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Obsolescence and Life Cycle Management for Avionics

November 2015

Final Report

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16. Abstract
This research identifies ways to identify and mitigate obsolescence risks in avionics and to provide related aviation safety input to the Federal Aviation Administration for the development of regulations, policy, guidance, and training. Obsolescence and obsolescence management of avionics products are a technically challenging and costly financial problem with many adverse business impacts for both the avionics suppliers and their customers. Though obsolescence is not unique to the aerospace industry, it presents special problems because of the typically long life cycle of aircraft and a requirement to comply with airworthiness regulations that make continuous change complex and costly. Obsolescence is the inevitable consequence of the dependence of aerospace on a supply base whose major markets are outside of aerospace and whose technology life cycles are much shorter than those of other markets. Aerospace has a continual demand for technological progress in aircraft system capabilities and safety improvements, but on a much longer timescale than the technology turnover timescale of the supply base. Obsolescence is an inevitable occurrence; therefore, the goal of obsolescence and lifecycle management is to minimize the recurring cost impacts and the disruption of supply to customers while maintaining continued airworthiness and regulatory compliance.

This report describes the current state of obsolescence management in the aerospace industry; the processes, standards, and tools now being used; and the underlying causes. The report addresses the identification, mitigation, and avoidance of issues related to obsolescence in systems, software, and airborne electronic hardware development; the related design assurance and certification considerations; and optimal methods for life-cycle maintenance and technical refreshment. The report identifies known and emerging obstacles, problems, issues, and gaps in existing standards and guidance; proposes standards and assurance techniques that may minimize the impact of obsolescence; and suggests how manufacturers can proactively plan and manage the life cycle of their products. The report describes the extant research on numerical methods for obsolescence risk assessment and related economic modeling, and provides recommendations for further public guidance and standards that would assist industry and users in adapting to a dynamic environment. The report suggests some industry and regulatory practices that could promote best practices; reduce costs and inconvenience; and improve the product life-cycle planning process. Finally, the report suggests some relevant research topics that are not well addressed presently and should be considered for future work.

The report suggests that the obsolescence problem cannot be solved only by engineering methods, but also requires proactive measures and risk-awareness planning by both customers and suppliers. Obsolescence is a complex mix of engineering, economic, and business issues with many associated uncertainties. These uncertainties arise from the supply base and the customer base, which require marketing, engineering, and economic planning and analysis using numerical risk-assessment methods that measure uncertainty.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance-Broadcast
AEH	Airborne electronic hardware
ASIC	Application-specific integrated circuit
ATC	Air traffic control
B2B	Business-to-business
BB	Bridge buy
BGA	Ball grid array
BOM	Bill of materials
BSI	British Standards Institution
CAST	Certification Authorities Software Team
CCA	Circuit-card assembly
CFR	Code of Federal Regulations
CIS	Component information source
CM	Configuration management
COTS	Commercial off-the-shelf
COTS IP	Commercial off-the-shelf intellectual property
CPDLC	Controller-pilot data link communications
DAL	Design assurance level
DoD	Department of Defense
DLS	Data link services
DMEA	Defense MicroElectronics Activity
DMSMS	Diminishing manufacturing sources and material shortages
EASA	European Aviation Safety Agency
ECMP	Electronic Components Management Plan
EIA	Electronic Industries Association
EOL	End of life
EOS	End of support
EU	European Union
EUIR	European upper flight information region
FAA	Federal Aviation Administration
FFPA	Functional failure path analysis
FPGA	Field programmable gate array
GA	General aviation
GEM	Generalized Emulation of Microcircuits
GIDEP	Government and Industry Data Exchange Program
HAL	Hardware abstraction layer
HDL	Hardware description language
HLR	High-level requirements
ICA	Instructions for continued airworthiness
IEC	International Electrotechnical Commission
IECQ	International Electrotechnical Commission Quality Assessment System For Electronic Components
IHS	Information Handling Services

IP	Intellectual property
ITRS	International Technology Roadmap for Semiconductors
LCC	Life cycle cost
LOTE	Life of Type Evaluation
LLR	Low-level requirements
LRU	Line replaceable unit
LTB	Last Time Buy
MAB	Multi-arm bandit
MOCA	Mitigation of Obsolescence Cost Analysis
MRI	Material risk index
MSL	Moisture sensitivity level
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NPRM	Notice of Proposed Rulemaking
NRE	Non-recurring engineering
OEM	Original equipment manufacturer
PBL	Performance-based logistics
PCN	Product/process change notice
PD	Programmable device
PLD	Programmable logic device
QA	Quality assurance
RNAV	Area navigation
RoHS	Restriction of (the use of certain) hazardous substances
RTCA	Radio Technical Commission for Aeronautics
SAC	Sn/Ag/Cu
SB	Service bulletin
SESAR	Single European Sky Air Traffic Management Research
SIL	Service Information Letter
TC	Type certificate
TOC	Total ownership cost
TSO	Technical Standard Order
UL	Underwriters Laboratories
VHDL	Very High Speed Integrated Circuit Hardware Description Language
YTEOL	Years to end of life

EXECUTIVE SUMMARY

The approach to the obsolescence and life-cycle management problem should be multifaceted, containing both an engineering element and a business/cost element. There should be both a system-level approach with top-down analysis and a component-level approach with bottom-up analysis. Both of these should be supported by business and economic analyses of a range of alternative solutions with the objective of selecting a solution that is optimal. Module-/subsystem-level design and analysis will work as a link between these two approaches. The analysis must include both technical and market forecasts from all sectors of the industry and the underlying supply chain. Any long-term planning for tackling obsolescence must recognize that "commercial off-the-shelf" is now the normal business model for avionics systems in all markets, except space and specialized military, and the supply chain is no longer focused on aerospace as its principal market segment. Obsolescence management practices must recognize that technological advancement is a necessary and desirable feature of the aerospace business and cannot be sacrificed solely to maintain old systems.

The military specification system for components and the captive supply base that dominated aerospace for so many years is now redundant and ineffective for all practical purposes. The bulk of the supply chain has changed its focus to serving other higher-volume markets than aerospace. To minimize obsolescence resolution costs, the risk of loss of configuration control, recertification cost, customer dissatisfaction, and other negative impacts of this revolutionary change, the avionics manufacturing industry is investing in obsolescence management infrastructure and practices; however, these are largely reactive to notified obsolescence events. The next step on the obsolescence management capability ladder is to develop proactive and predictive methods that take a holistic life-cycle view to improve the product life-cycle planning capability.

The problem is highly complex and intimately tied to the business objectives of many stakeholders, so there is no single answer and probably no simple answer. The solutions must include a comprehensive business-, data-, and economics-driven approach to selecting and managing parts and planning the life cycle of a product; recognition that some form of intra-industry and government-industry cooperation is necessary to promote best practices; and complete acceptance of the transformation in engineering methods and product life-cycle planning that this implies. Essentially, the obsolescence and life-cycle management problem is one of making use of available data and analytic tools to make predictions about future events, then prepositioning activities that can respond quickly and at minimum cost to those events, if and when they occur.

Like any forecasting methodology, the proactive, predictive approach does have its limitations. This approach cannot take into account future gluts and scarcities in the component market due to unforeseen market crises, natural disasters, disruptive technology innovations, or mergers and acquisitions. Obsolescence can never be eliminated; it is a natural part of the continuing technology advancement needed to respond to customer and end-user needs, but manufacturers can improve the efficiency of their operations and provide a better experience for their customers.

1. INTRODUCTION

This research identifies ways to mitigate obsolescence-based risks and to provide related aviation safety input to the Federal Aviation Administration (FAA). This report addresses the identification, mitigation, and avoidance of issues related to obsolescence in systems, software, and airborne electronic hardware (AEH) development; design assurance; certification; life-cycle maintenance; and technical refreshment. This report also considers the ways in which avionics manufacturers can proactively manage the life cycle of their products. The outputs generated from this research will be used by the FAA as inputs for the development of FAA regulations, policy, guidance, and training. This report details the investigations of the issues and causes of obsolescence in aircraft, systems, software, and AEH, and the possible methods of mitigating these risks. This report identifies known and emerging obstacles, problems, issues, and gaps in existing guidance and proposes standards and assurance techniques that may minimize the impact of obsolescence risks. This work was conducted in two phases.

Phase 1 focused on general aviation (GA) aircraft. The objective of the first phase was to develop, execute, and complete a plan that addressed the following questions:

1. What are the causes and effects of GA parts obsolescence (e.g., changing operational environments, such as using Global Positioning Systems versus VHF omnidirectional range, Automatic Dependent Surveillance-Broadcast (ADS-B) versus Radar, Next Generation Air Transportation System (NextGen), etc.)?

