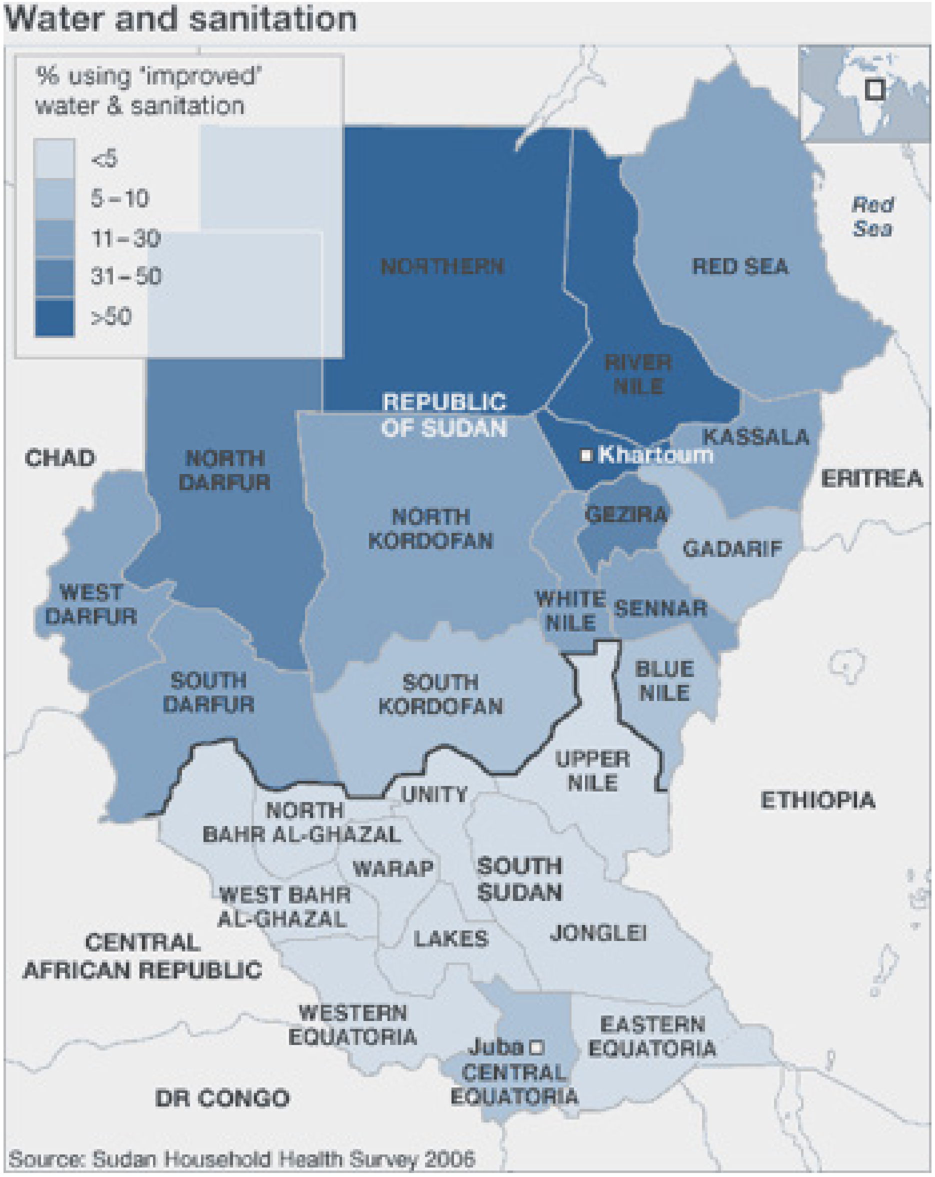
In 1821, Egypt conquered Sudan until 1881 when Sudan successfully revolted. Their freedom was short-lived however, as the British and Egyptian forces jointly conquered them again. As a result, there is a great deal of resentment in Sudan towards the west.

The signatories of the 1959 Agreement facilitated the construction of the Roseires Dam (completed in 1966 on the Blue Nile in the Republic of Sudan), and the Khashm al-Girba Dam (completed in 1964 on the Atbara River in the Republic of Sudan).

South Sudan gained independence in July 2011, but two decades of conflict with the Republic of Sudan in the north, has left them a watercourse resource environment fraught with conflict and neglect. In the Northern Republic of Sudanese states of Khatoum, River Nile and Gezira, two-thirds of their people have access to piped drinking water and pit latrines. Whereas, in the South Sudan, boreholes and unprotected wells are the main drinking sources. More than 80% of South Sudanese have no toilet facilities. Some 75% of all the oil lies in the South Sudan, however, all the pipelines run north. (See Figure 1)

Throughout the two Sudans, access to primary school education is linked to household earnings. In the poorest parts of the South, less than 1% of the children finish primary school whereas in the wealthier North, up to 50% of the children complete primary education.

In summary, the availability of reliable water sources for North and South are unpredictable. It is an isolated entity with political conflict(s) and a fractured



Source: Sudan Household Health Survey 2006

FIGURE 1 – NORTH AND SOUTH SUDAN

infrastructure; all of which signal a long road ahead before reliable water access can be assured.

Egypt

The Nile River is essentially the sole source of water supply for Egyptian irrigation. An arid region, the cooperation of Sudan (the upriver nation) is needed to ensure sufficient and usable river water reaches Egypt (the downriver nation).