2. What issues (e.g., inability to address an unsafe condition during the Airworthiness Directive development process when engineering resources; development environments and tools; software; and/or electronic parts that are no longer available) and related costs (e.g., new replacement parts) are incurred in aerospace applications because of GA parts obsolescence?

3. What trends in cost/savings can be achieved by resolving or improving the GA parts obsolescence issues, and what can practically be done (e.g., mandating that manufacturers make lifetime spares buys and/or provide free product recalls/updates, or FAA taking ownership of "orphaned" software or hardware)?

4. How does the evolution of electronic device interfaces and the associated standards result in GA parts obsolescence issues, including those associated with timing, power, thermal, environmental, and component\technology size characteristics?

5. How do the evolution of software standards, tools, languages, and on-aircraft applications affect GA parts obsolescence issues and cost?

6. How do the evolution of required skills, the perishable nature of those skills, and changes in associated tools and processes result in GA parts obsolescence issues, including those associated with training, retraining, concurrent personnel requirements, personnel acquisition strategies, and related GA parts obsolescence risks?

7.	How does GA parts obsolescence in airborne systems—including displays, communications, local area networks, flight control, guidance, and navigation—affect aircraft life-cycle maintenance and requirements for technical refreshment?

8.	How does the continuing trend toward larger, more complex systems on aircraft affect life-cycle GA parts obsolescence at all aircraft levels, from components to GA aircraft?

9.	What approaches are being used by industry to minimize the impact of obsolescence on GA aircraft systems, software, and airborne electronic devices? What technologies can be used to mitigate the issues and costs of GA parts obsolescence (or should we limit technology or mandate strict standards for processors, languages, etc.)?

Phase 2 focused on the following:

1.	Conduct literature searches, surveys, and/or other contact approaches to aid in identifying current and future GA parts obsolescence risks, mitigation practices, and related issue and cost information.

2.	Identify current industry practices for GA parts obsolescence risk detection, mitigation, and metrics for the occurrence in avionics life cycle applications.

3.	Identify known and emerging obstacles, problems, issues, and gaps in existing GA parts obsolescence guidance. Recommend mitigation techniques related to current and future GA parts obsolescence faced by equipment developers (i.e., component, subsystem, and system), government, and airlines.

4.	Determine existing research and development (R&D) work in GA parts obsolescence related to these causes and issues, and propose approaches to mitigate these obstacles, problems, gaps, and issues.

5.	Propose standards and assurance techniques that may minimize the impact of GA parts obsolescence risks.

6.	Identify industry approaches that may require new or modified design assurance, certification/airworthiness policies, standards, and guidelines/technologies to mitigate GA parts obsolescence risk.

2. LITERATURE SEARCH

Extended obsolescence and life-cycle maintenance references, including some with abstracts, are provided in appendix C. These references are listed alphabetically by first author. A separate list of the references listed in the text is provided in section 13.

These references relate mainly to hardware, though a few discuss software obsolescence. The literature is largely silent on obsolescence at the system level (e.g., that arising from changes in the operating environment or from regulatory action) and on the problems associated with maintaining tools and platforms for long periods.

The majority of references are generated within the aerospace industry, but some come from the nuclear, oil, gas, and chemical industries, which have many of the same concerns as aerospace (i.e., their regulated and safety-critical nature).

The economic modeling references are generated predominantly by universities. These references belong to a largely self-contained group and do not appear to have had significant take-up by industry because they are not cited in the other literature to any significant extent.

There are few references that deal with the specifics of industry internal processes, which can be attributed to a desire to protect proprietary information and a competitive position.

The sources for these references fall into four main classes:

- Engineering journals and conference papers
- National and international standards and other guidance materials (e.g., military and regulatory documents)
- MSc. and PhD. university theses
- Economic modeling journals and conference papers

3. CURRENT INDUSTRY PRACTICE

Obsolescence management is the sum of the methods, tools, and processes for detecting and resolving obsolescence cases when they arise (the reactive process) and of the methods for taking active measures to avoid or reduce the impact of obsolescence (the proactive process) [1]. Proactive methods include, for example, identifying and ranking critical components according to their forecast risk of obsolescence prior to its occurrence or notification through predictive methods; quantitative methods for the selection of resolution options; and imposing quantitative obsolescence risk assessment rules and restrictions within the design processes. Presently, best-in-class industry maturity can best be described as being at the top end of reactive because many of the above techniques for proactive obsolescence management are either not available or not widely implemented.

Recognition of obsolescence as a problem (and its subsequent management) has been an evolutionary process in most organizations. Consider the following hypothetical electronic systems manufacturing company. Initially, a new company with a new product design is unlikely to have any immediate experiences of component obsolescence and, therefore, will not develop formalized processes to deal with it until it becomes a regular occurrence. In the aviation industry, there is little or no public guidance to assist companies in setting the scope or content of obsolescence management processes. What usually develops first is a reactive process involving a few key departments, such as purchasing and engineering. In a small firm with a limited product line, this may suffice indefinitely; however, in companies with broad and aging product lines, priorities often begin to conflict and departmental boundaries reduce the level of communication. These factors, the cost of reactively resolving problems, the loss of revenues (through stalled production and sales), and downtime (through lack of available spares) eventually drive the firm to expand the scope of the reactive resolution process, often supplementing the process with an action-tracking tool that records the progress of resolution

from notification to implementation. As obsolescence management in the organization matures, it will devote resources to the monitoring of the component life cycle and use that information to take mitigating action prior to development of a critical situation (proactive management). At this maturity level, the organization is willing to make tradeoffs, such as devoting less engineering budget to new product development in favor of the rejuvenation of older products or deciding to stop production or support of aging products at the expense of potential revenue. The more time that is available to react to obsolescence, the better the solutions will be in terms of cost and ease of implementation. Ideally, an effective obsolescence management process addresses the product design; qualification; test and certification; supply chain; inventory; and the manufacturing and repair implications of the solution, and it also engages each affected business function at the optimum point. Nearly every business function, from marketing to product support, feels some impact from an obsolescence event.

The overriding goal of obsolescence management is to minimize life-cycle cost (LCC) (i.e., enact the most cost-effective solution in terms of component costs, overhead, schedule impact, factory downtime labor consumption, support, and operations costs that satisfies customer needs). It is important to note that LCCs are borne by all the stakeholders (i.e., operators, aircraft and avionics suppliers), so minimum LCC can mean different things to different stakeholders.

To make these decisions, the participants must have access to all relevant information (e.g., the last time buy window; what second sources or equivalents can be found; what component stocks exist in distribution or can be sourced through brokers or aftermarket suppliers; and what the demand forecast is, possibly across multiple programs). They must be granted the latitude to act decisively in the resolution of obsolescence cases. What must not be lost in the process is a focus on the needs of the customer.

Discontinuance by component manufacturers, resulting in obsolescence, is driven by several factors (e.g., when a component manufacturer realizes that a given component or technology is no longer profitable; is less profitable than others; could be produced using the same factory floor space and work force; or the manufacturing process is underutilized). Alternatively, component manufacturers may discontinue a component because of market changes; legislation; corporate policy changes; product line rationalization after mergers and acquisitions; and other external influences [2].

In the semiconductor industry, there is an established process by which component manufacturers issue product/process change notices (PCNs). They communicate everything from minor manufacturing changes to component end of life (EOL) using the PCN vehicle [3]. This practice builds an expectation that all component manufacturers should issue such notices with the same level of discipline; unfortunately, the level of communication varies among manufacturers.

The PCNs are distributed in text format by various means. These means, in general, require that avionics manufacturers manually review and process each one of them to determine if it is relevant and, if it is relevant, open a case resolution record in the action tracking tool.

Business-to-business (B2B) systems are not yet widely deployed to at least semi-automate PCN processing by the recipient.

For most component manufacturers, obsolescence is usually announced 6–12 months in advance of the last time buy date, but can also occur instantaneously as the result of natural disasters or the demise of a key supplier of materials or technology; lesser notice periods are not uncommon. The terms "last time buy" and "lifetime buy" are closely related and used by the industry. There may also be a 6–12 month later last ship date by which the component manufacturer will have shipped all available product. A single PCN may include many different components from that manufacturer. A PCN may also announce that an EOL notice is withdrawn. The PCNs may or may not identify alternative components. Automated manufacturing processes often need components to be supplied in packaging that is compatible with pick and place machines. Avoiding manual handling greatly improves productivity and reliability. If the component manufacturer discontinues or changes the packaging, it may no longer be compatible, effectively making the component obsolete even though it is still available.