Under the 1959 trans-boundary treaty agreement, Egypt was awarded a quota of 55 billion cubic meters per year from the Blue Nile, with Sudan getting 18.5 billion cubic meters a year. Egypt, with a population of 82 million, already uses its entire quota, and of that amount, it is estimated that roughly 47 billion cubic meters of water is used for irrigation and agriculture. By 2050 its requirement is expected to increase another 21 billion cubic meters a year [5]. The treaty also allowed for the construction of the Aswan High Dam that opened in 1971. The Aswan High Dam has disrupted the ecosystems of the Nile River, the delta, and the Mediterranean resulting in reduced agricultural productivity and fish stocks. It also caused a series of seismic events due to the extreme weight of the water in Lake Nasser, one of the world's largest reservoirs.

Egypt came to realize that the Aswan Dam had not solved their historic dependency on the Nile waters during the drought and famine years of the 1980s. Later that decade Egypt and Ethiopia began to work cooperatively until Egypt, during the Sadat administration, built the Toshka Canal, which used 10% of the waters in Lake Nasser to irrigate Egypt's sandy Western Desert. This resulted in a net increase of their need for Nile water. Even if Egypt maintained their 1959 treaty share of water use, less water for crops means less food for consumption, and the country's financial woes—which include becoming a net importer of staple commodities like oil—have left Cairo struggling to afford higher volumes of food, particularly wheat [6]. Given Cairo's inflexibility on this issue, there's been talk that the Nile dispute could lead to actual conflict. Egypt is a western-style democracy, and is the recipient of the second-largest US foreign aid package in the world, $2 billion per year, behind Israel. In 2013 Egypt's military crushed the Muslim Brotherhood at home, now Egypt's military plan is to undermine the Palestinian militant group Hamas, which runs the neighboring Gaza Strip. They plan to work with Hamas' political rivals Fatah and supporting popular anti-Hamas activities in Gaza. But the situation is very different in Gaza, where Hamas, an offshoot of the Brotherhood, is heavily armed, has years of experience fighting Israel, and moves swiftly to squash dissent.

In summary, unintended environmental consequences from the development of the Aswan Dam and internal and political conflicts are continuing to drain Egypt's economy; the war on terror, courtesy of Hamas' presence, will also impede Egypt's goal of obtaining reliable water.

Turkey

Turkey, located at the headwaters of the Tigris and Euphrates Rivers, controls water flowing downriver through Syria and Iraq into the Persian Gulf and is building two dams along the upper Tigris and Euphrates to generate electricity and to irrigate a large area of land.

Former Turkish President Turgut Ozal decided to build a series of twenty-two dams on the Tigris and Euphrates river systems. The Ataturk Dam, the world's fifth largest, is part of the Southeastern Anatolia Project, or GAP. GAP is designed to bring electricity to the area and provide irrigation to almost 30,000 square miles of arid and semi-arid land. The area is larger than the area of the Benelux countries combined and will supposedly allow Turkey to grow much of the food for the Middle East. The venture is projected to irrigate 1.7 million hectares (4.2 million acres) of land that will produce an estimated $6 billion food surplus. The irrigation would enable Turkish farmers to raise cotton, sugar beets, tobacco, soybeans and other cash crops instead of the grain they now raise. The controversy is not only just over what rights a country has over water and the politics of water, but archaeologists are also protesting the fact that these dams are destroying many unexplored ancient Kurdish cities.

When completed, these dams will reduce the flow of water downriver to Syria and Iraq by as much as 35% in normal years, and much more in dry years. Excessive withdrawal of water from rivers and aquifers leads to disappearing species, lower water tables, declining fish populations, altered river flows, shrinking lakes, loss of wetlands and declining water quality.

Because of these controversies the World Bank refused to fund the building of these dams. Turkey built the Ataturk Dam anyway. Anticipating its neighbor's complaints, the Turks increased water flow 50% from the Euphrates River for six weeks before cutting the flow to a trickle in order to fill their reservoir, an action which was not well received by the downriver countries

Besides the environmental problems that go along with an irrigation project of this magnitude, Turkey has a history of strong earthquakes that could potentially destroy the Ataturk Dam. The Turks claim the dam was designed to withstand quakes of up to eight on the Richter scale. However, this is a trans-border issue and what one country does with water upriver has a significant impact on downriver countries. There are now legal reasons why a country has to allow water to flow downriver: failing to do so, could lead to war. Pollution, from agricultural runoff and sewage, also has an impact on areas downriver.

The European Union membership has served as an impetus for reforming Turkey's environmental policy, including their water policy, gaining ground after Turkey's official recognition as a candidate for full EU membership in 1999 [7]. Former Turkish

Foreign Minister Yaşar Yakış commented in March 2013 that while Turkey has recently attached greater importance to water issues, effective water management policies are not in place in Turkey, nor does it have many qualified experts on water, unlike other countries in the Middle East. "Therefore," in his view, "Turkey needs to establish departments on water issues at Turkish universities to train domestic water experts as soon as possible [8].

In summary, internal minority and trans-border political friction(s), the availability of solid financial resources and an earthquake prone geological background are major hurdles for Turkey reaching reliable watercourse relationships with its downriver neighbors.

Syria

The Ataturk Dam in Turkey has had a devastating impact on the downriver countries of Syria and Iraq. In the beginning of 1990, Turkey began to fill the reservoir behind the giant Ataturk Dam in the southeastern part of the country. The dam sits on the Euphrates River that also supplies Syria and Iraq with a large part of its water supply. (See Figure 2)

FIGURE 2 – THE EUPHRATES RIVER IN SYRIA

Syria's population, growing at an annual rate of 3.8% a year, can be expected to make water issues even more critical in the future. Projected to almost double its population between 2006 and 2050, it plans on building more dams and withdrawing more water from the Jordan River, decreasing the downriver water supply for Palestine, Jordan and Israel. Syria also plans to build a large dam along the Euphrates to divert water arriving from Turkey. This will leave very little water for Iraq and could lead to a war between the two countries. Syria has been creating dams on the tributaries of the Yarmouk River in order to increase the agricultural potential on the part of the Golan Heights which remained under Syrian control after the Six Days' War in order to support the 150,000 people who fled from the aftermath of the 1967 and 1973 wars. Syria's depletion of these waters has exceeded 200 mcm annually and is still growing [9]. As the population of an area increases and available water resources are depleted, water issues become very severe. Cholera outbreaks during the 1980s when draughts plagued this region, give an indication of how quickly disease can spread without adequate potable water supplies. Food also becomes a problem when one must depend upon others to feed their people. The current conflict has caused more than nine million people to flee from their homes. More than 2.5 million Syrians, mostly women and children, have fled Syria into Lebanon, Jordan and Turkey; those three countries struggle to accommodate the flood of new arrivals. A further 6.5 million people are believed to be internally displaced within Syria, many without access to aid, bringing the number forced to flee their homes to more than 9 million, or half the population.

The US and Russia began to work towards a conference on Syria in Switzerland. It commenced in January 2014 but broke down after two months because a UN-backed international agreement called for the establishment of a transitional governing body in Syria, on the basis of mutual consent, Syria's refusal to discuss opposition demands and its insistence on labeling the Syrian population fighting the government "terrorists."

In summary, Syria, a downriver country, is co-dependent upon the watercourse resource management activities of Turkey. The killing and displacement of their peoples due to ongoing-armed political conflicts is acerbating their already fragile potable water situation.

Iraq

Since the beginning of recorded time, agriculture has been the primary economic activity of the people of Iraq because Iraq has more water than most Middle Eastern nations; e.g., in 1976, agriculture contributed about 8% of Iraq's total GDP and it employed more than half the total labor force. In 1986, despite a ten-year Iraqi investment in agricultural development that totaled more than US$4 billion, the sector still accounted for only 7.5% of total GDP. In 1986 agriculture continued to employ a significant portion—about 30%—of Iraq's total labor force.

Part of the reason the agricultural share of GDP remained small was that the sector was overwhelmed by expansion of the oil sector, which boosted total GDP. Most Middle Eastern countries do not trust one another, so they try not to be dependent upon others; this is especially true in the area of agriculture. Although many food items may be cheaper to import, most of these countries prefer to grow their own food, which drains a very large portion of these nations' available water supplies.

Because of the dams built by Turkey, Iraq has actually threatened a regional war if its water needs are not met. Iraqi officials protested the sharp decrease in the river's flow, claiming irrigated areas along the Euphrates in Iraq dropped from 136,000 hectares to 10,000 hectares from 1974 to 1975. Turkey claims its water policy is not political but has been very critical of Kurds, who live in Iraq but conduct cross-border raids into Turkey in retaliation for the destruction of ancient Kurdish cities as part of the Turkish dam building. Statistics indicate the production levels for key grain crops remained approximately stable from the 1960s through the 1980s, with yield(s) increasing while total cultivated area declined. However, increasing Iraqi food imports indicated agricultural stagnation. In the late 1950s, Iraq was self-sufficient in agricultural production but, in the 1960s, it imported about 15% of its food supplies and by the 1970s it imported about 33% of its food. By the early 1980s, food imports accounted for about 15% of total imports, and in 1984, according to Iraqi statistics, food imports comprised about 22% of total imports.

Geographic factors also contribute to Iraq's water problems. Like all rivers, the Tigris and the Euphrates carry a large amount of silt downstream that is deposited in river channels, canals and on the flood plains. In Iraq, the resulting soil has a high saline content and, as the water table rises through flooding or through irrigation, salt rises into the topsoil, rendering agricultural land sterile. As Iraq is relatively flat, draining their lands of this silt is problematic.[10]

To summarize, experts believe Iraq has the potential for substantial agricultural growth, but restrictions on water supplies caused by Syrian and Turkish dam building on the Tigris and Euphrates Rivers, plus large rainfall variability and declining total cultivatable land limit this expansion potential.

Palestine, Israel, and Jordan

Potable Water Sourcing

Jordan, Israel and Syria are characterized by an arid climate, with evaporation exceeding rainfall for most of the year [11]. Territory classified as arid covers 80–85% of Jordan, 60% of Israel, and 50–65% of Syria [12]. Palestine, the Gaza Strip, and the Wadi Gaza area have a semi-arid climate.

Palestine, Gaza Strip, West Bank

The Jordan River, coursing through the most water-short region(s), provokes fierce competition for its water among Jordan, Syria, Palestine (Gaza and the West Bank), and Israel.

The Mountain Aquifer

For the Palestinians, the Mountain Aquifer source, derived from rainfall over the West Bank, makes up nearly the totality available for consumption. Jewish and Palestinian farmers going back as far as seventy years have utilized that aquifer within the present boundaries of Israel.

Albeit not considered trans-boundary water since its flow is almost entirely within the West Bank, the Palestinians, who claim priority in utilization of the Mountain Aquifer since most of its flow is derived from rainfall over the West Bank, accuse Israel of severely over-pumping the western basin of the Mountain Aquifer and wastefully using the highly subsidized water to grow non-economic crops, which threaten the future of this vital shared resource. They see such use of the natural resources of the Occupied Territories as contrary to international law.