Aerospace Qualified Electronic Components, an industry initiative, has written a procurement specification for electronic components for avionics use [4]. One of the requirements is that manufacturers supplying components to this specification should give five years notice of obsolescence or, if less, provide information on how to obtain components from alternative sources. This specification does not seem to have gained widespread adoption in the component supply industry; approximately five manufacturers are using it on a limited basis.

Equipment manufacturers are increasingly finding that it is no longer economically feasible to purchase and operate the capital equipment and facilities required for the assembly of today's high-density interconnect and miniature electronic components, so they rely on contract manufacturers to provide circuit-card assembly (CCA) services. If the equipment manufacturer chooses to delegate component procurement to the subcontractor (as many do), then there is a risk that the equipment manufacturer may no longer receive critical PCNs associated with the components. Regardless of the components used or the product manufacturing process, it is incumbent on the equipment manufacturer to detect all obsolescence activities at the earliest possible time and direct them to the correct areas or individuals within the organization for prompt disposition.

Current industry practice covers a range of capability from being completely reactive to being to some degree proactive, which is largely a function of size and available resources; the larger companies are able to devote more resources to obsolescence management. Manufacturers that are only reactive are largely oblivious to the looming obsolescence problem until they are unable to procure materials to fulfill additional production orders. Such manufacturers take no design measures to ease the resolution process or actively monitor the supply base for EOL announcements. As a consequence of this lack of preparedness, they experience frequent production stoppages and lose customers. At the other end of the spectrum, a manufacturer who is proactive recognizes the inevitability of obsolescence and maintains an active surveillance of the supply base and all the components used and designs products that minimize the frequency, cost, and time to make and field changes.

The U.S. Department of Defense (DoD) has developed a four-level scale to characterize this maturity level [5] (reproduced in table 1). Diminishing manufacturing sources and material shortages (DMSMS) is the military term for obsolescence. This scale is analogous to the software capability maturity model developed by Carnegie Mellon University and widely adopted by software-writing organizations. This scale is useful for grading all types of aerospace manufacturers:

- Level 1–largely reactive practices sufficient to resolve known obsolescence problems
- Level 2–more proactive practices sufficient to mitigate the risk of future obsolete items
- Level 3–proactive practices sufficient to mitigate the risk of obsolescence when there is a high probability/opportunity to enhance supportability or reduce total ownership cost (TOC) (these proactive activities may require additional program funding)
- Level 4–proactive practices implemented during the conceptual design of a new system and continued through its production and fielding

To move through these maturity levels, the manufacturer must have an increasingly extensive set of mandatory internal process rules and documents that detail the process steps and requirements; mature quality assurance (QA); and oversight mechanisms and methods to assure that they can be audited and followed.

Table 1. DMSMS mitigation practices for each intensity level [5]

Intensity Level 1	Intensity Level 2	Intensity Level 3	Intensity Level 4
DMSMS program established and funded DMT format DMT trained in • DMSMS fundamentals • DMSMS for executives DMSMS program plan written and approved Complete BOM developed with periodic reviews planned to keep it current Solutions to near-term obsolescence problems implemented For new acquisitions, DMSMS tasking and data byproducts inserted in the development, production, or support contracts	All Level 1 practices implemented BOM processing through a predictive tool Results of predictive tool output analyzed DMSMS solution database established Budget established to fund obsolescence solutions Website established Method established to prioritize LRUs/WRAs for DMSMS risk	All Level 2 practices implemented DMSMS life-cycle costs and cost avoidance estimates developed DMT trained in • DMSMS essentials • DMSMS case studies • Advanced DMSMS Funding shortfall and impact identified and communicated to decision makers For legacy systems, DMSMS tasking and data requirements included in applicable contracts DMSMS metrics established* Electronic data interchange used	All Level 3 practices implemented Technology road mapping used System upgrades planned Technology transparency attained Accessibility realized for alternate source development (VHDL, emulation, MEPs)

DMT = Diminishing Manufacture Technologist; BOM = bill of materials, MEP = Manufacturing Extension Partnership, VDHL = Very High Speed Integrated Circuit Hardware Description Language, LRU = line replaceable unit
*Metrics include number of cases, number of solutions implemented, life-cycle costs, and cost avoidance.

Current industry practice is variable, but can best be described as reactive (i.e., levels 1 and 2 in table 1, though some avionics manufacturers can justifiably claim elements from level 3). This is true for avionics manufacturers and even more so for aircraft manufacturers. Information on the specific practices of manufacturers is generally subject to proprietary information restrictions or is not attributable. This summary has been obtained through publically available information (e.g., papers, conferences, and articles). In general, the processes described do not particularly distinguish GA obsolescence or treat it any differently than is done for other aircraft types. A questionnaire to assist manufacturers in a self-assessment of obsolescence management capability maturity is given in appendix A.

Airbus has introduced a supplement to its top-level equipment requirements document, ABD-100 [6], to outline the key characteristics and objectives of an obsolescence management process that its suppliers should follow. The application of this supplement is dependent on specific contract language and is not known to have yet been invoked on procurement contracts.

Boeing document D6-55583 [7] is the top-level requirements document for a supplier Electronic Component Management Plan. This document is presently under revision to include obsolescence management.

In the military arena, Thompson-CSF describes a partially proactive approach encompassing a preferred parts list, obsolescence recovery actions, and life cycle analysis approaches to minimize future impact [8]. Raytheon has developed its own tool to track the life-cycle status of the components in its approved parts database [9]. Alenia has reported on a proactive obsolescence management process for military systems [10].

Honeywell implements a process that is documented through company-wide procedures enforced by the QA system. This process is shown in figure 1. Honeywell obtains notifications of impending obsolescence through various subscription services, operates an obsolescence management tracking tool to assign the resolution method implementation responsibilities, and tracks each case through to completion. In addition, a tracking tool is used to manage and account for the various inventories of obsolete components located in multiple manufacturing sites, and to estimate and manage last Last Time Buys (LTBs) to control and allocate burn down of stocks on a global basis.
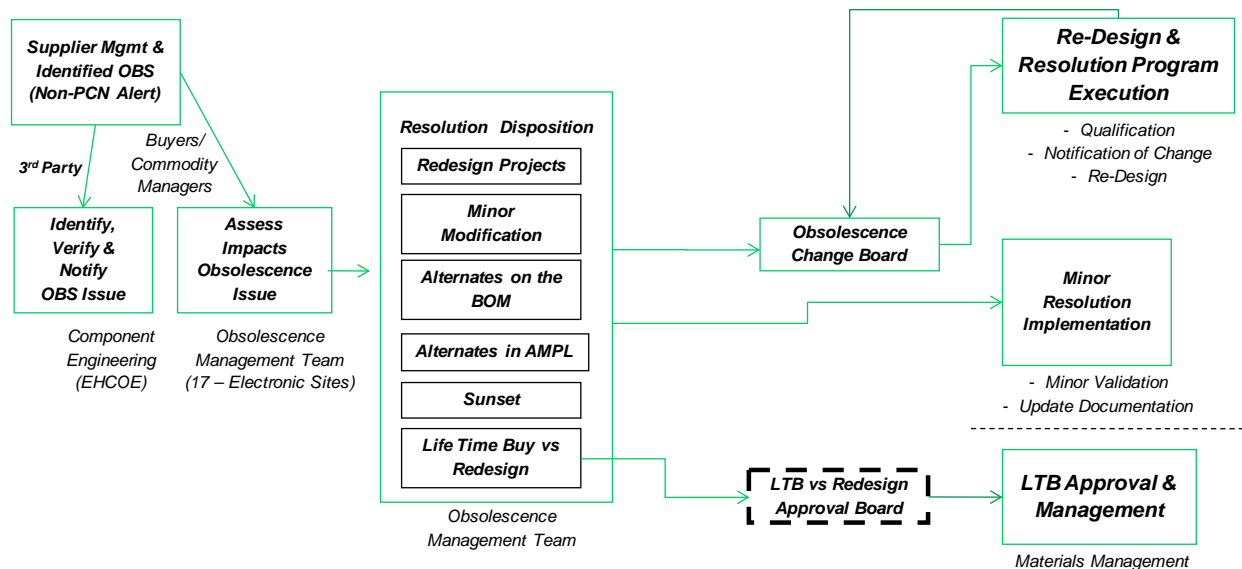

Figure 1. Honeywell obsolescence management process

3.1 RESPONSES TO OBSOLESCENCE

The types of obsolescence events mentioned above may occur at any time in the life cycle or even before first production has begun. If any of these events occur, the avionics manufacturer

has two basic options to choose from: 1) declare the product is discontinued (i.e., EOL) either immediately or at some future date or 2) attempt some recovery action to extend the life. These options are not mutually exclusive; EOL can be postponed by a recovery action and the EOL decision can be revoked at any time in favor of rejuvenation.