Israel bases its claim for the continued use of most of the flow of the Mountain Aquifer, which naturally drains into Israel, on its prior historic de facto use of the aquifer for essential human needs and economic purposes going back some seventy years, long before any major Palestinian use of the aquifer was initiated.

The Israelis say they have not increased their utilization of the Western or Northeastern Aquifers since 1967. They claim water usage rights based on the internationally accepted practice of recognizing historical use, e.g., the case of Egyptians' internationally recognized claim on the use of the Nile River, although none of it falls as rain over Egyptian territory. Within the limits of allowable safe yields of the Mountain Aquifer, Israel claims the Palestinians have been granted permission to utilize water resources and dig new wells in the West Bank [13]. The Northeastern Aquifer is trans-boundary, but it only contributed about 130 mcm of water, of which 70 mcm is brackish.

Only the Eastern Aquifer is entirely within the West Bank, but it only had 150 mcm of available water of which 70 were brackish. This was shared between the Palestinian population and the Israeli settlers living on the eastern part of the West Bank. In several parts of the Eastern Aquifer wells have been over-pumped, resulting in deterioration of water quality and may lead to seepage of brackish water into the fresh water body. Detailed studies in the Jordan Valley have revealed a rise in total salt concentration by 130% and chlorine by 50% in the period 1982–1991 [14].

The Jordan River Basin

The Western Aquifer (aka Yarkon-Taninim Aquifer) is trans-boundary to Israel and West Bank. Its yield is 350 mcm, 40 of which are brackish. Historically the Palestinians also used some of the flow from these springs and also an additional 20 mcm from traditional dug wells in the coastal area. The Western Aquifer was used as Israel's municipal supply and was their main source of drinking water.

The American Johnston Plan of 1955, though never formally approved, served as the de facto basis for the division of the Jordan and Yarmouk Rivers between Israel and Jordan. The Syrians never agreed to this division and diverted the Yarmouk River within southern Syria far beyond the proposed Johnston Plan allocation. The Jordanians and Palestinians claim that Israel pumps more than its allocation so as to promote the irrational export of water-intensive crops at the expense of basic Palestinian needs. As part of the allocation to Jordan, the Johnston Plan allocated water for use by the Palestinians in the West Bank. The actual plan to divert this water to the West Bank from the Yarmouk River was never carried out and the Palestinians claim this allocation is still due to them. The Jordanians claim that this is impractical because of the Syrian diversion of the Yarmouk River and the Jordanians have absorbed hundreds of thousands of Palestinian refugees after the 1967 and Gulf wars.

Prior to 1948 the Palestinians used water from the lower Jordan River directly for irrigation and water supplies all along the Jordan Valley. The diversion of major flows of the Jordan River into the Israel National Water Carrier in 1961 plus other diversions of the Yamouk River by Syria and Jordan reduced the overflow from Lake Tiberias to a minimum in the summer.

As for Israel, its claim to the existing waters of the Jordan River Basin is based on the Ruttenberg Concession of 1927, the de facto Johnston Plan allocation, and its natural riparian rights under international law. The Palestinian claim to this water is founded on de facto historic use prior to 1948 (taken away from them without their consent) and their natural riparian rights under international law, as well as the Johnston Plan allocation of water to the West Bank.

Surface and Groundwater in the Gaza Strip

Israelis and the Palestinians are also involved to a limited extent in sharing the surface and groundwater flow in the Gaza region. The Gaza Aquifer is essentially a part of the coastal aquifer in Israel. There has been severe over pumping of the groundwater in Gaza for the past forty years, particularly during the period of the Egyptian administration from 1948–67, resulting in severe "en-salination" of most of the wells; over pumping exceeds the natural rate of replenishment and in many areas the water is unfit for agriculture and drinking. Without sufficient water to replace this over pumping, a severe and urgent water crisis could cause a total "en-salination" of the aquifer in a few years time. This aquifer is fed almost entirely by direct local rainfall. The Palestinians point out that the post-1967 Israeli settlements in Hevel Katif and within the Gaza Strip, pump much of the water from the over pumped aquifer and Israel's drilling of a series of wells on the Israeli side of the border to the east of the Strip has greatly reduced the flow into the Strip, causing even more "en-salination" of the wells. Israel denies these charges, claiming that the "en-salination" is mainly the result of years of unregulated over pumping within the Gaza Strip. Recognizing the seriousness of the situation, Israel has taken some steps to alleviate it, including introduction of more water from the Israel National Water Carrier and the building of a small plant to desalinate brackish water at one of the refugee camps [15].

Israel

Israel's first priority was to develop their costal plain, conveying 420–450 mcm per year of water via conduit and 100 mcm/year of direct water extraction from Lake Tiberias [16].

Israel's use of important aquifers within the Jordan Valley and their vast development of desalination pipelines and distribution centers play pivotal roles in its prosperity and transformation. Their ability to harvest, transport and deliver water to the dry and arid lands of the Lower Jordan Valley defied those who could not imagine Israel would be able to meet their goals of expanding agricultural lands within areas of historically low and unpredictable rainfall patterns.

In 1990 more than 50% of the available renewable supply for water demand was provided by groundwater in Israel, Jordan, and the Occupied Palestinian Territories. From 2007 through 2010, Israel restructured and implemented their national policy master plan to require institutional and sophisticated technological changes needed to stabilize their potable water crisis and to manage their water sector more efficiently using a long-term perspective. They focused on water saving strategies, reclamation of large amounts of effluents, seawater and brackish water desalination plants and organizational change [17]. They changed the system components used to accommodate their more moderate-in-volume water supply solutions, thereby increasing their standards of living with higher water quality and reliability by using their public and private research and development sectors to arrive at both technological and economical solutions in the fields of water production and water treatment.

Much of Israel's water technology is in the area of rural and urban distribution systems that supply water directly to consumers. Initially, for non-bulk water treatment solutions, the quantified reliability metrics may not have been available when they began to develop some of their technology. However, new feature-based data assimilation methods help to reformulate this process, explicitly recognize the role of spatial structures and enabled inventory management of many different kinds of environmental systems characterized by distinctive spatial features such as rainstorms, wildfires, and algae blooms, among others [18]. The driver for refining this process is the possibility of lowering operational costs; a better understanding of systems reliability becomes apparent.

Israel has implemented sustainable development guidelines and legislation to maximize the utilization of existing water resources. This effort entails improved public water conservation and, most importantly, restructuring the water rates to reflect water supply costs, including both scarcity and upgrading sewage treatment. To maximize safety and minimize environmental risk from wastewater reuse, water quality standards are upgraded for both agricultural use of treated wastewater and its discharge into aquifers, streams and rivers. Most importantly, Israel's Water Management Program is not static by design; their dynamic approach integrates economic incentives, and environmental and health considerations to become even more efficient and responsible in order to accommodate future generations. They are disseminating new water production technologies, water treatment and advanced management tools. These programs to develop additional water supplies are aimed at addressing extreme decreases in the replenishment of natural sources. For example, the national desalination plan (505 mcm by 2013) is based upon a 10% drop in average multi-year replenishment concurrent with the need to address consecutive years of drought.

Israel has developed innovative demand management tools, such as production levies, whereby they harmonize "nature" and "ecosystems" as a "consumer," similar to agriculture, in their master plan and even include targeted allocations for main water ecosystems. The new national water sector policy incorporates a development plan founded upon three basic components: ensuring water supply, social and economic requirements, environmental and ecological needs, and it is based on their sustainable development program in the areas of water and sewage. For instance, water demand strategies include an increasing block tariff that is intended to achieve efficient patterns of water-use. Not only are higher prices paid for higher levels of consumption, but, prices differ among regions, accounting for water transportation costs.

The economic goals of the extraction levy are two-fold. First, for agriculture, farmers are encouraged to switch to recycled water or main supply system, the National Water Carrier, thereby utilizing the nation's water resources more efficiently, creating tools to manage overall water production using economic incentives, creating tools for regional management of water quantity and water scarcity, encouraging the development of new water sources and agricultural preservation, and the preservation of nature and landscape. Interestingly, a 20% decrease in potable water demand for agriculture has been accompanied by a steady increase in the overall value of agricultural output. Even though the population has grown seven-fold in the last 60 years and agricultural production expanded sixteen-fold, water usage did not increase. The invention and introduction of drip irrigation in Israel is the single most important innovation in local agricultural development. Additional agricultural efforts to save water, such as the use of drought-resistant trees (olive and almond), water-conserving technologies; storm runoff collection; and technologies to improve the agro-technical, environmental and health concerns involved with the reuse of wastewater effluents have enabled them to cut 35% of their water quotas but increase production by 42%; an excellent sustainable result. The proportion of wastewater produced that has been subjected both to collection and has been adequately treated was 94% in 2005.

The Water Authority decided to upgrade the quality standards for irrigation with treated wastewater and to make them more stringent. The intent: make the disposal of and irrigation with reclaimed wastewater a sustainable process. This involves safeguarding the appropriate sanitation and health standards while preventing damage to agricultural land, nature, streams and underground aquifers. The Authority will be investing ¼ billion dollars to upgrade sewage treatment facilities by 2015.

Second, for domestic and industrial use, economic incentives are used to encourage water-producing municipalities (or local Water Consortiums) to connect to the national water network to maximize aquifer rehabilitation and utilization, and to aid water supply and quality regulation. Water consumption is metered and users face increasing block rate pricing. This levy more than covers the cost of local water delivery. Desalination is the most recently adopted technological component of Israel's water management strategy. New membrane technologies and the reduced energy and economies of scale associated with mass production allow very high quality drinking water to be produced at a cost of $0.52/m3. The lower cost of desalinated water now makes it economically viable for both commercial and domestic use.

The Ashkelon plant on the southern tip of Israel's Mediterranean coastline is located adjacent to the local electric power station. The Build-Operate-Transfer (BOT) facility guarantees a production capacity of 100 mcm/year (about 5% of Israel's water supply). The project relies on Sea Water Reverse Osmosis (SWRO) technology, the largest and most advanced SWRO desalination plant in operation in the world to date, incorporates a treatment process to address the natural boron concentration in seawater with a removal efficiency of 92% enabling new opportunities for desert agriculture, and also the first desalination project ever to beat a target price of $0.52/m3. The Ashkelon plant's desalinated seawater's hardness levels are relatively low. When it was mixed into the national water grid, the city of Beersheva which had used this desalinated water, later found that their treated wastewater chlorides had plummeted to 100–150 mg/l when it was sent to the farms in the surrounding desert. These are concentrations that even critics of widespread sewage reuse find sustainable.