An example of a product discontinuation notice is given in Service Information Letter (SIL) KLN94 [11], which arose from the area navigation (RNAV) rule change [12]. This may either take place immediately or be postponed to a specific future date by depleting existing inventory, or it may be further postponed by using the numerous recovery options available (e.g., LTB, redesign, etc.). This may be followed by a decision to develop a replacement product.

Depending on the type of initiating event, a recovery action may be required from either the product design authority or the manufacturing source to extend the product manufacturing life to an undefined future date, when a further obsolescence event will again occur. The recovery action can be chosen from a number of options, such as redesign or substitution. A full list with descriptions is provided in two references [13 and 14]. Recovery action may also be needed to stand up the manufacturing process, execute manufacturing, and implement design tools with their host platforms, so that the redesigned product can be designed, verified, recertified, and produced.

Careful consideration of the business impacts and the use of decision-support tools is necessary to decide on an option that is, in some sense, optimal. Many options may be satisfactory from a narrow technical viewpoint, but each option will carry with it a different cost. Therefore, the decision is essentially to weigh the economics of the available options under conditions of considerable uncertainty. For example, uncertainty exists in the likelihood and timing of new airworthiness rules, legislation, planned product upgrades, new aircraft program launches, and future obsolescence events.

Customer goodwill can be lost when EOL is declared, driving customers to competitors. This can result in lost future sales and support revenue. The expense of recovery actions can range widely from minor (as with substitutions) to major (if the product needs to be recertified or if substantial reinvestment in design and manufacturing infrastructure is needed).

3.2 OBSOLESCENCE IN THE GA INDUSTRY

The nature and economics of the business and the relationship between the avionics supplier and the customer are significantly different between Part 23 and Part 25 avionics. There are a few large aircraft manufacturer customers for Part 25 avionics. Those customers sell to operating-cost-conscious airlines, and both consider LCC and negotiate long-term support contracts. The GA market is much more fragmented with more Part 23 aircraft manufacturers and many more owner-operator customers.

There are two basic types of GA avionics buyers: Part 23 aircraft manufacturers who, in turn, sell mainly to owner-operators and owner-operators who wish to add to the basic functionality provided as an original equipment manufacturer (OEM) fit. The GA avionics often have approved Technical Standard Order (TSO) alternatives from direct competitors that can easily be substituted. The GA avionics buyers are price sensitive; low initial cost to buy and install is a

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more important driver than long term LCC. The downside of this fragmentation and the cost sensitivity of the business is that GA aircraft owner-operators can only hope for continued support and can respond only by selecting an alternative product if this is not forthcoming.

Obsolescence management has much in common among all aircraft types; however, some features of the GA aircraft and avionics markets are unique. In general, GA aircraft and the smaller business class aircraft (generally Part 23 aircraft) use federated architectures consisting of a broad array of panel- and pedestal-mounted instruments interconnected by a similarly broad array of interface and wiring standards. Newer GA aircraft are trending toward more integrated systems offerings with flat panel multipurpose displays. This reduces weight and interfacing complexity, but also reduces flexibility to substitute competitor products.

Larger (Part 25) aircraft have integrated avionics suites that are certified for the particular type and are original equipment, though with some buyer-furnished equipment options. GA aircraft presently use mostly nonspecific, off-the-shelf TSO products that are certified for a broad range of GA and low-end business Part 23 aircraft. With the advent of integrated Part 23 avionics, similar unique certifications are beginning to apply to GA aircraft.

Though none of this affects the overall procedures used by avionics manufacturers in managing obsolescence, it does affect the economics of the possible resolution solutions that could be adopted and, therefore, the engineering and business solutions themselves. The underlying causes of obsolescence remain the same whatever the end market is. Obsolescence of avionics and aircraft is similar to that of any other durable goods product (i.e., competitor products may have more buyer appeal, which removes the market demand for the older products). Because of the high capital cost and the expense of change or replacement in avionics, manufacturers are pressured to continually adjust offerings to remain competitive. The Nash equilibrium point in marketing theory describes the situation.

Obsolescence is not simply a bottom-up supply chain issue causing lack of manufacturing and service capability. Obsolescence is also driven down from legislation, regulation, and aircraft manufacturers/owner-operators changing to a competitor's product. Avionics product obsolescence is either a consequence of the inability to produce or a consequence of a lack of demand. These consequences are due to different underlying causes.

3.3 MILITARY OBSOLESCENCE

Military programs suffer equally from obsolescence, though the management approach is significantly different from that of commercial aviation companies. The source of the differences is in the contracting/commercial business model and, therefore, the economics of the military business. The military program offices are generally responsible for the obsolescence problem for the unique systems and vehicles they procure and deploy. Military programs must plan to set aside a sustainment funding pot for supplier contracts for the refreshment of their systems over the complete life cycle, often 25 years or more. The military does not usually have the option of substituting a competitor product. For these reasons, the military logistics organizations (e.g., Defense Logistics Agency, Defense MicroElectronics Activity [DMEA], and various departments of the armed services) have invested heavily in obsolescence research [15 and 16]

and tools, and have sponsored the creation of several service-specific process guidelines (see section 3.10.3).

The military is beginning to address the uncertainties in the required logistics funding (of which obsolescence management is a part) by entering into performance-based logistics (PBL) contracts with platform and system suppliers. In PBL, the contractor assumes all logistics risk and charges it back at a contractually agreed-upon rate. Similar arrangements in the commercial market are called "power-by-the-hour" support contracts, initially conceived for Part 25 aircraft engines, but now also being used by fleet operators (mostly airlines) for all types of equipment. The supplier assumes all logistics risk and charges it back to the customer at an agreed rate based on operating hours. Both approaches require suppliers to price their overall risk at a profitable level, which is a difficult task given all the uncertainties that logistics entails.

This contractual approach could be applied in the GA market for many types of products, but this has not been done, likely because GA aircraft are not typically part of a large fleet with centralized maintenance. If the GA market did use the contractual approach, the same uncertainties in risk assessment and contract pricing models would apply. This is an economics research area that could leverage actuarial methods and models used in financial services and insurance industries that have been pricing risk for many years.

3.4 THE CAUSES OF OBSOLESCENCE

Figure 2 shows some causes of obsolescence. There are two major sources of obsolescence issues: 1) supply side, bottom-up supply-chain caused and 2) demand-side, top-down airspace-management and regulation-caused. Legislative action in the United States or abroad has the potential for either of these, as discussed in section 3.5.1. An obsolescence issue may arise because of product deletions in the supply chain of components; subassembly tools or platforms; legislation or standards; and airworthiness rule changes. The fundamental cause of the supply chain issue is that the aviation industry is not vertically integrated and depends on an extensive commercial off-the-shelf (COTS) supply base, which creates a gross technology life-cycle mismatch between the supply base and avionics manufacturing. The components supply chain is on a commercially focused technology cycle of approximately 2–7 years, whereas the life cycle of aircraft and avionics is typically 20 years or more. A more complete discussion of the underlying causes is provided in references [14 and 17]. The underlying cause of legislation-induced obsolescence is increasing societal demands for a less-polluted environment. Regulatory-induced obsolescence occurs along with the evolution of airspace management and associated air and ground systems in response to increasing public demand for more capacity, fewer delays, and continuous improvement of the safety record.
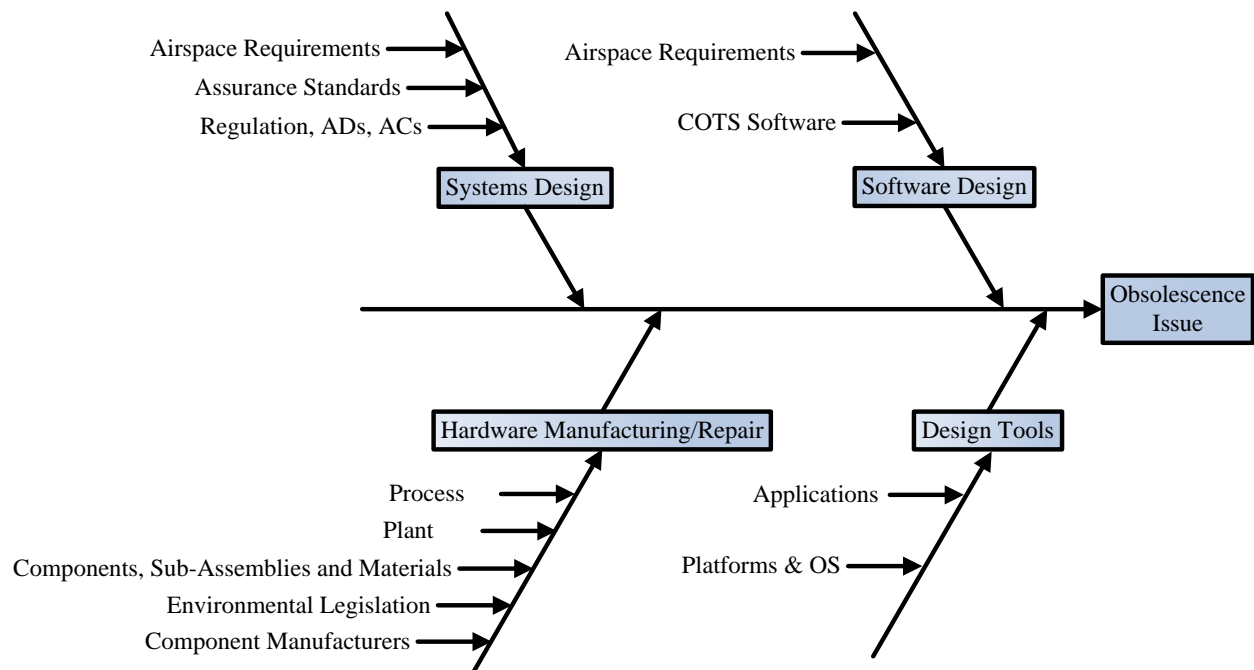
Figure 2. Obsolescence fishbone diagram

Figure 2 shows that many stakeholders cause or are affected by obsolescence. The avionics industry depends primarily on a commercial supply base for components and for most of the supporting tools used in design and manufacturing. The industry often uses contracted manufacturing and repair process capabilities, but is also driven by regulations and legislation.

3.5 OBSOLESCENCE OF SYSTEMS

Systems obsolescence refers to an entire line replaceable unit (LRU) reaching EOL because the manufacturer has made a business decision that recovery action is either not technically feasible or is not economical. Decisions are based on investment return or the fact that demand has declined to such an extent that the manufacturer believes continued production is not economical. Demand decline can occur when a competitor's product appears or the manufacturer introduces a new or upgraded product to maintain market share or occupy a new market niche. As with any product, the market ensures that supply and demand remain in balance.

Such cases may arise from either top-down causes, such as legislative or regulatory action (e.g., lead-free legislation and revised RNAV rules) or from bottom-up causes, such as actions taken in the supply chain, lost manufacturing capability, or from considerations of competitive position in the market.

Avionics suppliers generally notify customers and end users that a product has reached EOL by SILs or service bulletins (SBs). An example of an SIL arising from an RNAV regulatory rule change is given in section 3.5.2. This SIL was dated April 14, 2010, and the last order date was April 30, 2010. Some avionics suppliers offer continued repair support indefinitely; this is in

contrast to the obsolescence of components, which are not repairable. Even so, continued support eventually becomes impossible.

There are presently no recommended or enforceable requirements on avionics or aircraft manufacturers to offer guarantees of continued support after product discontinuance has been declared or for minimum notice periods. This is an area for which additional regulation could be applied, though manufacturers would have to price that additional risk into their products.

3.5.1 Legislation-Induced Obsolescence

Legislation has the potential to drive either the demand side or the supply side. Lead-free legislation is the major effect seen from legislation on the supply side. This legislation has reduced the supply of noncompliant components because the component suppliers are transitioning their lines and obsoleting the old components. The European Union (EU) lead-free legislation, Directive 2002/95/EC on the Restriction of Use of Certain Hazardous Substances in Electrical and Electronic Equipment (known as the "RoHS Directive" or "RoHS I"), has restricted the use of lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls, and polybrominated diphenyl ethers in certain electrical and electronic equipment since July 1, 2006.

This legislation has caused component manufacturers to obsolete large numbers of components and to replace them with versions that use a lead-free frame or contact plating material (e.g., pure tin or palladium). Modifications may also be made to the packaging to allow for the higher reflow temperature required by Sn/Ag/Cu (SAC) solders or to maintain the moisture sensitivity level (MSL) rating [18]. The MSL specifies time available between removing components from their dry-shipping containers and completion of reflow soldering. The MSL rating reduction arises because the higher SAC peak reflow temperature leads to a greater susceptibility for package and die damage (e.g., cracking and delamination) caused by explosive vaporization of absorbed moisture trapped in internal voids.

Some types of lead-free components (e.g., through hole and surface mount) can be successfully soldered using an Sn/Pb solder process so the lead-free alternates can readily be substituted. This is not true for lead-free ball grid array (BGA) packages. The BGA packages use SAC solder balls that are incompatible with an Sn/Pb solder process because the SAC solder has a higher melting point that does not adequately reflow at the lower temperature of an Sn/Pb solder process. Techniques for reliably soldering lead-free BGAs using Sn/Pb solder pastes are still being researched.

The advent of tin finishes as a response to lead-free legislation has led to the use of tin whiskers as a new failure mechanism. This mechanism was not present with the older components or soldering processes [19] and is another assembly process aspect that avionics manufacturing companies need to address when substituting obsolete components.

Lead-free legislation may also make it an offense to continue to sell, lease, or repair the product in its present configuration if it cannot be certified to Restriction of Hazardous Substances (RoHS). The avionics manufacturer must then discontinue the product or reinvest in the redesign of the product and the assembly process and can no longer provide support or repair for fielded

products. For now, various exemptions in the European legislation and the present lack of United States legislation makes this a future risk rather than a present risk. Even though similar legislation has not been passed in the United States, the globalization of the component supply base and contract manufacturing services means that U.S. avionics manufacturers are nonetheless affected.

3.5.2 Regulation- and Mandate-Induced Obsolescence

Within the U.S. legislative framework, Title 14 Code of Federal Regulations (CFR) governs aviation. Regulatory bodies such as the FAA and the European Aviation Safety Agency (EASA) create and implement binding rules, requirements, and standards to ensure aircraft and operator airworthiness and safety. Because the rules, requirements, and guidance are subject to change, existing in-service products may no longer meet the new airworthiness requirements. New certification rules, airworthiness regulations, and airspace operations rules may impose such a major restriction on usability (or ban use entirely) that demand for a product disappears. An example is the revised RNAV rules [12], which placed operational restrictions on the use of a particular piece of GA navigation avionics. In this case, the product remained manufacturable, but the manufacturer declared that it had reached EOL because the extent of the change necessary to overcome the restrictions was not economically viable [11]. The manufacturer continued to provide support and repair for in-service products, but was under no obligation to do so.

Legislative and regulatory actions (e.g., mandates, Advisory Circulars [ACs], and Airworthiness Directives) are potential sources of both system functional (demand side) obsolescence and component (supply side) obsolescence. If an LRU is not compliant with a new rule or mandate, it can no longer be used or is subject to significant usage restrictions. Rules and mandates are regulatory instruments that impose new operational requirements or procedures. They may impose new functional requirements on aircraft, engines, and avionics; GA and non-GA that cannot be accommodated by upgrades, but require new equipment and installation (see references 11 and 20 for examples of mandate-induced obsolescence). Therefore, it is important to track such legislation and mandates because the required changes provide ideal opportunities to reset the obsolescence clock by introducing obsolescence resolutions that have been accommodated by LTBs.

Rules and mandates are the primary governmental mechanisms for introducing air traffic control (ATC) system improvements and are, therefore, continuing factors that impose upgrade requirements on aircraft operators. A series of these may continue as the U.S. National Airspace System (NAS) and the EU ATC System are upgraded through the U.S. NextGen and EU Single European Sky Air Traffic Management Research (SESAR) [21–23] programs, respectively. These upgrades are typically major; equipment upgrades through modification are often not economically or technically feasible. The existing installed equipment is rendered functionally obsolete and there is a complete collapse of the market for that obsolete equipment. A study of the NextGen equipage costs for the ground and air segments is given in references 24 and 25. Sections 3.5.2.1 and 3.5.2.2 discuss some anticipated and in-progress rules and mandates that affect avionics and engine equipment.