Oil-rich countries such as Saudi Arabia and the United Arab Emirates (UAE) have on-going desalination processes but are returning the salts removed from the seawater back into the ocean, which threatens marine life and regional fishing [19]. This action reduces the ability of the ocean to reliably supply food to the neighboring populace and decreases the biodiversity of the food chain. For every gallon of fresh water produced, another gallon of doubly concentrated salt water must be disposed. Desalination inadvertently kills millions of plankton, fish eggs, fish larvae and other microbial organisms that constitute the base layer of the marine food chain, thus wreaking havoc on the sustainability of the marine ecosystems [20].

Seawater SWRO uses less energy than distillation and does not require thermal energy. RO membrane technology has advantages in desalting brackish waters, although electro dialysis (ED) membrane technology has some advantages over RO in brackish water treatments and other specific environments [21]. Although desalination uses renewable energy; solar or wind is not a common technological solution yet; with the spiraling costs of energy, projects integrating these technologies make good sense, particularly for small communities in remote locations [22].

One take-away of Israel's efforts is: projects such its coastal plain development can be viewed as problem solving that utilizes a Systems of Systems (SoS) approach. Designing an SoS is a new strategic approach with an integrated systems perspective enabling the management of technological solutions via inter-discipline interaction amongst sciences, organization(s), process(es) and the environment(s) as well as political, information, and supporting technology bases. It is critical to understand and manage watercourse systems with their multifaceted interdependencies and interrelationships across their boundaries, in areas such as policy making, planning, decision making, resource allocation(s) and action(s) in order to accomplish a goal of sustainably managing the delivery and use of potable water. Each essential phase from definition through deployment involves human, behavioral, economic, environmental, enterprise and political concerns; each rife with its associated analysis, formulation and interpretation challenges [23].

Equally important, the resulting Systems Architecting paradigm(s) provides clear separation of drivers or concerns—particularly the dynamic consistency between the competing enterprises which must yield an integrated framework for an ecologically conscious process within a more global perspective—a daunting challenge even for a country such as the U.S.

Jordan

The government was concerned the scarcity of water could ultimately place a cap on agricultural and industrial development. The King Talal Dam built in 1978 on the Az Zarqa River, formed Jordan's major reservoir. In 1985 Jordan consumed about 520 million cubic meters of water, of which 111 million cubic meters went for industrial and domestic use, and 409 million cubic meters went for agricultural use. By 1995 it was estimated that domestic and industrial consumption would almost double and agricultural demand would increase by 50% so total demand would be about 820 million cubic meters.

Although no comprehensive hydrological survey had been conducted by the late 1980s, some experts believed the demand for water could outstrip supply by the early 1990s. Average annual rainfall was about 8 billion cubic meters, most of which evaporated; the remainder flowed into rivers and other catchments or seeped into the ground to replenish large underground aquifers of fossil water that could be tapped by wells. Annual renewable surface and subterranean water supply was placed at 1.2 billion cubic meters but total demand was more difficult to project.

In the late 1980s, the government had completed several major infrastructure projects in an effort to make maximum use of limited water supplies and was considering other projects. A second major construction project underway in 1989, the Wadi al Arabah Dam, captures the floodwaters of the Yarmuk River and the Wadi al Jayb (also known as Wadi al Arabah) in a 17 million cubic meter reservoir. These two dams and innumerable other catchments and tunnels collected water from tributaries that flowed toward the Jordan River and fed the 50-kilometer-long East Ghor Canal. Plans called for the eventual extension of the East Ghor Canal to the Dead Sea region, which would almost double its length. In 1989 about fifteen dams were in various stages of design or construction, at a total projected cost of JD64 million. (See Figure 3)

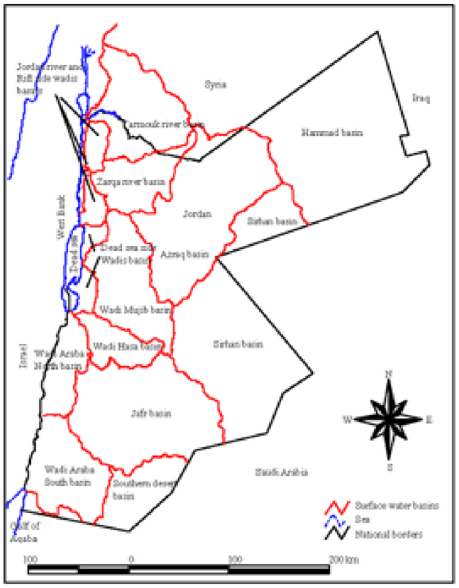


FIGURE 3 – JORDAN'S SURFACE WATER BASINS

By far the largest of these projects, a joint Jordanian-Syrian endeavor to build a 100-meter-high dam on the Yarmuk River, is the Al Wahdah Dam; named to reflect the political rapprochement that made construction feasible (Al Wahdah means unity). In 1988 the United States attempted to mediate between Jordan and Israel, each fearing the dam would limit its own potential water supply; Syria, however, refused to join any tripartite negotiations. In 1989 serious consideration was being given to two proposals to construct major pipelines to import water. Completion of either project could be a partial solution to Jordan's water scarcity. Because of cost, however, neither project was likely to be constructed in the near future. One project was to construct a multibillion-dollar 650-kilometer-long pipeline from the Euphrates River in Iraq. The pipeline would supply Jordan with about 160 million cubic meters of water per year. The other project, on which feasibility studies had been conducted, was to construct a 2,700-

kilometer-long pipeline from rivers in Turkey, through Syria and Jordan, to Saudi Arabia. Jordan could draw an allotment of about 220 million cubic meters per year from this second pipeline. The estimated US$20 billion cost of the latter project was thought to be prohibitive. By the year 2000, projected demand was estimated at 934 million cubic meters. Jordan, therefore, would need to harness almost all of its annual renewable water resources of 1.2 billion cubic meters to meet future demand, a process that would inevitably be marked by diminishing marginal returns as ever more expensive and remotely situated projects yielded less and less added water. The process also could spark regional disputes—especially with Israel—over riparian rights.