3.5.2.1 Avionics

In early 2004, the EU SESAR Committee agreed on a first set of mandates to be given to EUROCONTROL [26]. This set covered flexible use of airspace, airspace design, functional airspace blocks, and charging scheme. The Director General requested the Provisional Council and the Permanent Commission of EUROCONTROL to appoint a general delegation to accept and execute the mandates sent by the European Commission. Later in 2004, a second set of three mandates dealing with interoperability (Initial Flight Plan, Flight Message Transfer Protocol, and Coordination and transfer of flights between air traffic services) was examined by the SESAR Committee and sent to EUROCONTROL by the European Commission with expected work completion in 2005. In 2005, seven new mandates were received and accepted by EUROCONTROL. Four relate to the following areas:

- Air traffic flow management
- European upper flight information region (EUIR)
- Single Aeronautical Information Publication for EUIR
- Performance review

The other five are an extension of the scope of regulatory activities on interoperability:

- Mode S Interrogator Code Allocation
- Surveillance performance and interoperability requirements
- Aeronautical data integrity
- Data link services (DLS)
- Air-ground voice channel spacing

A draft rule for EU Link 2000+ DLS mandate [27] has been issued in support of controller-pilot data link communications (CPDLC) requirements in EU airspace. This rule mandates CPDLC on new aircraft out of the factory beginning January 1, 2011 and retrofits by February 15, 2015. The mandate impacts all aircraft operating under instrument flight rules above flight level 285. Compliance will involve a data link utilizing a very high frequency (VHF) radio that will enable transmission of commands via a textual system [28].

In the United States, the FAA has published new rules (in 14 CFR 92.225 [29] and 91.227 [30]) mandating that by January 1, 2020, any aircraft operating in Class B or Class C airspace, or above 10,000 feet mean sea level, will be required to have ADS-B Out equipment onboard. In December 2010, the FAA issued AC 90-114, requiring ADS-B Out capability [31]. In May 2010, AC 20-165 was issued, which provides guidance for the installation and airworthiness approval of ADS-B Out systems in aircraft. The FAA has not yet issued any rule requiring ADS-B In operations; therefore, operators are free to decide if or when to equip themselves for it. The ADS-B rule mandates ADS-B Out avionics performance when operating within designated affected airspace and gives aircraft owners approximately 10 years to equip their aircraft. The ADS-B is a fundamental part of the agency's planned NextGen ATC system, and ADS-B Out is projected to eventually supersede the use of primary radar systems for tracking aircraft movements. The FAA has published a Final Rule in the Federal Register [32].

Other upcoming mandates include satellite-based augmentation system - localizer performance with vertical guidance and required navigation performance. All of these mandates will require specific avionics capabilities and will render non-compliant avionics obsolete for which they are unable to be suitably upgraded and operated in the affected airspace.

3.5.2.2 Engine Equipment

Engine-mounted electronics are subject to the same obsolescence risks as other types of equipment; therefore, the same approaches to obsolescence management are applicable. There is one additional functional obsolescence concern for engines arising from current and proposed legislative action, primarily in the EU, regarding green initiatives to reduce the environmental pollution caused by engines emissions, either by efficiency improvements or by the use of new fuels.

The EU has implemented new legislation for industrial emissions of all kinds and has recently included aircraft engines. The legislation was first enacted in 2006. It is a cap-and-trade scheme that imposes fines on operators who exceed their allowances. The EU initially included aircraft using EU airspace in the emissions trading scheme in 2012. In response to intensive foreign lobbying, the EU suspended the application of these rules for aircraft flying to or from non-EU airports—until at least after the November 2013 International Civil Aviation Organization meeting—in the hope of negotiating an international agreement [33].

These regulations have the potential to force obsolescence of engines in service today and, therefore, the associated control electronics. The implications are not limited to engine electronics; ancillary functions (e.g., auxiliary power units, environmental control systems, thrust reversers, and electrical power management) could also be directed towards functional obsolescence.

Work is underway by the SESAR/FAA Joint Undertaking group Atlantic Interoperability Initiative to Reduce Emissions [34]. The group is running numerous test flights to experiment with methods to reduce emissions using new operating procedures with currently installed engines and equipment. Any new procedures arising from this work may lead to new airspace rules and then to updated functional requirements for an extensive range of avionics equipment, such as flight management, cockpit displays, autothrottle, and flight guidance. The timescale for new rules, if any, is not yet known, presenting a set of risks that cannot presently be reasonably assessed or mitigated.

3.6 OBSOLESCENCE OF SYSTEM SOFTWARE

In-house software (and the hardware description language [HDL] used in application-specific integrated circuits [ASICs]and field programmable gate arrays [FPGAs] is perpetual and cannot become obsolete in the same way electronic hardware does. Software and HDL can become effectively obsolete because the requirements, airworthiness rules, or standards change, which requires a needed change to the software/HDL. However, this change cannot be completed in the current version of the software/HDL [35]. Processors, FPGAs, and other execution hardware can also become obsolete or unable to accommodate new software required to meet the new requirements because of throughput, memory space, interface protocol, or other considerations.

Some avionics items include a navigation database that is supplied by a third party. Navigation databases have historically grown in size over time so that eventually the available storage becomes insufficient to accommodate them and the system cannot remain compliant with the required data standard unless additional storage can be added. Such a case arose with the Universal Avionics UNS-1 Flight Management System [20]. The decision was to EOL the product, with parts obsolescence also cited as a contributing factor. Software obsolescence is a collateral consequence of all of these other types of events. The same is true for COTS libraries compiled into software and HDL, provided perpetual licenses are purchased.

Frequently, the only option available is the recompilation and recertification of the system for a new, underlying architecture. The use of high-level languages is near universal, but the application of portable coding standards during initial software development can ease this transition [36 and 37] by avoiding hardware-specific constructs, such as assembly level inserts or specific types of code optimizations that leverage architectural features of the underlying hardware.

One other option to preserve the usability of the original software in binary image form is to reconstruct the obsolete processor in a custom integrated circuit (see section 3.10.2). This option may reduce the cost of recertification because much of the existing DO-178B [38] certification artifacts can be reused.

3.7 OBSOLESCENCE OF HARDWARE COMPONENTS

Electronic components typically follow a life-cycle curve in which shipments increase from zero, plateau for a time, and then decline to zero. This curve is typically approximated by the normal curve (after its functional similarity to the normal probability distribution curve) and is described in references 39 and 40. The curve is reproduced in figure 3.
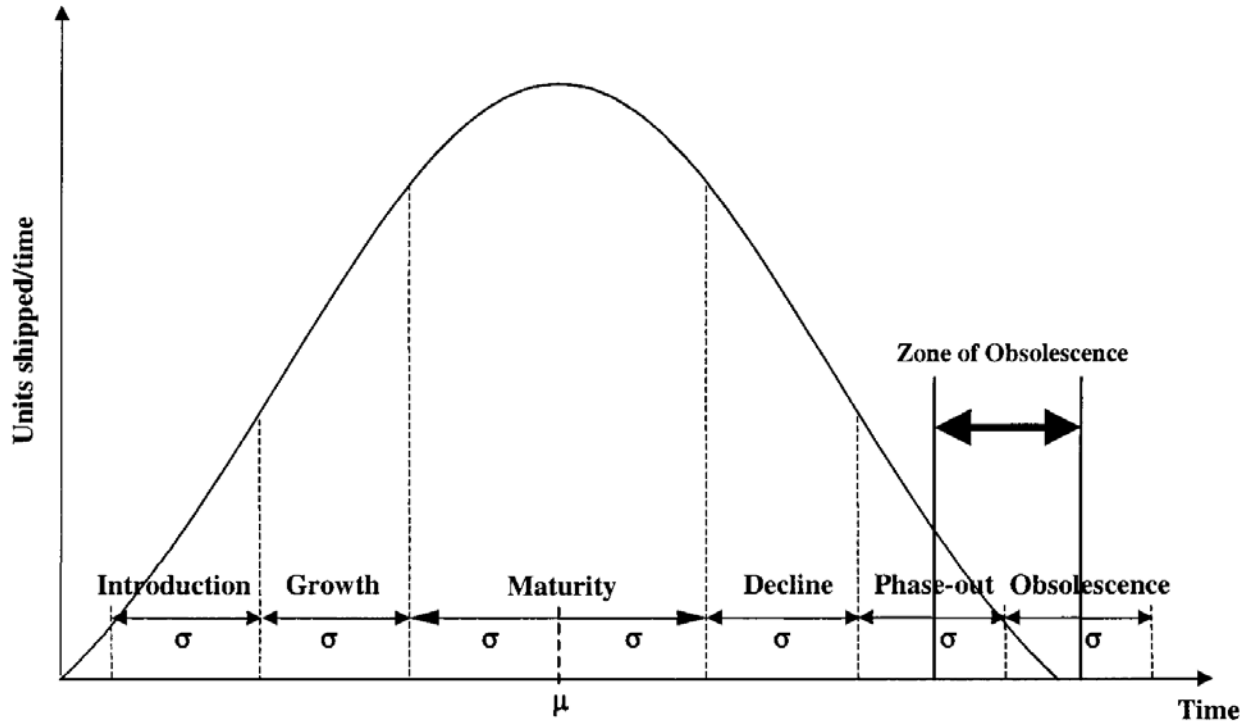
Figure 3. Life-cycle curve

Product deletion decisions made by the component suppliers may arise for commercial or legislative reasons. This results in supplies beyond LTB of some of the component parts of the product—as listed on the bill of materials (BOM)—being unobtainable (i.e., subassemblies and components). Product obsolescence then occurs when the avionics manufacturer's or contract assembler's stock of one or more of these obsolete parts has been exhausted. In this event, new copies cannot be manufactured and existing fielded copies cannot be repaired. Because a single component may be used in many products, this event may render several products obsolete simultaneously.

This is not confined to components. Some avionics manufacturers have adopted modular design as an obsolescence mitigation strategy by buying complete subassemblies, such as COTS electronic cards and power supplies. Unfortunately, this strategy is only partially effective because the manufacturers of these subassemblies are subject to the same obsolescence forces that result in the same obsolescence problems, and alternate sources may not exist.

3.8 OBSOLESCENCE OF TOOLS AND PLATFORMS

The development and modification of system software, ASICs, and FPGAs depend on the use of a variety of COTS tools and platforms, such as compilers, libraries, PCs, and other types of workstations. These may have been scrapped or are no longer available or supported, or they may have undergone changes that render them to no longer be qualified per the requirements of DO-254 [41] and DO-178B [38]. The lack of tool qualification makes the tool unusable for the recertification of a modified system. This requires a response—either tool requalification or a new tool or product discontinuance. Some are in-house tools and, therefore, largely immune to

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obsolescence, but some are COTS items that can be removed from the market at any time or support can be terminated. Execution platforms carry no guarantee of continued availability beyond the warranty period.

Avionics manufacturers recognize these problems, and processes have been developed to archive tools software and the supporting platforms until all products they support are discontinued (i.e., they will not require any further design changes). Because production may continue for many years until redesign or discontinuance, it is a difficult and expensive task that is subject to much uncertainty regarding when the required tools and platforms will be needed, or even if they will still work. Some avionics manufacturers use virtual machine software tools to emulate obsolete platforms on current workstations so that the original tools can still be used, similar to the emulation of Intel® x86 microprocessor architectures on Mac® platforms and vice versa. No established guidance or requirements are known to exist on avionics manufacturers to implement these kinds of software and HDL obsolescence protection measures. This is purely a manufacturer-specific commercial judgment based on economic realities and a desire to support, within reason, existing products and customers.

There are no known standards or channels for notification of obsolescence in COTS tools and platforms. The unavailability of these original tools and standing-up replacements become a cost factor when deciding which resolution option to pursue.

3.9 OBSOLESCENCE OF MANUFACTURING AND REPAIR FACILITIES

The manufacturing and repair capability may become defunct or unusable (e.g., because of RoHS legislation). The necessary manufacturing process materials may be obsolete (e.g., chemicals or solder) or the manufacturing equipment (e.g., reflow soldering, CCA, and LRU test) may become nonfunctional and beyond economic repair. If so, the product can no longer be manufactured or repaired. Many avionics suppliers now contract manufacturing and the procurement of necessary components. Equipment manufacturers (and their subcontract manufacturers) have many customers and limited resources, so they may decide that maintaining a capability for a low-volume product is not viable, or they may wish to reallocate those facilities to higher-volume products. The avionics supplier then has to stand-up a new assembler or discontinue the product.

3.10 OBSOLESCENCE MANAGEMENT TOOLS AND RESOURCES

The problem of obsolescence has been known to exist for many years. It is a natural consequence of technological advancement. Industry has come to supply the demand for both obsolete components and component life-cycle information. The customers for these tools are mainly the avionics manufacturing companies and military program offices. These tools and services are for components only; no similar services are known that focus on tools or systems obsolescence.

3.10.1 Component Obsolescence Information Services

A number of commercial services are available on a subscription basis, which notify component users of impending obsolescence. The standard method by which component suppliers notify their customers that they intend to discontinue a component is via the PCN, the same vehicle

used to notify customers that some aspect of the component design or manufacturing is changing, such as a manufacturing location, a lead frame plating material, or a die shrink. These notices generally give users 6–12 months' notice and the opportunity to make an LTB. Because the majority of avionics manufacturers buy components through authorized distributors, the component manufacturer may not be aware of all the customers and may therefore make these notices available through their authorized distributors and third-party PCN distribution services.

A commonly used service for PCN distribution is PCN Alert (owned by Information Handling Services [IHS]), which provides a website and daily email messages to registered users. Equipment suppliers are also able to access PCNs and check the current status of components through subscription BOM analysis tools, such as:

- CAPSExpert (IHS) (http://urlm.co/www.partminer.com)
- 4D-Online Parts Universe (IHS) (http://www.4donline.com)
- TacTrac Comet (IHS) (http://a1024.g.akamai.net/f/1024/13859/1d/ ihsgroup.download.akamai.com/13859/engineering/tactrac-comet/loader.html)
- Silicon Expert (http://www.siliconexpert.com)
- QSTAR (QTEC Solutions) (http://www.qtec.us)
- Total Parts Plus (http://home.totalpartsplus.com)

IHS also provides a subscription component information source (CIS) data feed so that avionics manufacturers can populate their own database tools. The U.S. military operates the Government and Industry Data Exchange Program (GIDEP), a collaborative organization that provides numerous resources to identify obsolete and soon-to-be obsolete components.

All of these services provide current status and some measure of future obsolescence risk by means of a life-cycle coding scheme according to the scale shown in figure 3 and a forecasted years to end of life (YTEOL). The algorithms used for these predictions are usually proprietary and, therefore, concealed. The typical scale is from 1–6: 1 is introduction and 6 is obsolete [14, 39, and 42]. FreeScale (a semiconductor manufacturer) uses an extended Electronic Industries Association (EIA) scale (0–8) as shown in figure 4. Such services are primarily reactive tools (i.e., they provide warning that an obsolescence problem is coming in the short term, but are not presently capable of giving a forecast that is suitable for product life-cycle planning decisions). For this purpose, a predicted obsolescence date with some confidence interval around it is needed (see section 4.1).

Life Cycle Stage Codes	Life Cycle Description	Displayed Web Status	Meaning	Additional Information	Notes
0	PRODUCT INTRODUCTION PENDING	Introduction Pending	Product is in planning or early design stage. Samples may or may not exist. Specification changes can occur and planned introduction dates may be delayed.	No orders or product shipments permitted.	Note: This life cycle stage is not part of EIA-724 (Product Life Cycle Data Model).
1	PRODUCT NEWLY INTRO'D/RAMP-UP	Active	Beginning to ramp up production. Can supply limited quantities.	Orders and shipments permitted.	Note: See EIA-724 (Product Life Cycle Data Model) for more information.
2	PRODUCT RAPID GROWTH		Product in rapid growth phase. Manufacturing capacity is being added.	Orders and shipments permitted.	Note: See EIA-724 (Product Life Cycle Data Model) for more information.
3	PRODUCT STABLE GROWTH/MATURITY		Product growth stabilizes and peaks. Product quality is very high.	Orders and shipments permitted. Product is highly recommended for use in new designs.	Note: See EIA-724 (Product Life Cycle Data Model) for more information.
4	PRODUCT MATURITY/SATURATION		Sales and capacity have leveled out.	Orders and shipments permitted.	Note: See EIA-724 (Product Life Cycle Data Model) for more information.
5	NOT RECOMMENDED (DECLINING)	Not Recommended for New Design	Capacity beginning to decline.	Orders and shipments permitted. Product not recommended for new designs.	Note: See EIA-724 (Product Life Cycle Data Model) for more information.
6	PROD PHASE OUT/SEE LAST ORD DT	End of Life	Capacity declining rapidly. Formal discontinuance notice may be issued.	Limitations on shipments can occur, but orders are pressed toward final and last buy. Product should not be considered for new designs.	Note: See EIA-724 (Product Life Cycle Data Model) for more information.
7	PRODUCT LAST SHIPMENTS	No Longer Manufactured	Product in final stage of shipments after a formal Life Time Buy notice or product cancellation.	Shipments made to existing orders. Manufacturing capacity limitations may exist. New orders are limited to existing or residual inventory.	Note: This life cycle stage is not part of EIA-724 (Product Life Cycle Data Model).
8	REMOVED FROM ACTIVE PORTFOLIO		Product is considered no longer available. Inventory is removed. All supporting hardware, software, and documentation for the product are removed.	No new orders, no shipments, and no inventory exist.	Note: This life cycle stage is not part of EIA-724 (Product Life Cycle Data Model).