The Jordanians' interest in increasing irrigated agriculture of the lower Jordan valley, (see Figure 4), led them to build the King Abdullah canal enabling them to use 120-130 mcm of the water from Yarmouk River, in addition to the Zarqa River as well as several other intervening seasonal streams [24].

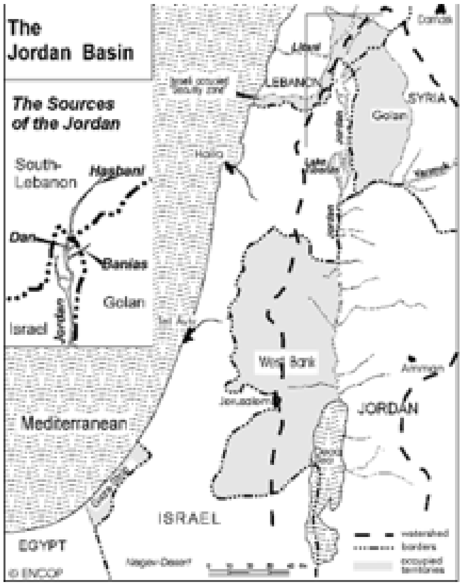


FIGURE 4 – THE JORDAN BASIN

Designing Reliable Support Systems During Politically Discontinuous Times

Nearly a third of the world's population will face severe water shortages in the next 25 years [25]. Given potable water scarcity is likely to be a problem affecting all of us how can we effectively use reliability analysis to help make the all-important decisions of helping water users optimally manage this scarcity situation?

Using Israel's potable water solutions as an example, their products and systems are designed for a harsh desert environment, replete with sand and dust that clog machinery. They work well in this environment, but are not necessarily readily transferable to an environment such as found in Holland, for instance, which has different environmental requirements. Given the precarious nature of Israel's regional political situation, the logistics support system must ensure supply, maintenance and distribution policies are properly balanced for both times of peace and war. Commercial product reliability may be driven by competitive marketing strategies, liability concerns, and warranty cost goals, whereas their military goals may focus on the operational needs of their users as constrained by support cost considerations. These objectives are typically specified by metrics requirements for logistics product reliability and mission system reliability. Without product or system redundancy, these metrics are equal.

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

Defining End-User Requirements

Developing reliability requirements for products and systems is a multi-step process comprised of requirement scenarios that can either be Explicitly Expressed, Implicitly Expressed or Not Expressed. These three scenarios use differing techniques to address product or system requirements.

Explicitly Expressed implies specifications and quantitative data are available to establish the mean-time-between-failure (MTBF) for the reliable delivery of water or the percent of reliability mean-time-between-critical-failures (MTBCF) for the entire water system's reliability, etc. These values are adjusted to consider local factors (e.g., infrastructure, political dissent amongst water sharing entities, etc.) that may cause failures and help to enhance design goals.

For the *Implicitly Expressed* scenario, there are specifications available for providing water delivery or system-wide characteristics, such as infrastructure or support costs. Known or hypothesized relationships are used to adjust the specifications (frequently using trade-offs to find the best possible solution), given the stated constraints, so that the level of reliability needed can then be derived.

Scenarios that are *Not Expressed* generally do not have similar or competitive products or system data and must use other approaches to obtain information, such as surveys, or past experience, or Quality Function Deployment (QFD), etc.

Development of Goals and Requirements: Design

Designing a strategy to derive goals and define requirements begins with understanding the characteristics of the hydro and geo-political environment in which the water product and/or system will ultimately be used. Very few environments are static, as seen in the above descriptors for the various countries/states but, even in a vacuum or totally isolated state, with time a factor, that environment, over time, will succumb to stress.

Determining the operational stresses over time the water product or system may be expected to experience is the first step in establishing performance-based reliability requirements. This process is used to identify the scope and magnitude of the end-use environments to which the product or system will be exposed throughout its useful life; the Al Wahdah Dam and subsequent pipeline projects serve as an example.

Fault-Tolerance (or graceful degradation) is the description of a design property that enables a product, with its rules of interaction amongst the system(s) delivering it, to continue to operate properly despite the occurrence of a failure of one or more of the system components or parts. If the operational quality decreases at all, the decrease is proportional to the severity of the failure, as opposed to an approach that has not been designed in alternate means to continue product or system operation when components fail. Fault-Tolerance is particularly useful in high-availability or life-critical products, such as clean water delivered to a country or state, or systems. Increasing redundancy does yield higher-level product goals, but lowers the series reliability potential by increasing the chance for masking dangerous failures [26]. Fault tolerance approaches, at the macro level—"x" gallons of clean water delivered per "y" hectares of farmed land—would be difficult to introduce to third world countries. However, fault tolerance approaches throughout those countries' water delivery infrastructure would be a necessity.

Allocations design translates product level reliability goals and requirements into reliability goals and requirements for the lower assembly level, e.g., water delivery infrastructure, requirements based upon complexity, part counts, etc. It also provides an effective means to check reliability requirements for realism.

Development of Goals and Requirements: Analysis

While availability of water is synonymous in the advanced industrialized countries with a 24-hour uninterrupted supply, the situation is radically different in most developing countries, as evidenced above and in Part 1's article, where water is often available only on an intermittent basis. Thus, it's difficult to envision a robust, in-depth, RMS-centric engineering approach and outcome(s) while conducting anything close to a "deep analysis" of the design plans for the water delivery infrastructure/systems in third world countries. However, portions or higher-level adaptations of the following analysis techniques would be appropriate and necessary during the development of, or improvements to, the existing water delivery infrastructure of any developing country or state. In addition to design elements, analysis techniques are used to develop reliability requirements, e.g., a *Durability Assessment*, which determines whether or not the mechanical strength of the water delivery infrastructure, including containment, will remain adequate for its expected life and identify any life-limiting aspects.

Required test plans and test allocation must be carefully selected to ensure cost(s) versus minimal need and determine if a reasonable compromise between the accuracy and the cost of the test(s) has been met [27].

Given the harsh climate(s) these developing countries live in, *Environmental Characterization* would be a necessity in order to define the operational and environmental stresses that the water delivery systems will experience. Without an understanding of the stresses to be experienced by a product, the statement of reliability objectives, explicitly or implicitly, is meaningless.

Other analysis tools/techniques to consider deploying would include: Life Cycle Planning, Analytical Modeling and Simulation, Predictions Analysis, Thermal Analysis and Benchmarking.

Available resources, the technical capabilities and the culture(s) of the states/countries will influence the selection of any analysis tools. Centuries of existence have formed deep-rooted social and political forces amongst and between these countries. These cultural settings will be formidable influencers over any attempts to introduce or balance the water needs of neighboring or close-by countries.

Conclusions

Water scarcity is a serious threat to regional peace and stability. There is potential for saving water in the agricultural sector by improving efficiency of water use and improving irrigation management. Although social development is likened to energy and electricity supply, building dams is not the total answer to economic prosperity. To end poverty and advance economic development, countries such as Ethiopia may need to make other policy choices and invest in good governance, education and public health.

Many of the countries surrounding Israel have populations that could benefit from being a participant in local water technology improvement work projects and also benefit from increased training opportunities. This could be an opportunity for the entire Middle East and Israel, should they decide to work cooperatively to plan, and install potable RO water solutions throughout all their regions together. If Israel would be willing to train and hire the customer countries' local population labor forces to use for their labor pool when installing new potable water systems, they would have access to a work force that is less expensive than their current one. The customer country would also benefit from this arrangement by having more of their population receive some training and income, which results in a "trickle down" effect for their economy, helping it become even more reliable and stable. As part of their contract, the customer country may also agree to increased capacity building in the water sector to ensure the operational environment includes training and educating of their managers and technical staff, and to ensure their work meets the accepted international quality standards, so each country's local population may be able to manage their own water systems once they are in place. Israel, Jordan, Palestine, and Egypt all use wastewater management, and their programs are overseen by internal federal agencies.

Additionally, policy makers will need to become versed in the need for their oversight and planning support by creating defining guidelines, implementing new contracts as required and ensuring there are methodologies in place so the legal framework is in sync with the newly installed water technologies. This could also be a contractually specified training program option [28]. These customer countries would benefit from reduced operating costs by having their own populace managing their day-to-day operations internally. They would also benefit from having a net increase of internal capabilities by having their populace employed and receive on-going training as new technologies and processes evolve. Countries may further benefit by inviting private sector participation (PSP) into mutually beneficial partnerships, that can share the risks, provide capital investments, and add operational efficiencies and high-tech expertise, such as the local Water Consortiums used in Israel. This presumes the water consumers are able to afford their services, or alternatively, the Government is able to provide an adequate guarantee, so the water provider can make a fair return on their monies invested. Some contracts may provide an asset transfer back to the Government, once the privet sector trains the Government workers, stabilizes, and standardizes the internal operational processes. Or, the contract could be a term contract and would be renegotiated after a specified expiration date [29]. Creative "teaming" is an option to help build bridges between countries struggling to help their populace survive during these uncertain times.

Even if all of the forgoing options are unlikely to be accepted as possible by all the people at the same time, the need is so critical that even smaller, incremental steps are important and worthwhile doing. By agreeing to a limited trial of a small, well-defined project, it can become an all-important-first-step towards ensuring potable water for this and future generations.

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About the Author

Katherine Pratt holds a B.A of business administration in management systems from the University of Iowa. She is president of Enviro-Logistics Inc., West River, Maryland, having provided comprehensive services to agencies and corporations in the areas of Access SQL, technical writing and contract administration. She has been a professional logistician and contracts administrator for over 17 years; she is currently serving as the Coordinator of Environmental Affairs for RMS Partnership Organization, and has been a member of the Board of Directors for The Society of Logistics Engineers (SOLE). Some of the awards she has received include:

- SOLE: Rear Admiral Bernard Eccles Award (recognized excellence in logistics), '97
- "ISO 14000, A Framework For Environmental Management," presentation at International Society of Logistics 1996 Symposium, August 1996, Washington DC (awarded Prize Paper Proceedings)
- "Environmental Economics and Logistics Engineering" Journal of the Society of Logistics Engineers Logistics Spectrum", Vol. 27, No. 2, pp. 22-27, July 1993 (awarded Best Paper honorable mention)

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