Figure 4. FreeScale life-cycle coding scheme [43]

3.10.2 Obsolete Component Sources

Manufacturers try to recover from obsolescence by taking the lowest-cost solution. Generally, this turns out to be alternate-part substitution or LTB, which do not require redesign, do not affect software, and require minimal requalification. Forecasting LTB quantities has inherent difficulties and limitations. When an LTB turns out later to have been too little and when the LTB option is no longer available, securing alternate components is needed. If so, there may still be some options available before resorting to more expensive measures. Manufacturers sometimes transfer all the intellectual property (IP) and tooling of an obsolete component to an aftermarket or sunset supplier with whom they have an agreement. Examples of sunset suppliers include Rochester Electronics and Lansdale Electronics. These companies are able to remanufacture small batches of components for which they have the rights. The DMEA established the Advanced Reconfigurable Manufacturing for Semiconductors program facility to take over obsolete component manufacturing information and continue production through a public/private partnership with commercial foundries. The price is usually many times that of the original and is subject to high minimum-order quantity, but these companies satisfy a market need, usually of interest only to military customers. Typically, only low-technology components are available in this way because the lines do not exist for submicron technology components.

A second approach is through reverse engineering and emulation. One company that specializes in this is the Generalized Emulation of Microcircuits program operated by SRI, originally a spinoff from the DMEA [44]. This technique is largely for low-technology components and of most interest to military customers because their product is Qualified Manufacturers List qualified. Some success has been reported on the use of emulation to execute the unchanged binary image on new hardware [45]. Processors can be emulated using FPGAs that maintain the original code base [46–50].

Some companies specialize in reproducing cycle-accurate, binary reusable, obsolete processors (e.g., Innovasic). All of these emulation techniques incur substantial re-engineering costs and must be compared with the redesign option to establish both technical and economic feasibility.

A network of component brokers exists, mostly in China. These brokers speculate by buying up stocks of soon-to-be obsolete components in the hope of selling them at a high profit. Equipment company buyers often trawl these brokers for additional parts when the LTB that was made on the original obsolescence has proved to be insufficient. This strategy is not without risk because the provenance and location of origin and quality is often lacking, and many have been found to be used or counterfeit [51–55].

Although LTB or finding alternate sources often does turn out to be the lowest cost solution, it is difficult to be sure without at least some rudimentary cost analysis of the various options. Equipment suppliers must consider that obsolescence will eventually recur and necessitate further recovery.

3.10.3 Standards, Guides, and Other Documents

The military (primarily within the United States) has sponsored the development of numerous guides on military obsolescence management [5, 56–65] and has sponsored some study programs

[15, 16, 66, and 67]. Some more commercially relevant material has been developed by ARINC [68] (for aerospace, somewhat dated) and the British Standards Institution (BSI) [69–71].

The semiconductor trade body JEDEC® provides a guidance document [72] that requires component suppliers to provide at least 6 months' notice, during which an LTB order can be placed, and at least 12 months' notice for final shipments. This is generally adhered to by the component suppliers, but it is not binding on them. There are no SIL or SB guidelines known that indicate periods similar to those provided by component manufacturers.

The International ElectroTechnical Commission (IEC) TC56 committee has published a guide to obsolescence management [73]. A revision of the IEC Electronics Component Management Plan (ECMP) [74] is presently in draft form, being prepared by IEC TC107 (Process Management for Avionics). This draft currently provides a high-level skeleton for an obsolescence management plan that could form the basis for an obsolescence management section in a manufacturer's component management plan [75]. The skeleton covers awareness (reactive), proactive measures, and reporting requirements. The document recommends that all components be rated for risk of obsolescence that outlines factors for consideration, but does not provide a detailed methodology.

To the knowledge of the authors, this document has not yet been specified as applicable in any procurement contracts. It is probable that this ECMP document will eventually be incorporated by reference in Airbus and Boeing subcontractor general requirements documents and will appear in procurement contracts. TechAmerica (previously GEIA) has published a similar guide to the contents of military DMSMS management plan [3].

The FAA has published Certification Authorities Software Team (CAST) Position Paper 3 [76], which discusses software certification considerations when equipment is modified to resolve an obsolescence issue. This document addresses ensuring that if software is affected by the change, appropriate steps are taken to maintain the previously developed software design assurance. The CAST papers do not set out any regulatory position and are to be regarded only as indicative of FAA philosophy, which may inform future guidance and policy.

4. KNOWN AND EMERGING ISSUES

4.1 COMPONENTS OBSOLESCENCE FORECASTING

Obsolescence forecasting is currently reactive (i.e., based on the receipt of a PCN). A PCN is the usual means to notify the customer that a component has been declared obsolete. A PCN typically provides 6–12 months' warning that a component is becoming obsolete, with a further 6–12 months' available for placing LTB orders. Component information services such as IHS Parts Universe and PartMiner CAPS (now acquired by IHS) products provide lifecycle codes. However, industry experience with these is that a life-cycle code is not sufficient for decision making because it cannot be used to predict an obsolescence date. Prediction of an obsolescence date requires that the shape of the curve (see figure 3) and at least two of its points be known, and that cannot be deduced from a life-cycle code. Life-cycle codes are self-reported by the component manufacturers and rarely show decline until just before EOL is declared. This situation is to be expected because a decline status declaration is a self-fulfilling prophecy that

results in market collapse. Parts Universe also reports a YTEOL value, but the algorithmic basis of this forecast is proprietary to IHS. The YTEOL could possibly form the basis of a forecasting algorithm if the date that a part was first introduced to the market was also known. Presently, introduction date is not recorded in the available tools.

Techniques for projecting the component life cycle to future dates are not widely available. Some researchers report the outlines of possible methods [77–80], but these cannot yet be considered as mature; much further work needs to be done. This lack of forecasting ability is the basic cause of obsolescence management being presently reactive (i.e., reactive to EOL information provided by component manufacturers through PCNs). Significant steps need to be taken to progress to proactive obsolescence management. Proactive obsolescence management activities depend on the availability of component obsolescence forecasts.

4.1.1 Predictions Uncertainty

This report has discussed techniques to manage obsolescence based on quantitative economic modeling methods. All of these methods depend fundamentally on forecasts of future obsolescence events coming up from the components supply chain and forecasts of product demand. Demand forecasts come from the customer base via the avionics supplier marketing function and are ultimately derived from sales forecasts provided by aircraft manufacturers.

Commercial data services, such as IHS, offer a forecast value of YTEOL for expected component obsolescence. The IHS values are based on proprietary data and algorithms. They do not provide any substantiation or confidence level.

Research is necessary to develop open, data-driven, predictive obsolescence modeling methods that are statistically sound. Section 5.2.1 describes some emerging approaches. This type of analysis is usually referred to as predictive analytics, which are widely used in diverse fields, such as insurance underwriting, marketing science, and financial options pricing. Predictive analytics are used to predict a particular outcome for a given set of data and assumptions, possibly with an associated confidence level, using an input data set whose elements have associated uncertainty. Typical data items that seem likely to be relevant include component demand forecasts for new production and repair, forecasts of trends in semiconductor process technology (e.g., International Technology Roadmap for Semiconductors [ITRS] 2011) [81], categories of components grouped by family sharing the same underlying technology, and manufacturer-specific historical data on obsolescence notices. The research objective is to gain insight on predictive analytics tools and algorithms, their uses in the obsolescence prediction domain, and what data would be necessary. Predictive analytics methods can be used to construct a product life-cycle plan.

It must be cautioned, however, that forecasts are beset with both epistemic and aleatoric uncertainty. Epistemic uncertainty can be assessed by statistical methods, but aleatoric uncertainty is completely unpredictable [82 and 83]. The latter resulted from a business decision to reposition the company into the embedded computer market with consequent obsolescence of many consumer-oriented components. Events such as these cannot realistically be forecast or planned for, but because they typically take some time to implement, it gives the users some time

to develop mitigations and recoveries. The only realistic option in these cases is to reactively revise the product life-cycle plan when such events occur.

A third type of uncertainty arises from the demand side, in which existing aircraft programs depart from the predicted demand profile. A decrease in demand leads to excess inventory and capacity in suppliers, and an increase in demand leads to production shortages, extended lead times, and early exhaustion of LTB stocks [84].

The results from a predictive analytics process are necessarily probabilistic in nature because of uncertainties in the input data. Therefore, it is necessary to treat the results as an estimate of the risk associated with a particular outcome and to make a judgment on what level of risk is acceptable. The acceptable level of risk is subjective.

4.2 LTB ESTIMATION AND INVENTORY MANAGEMENT

The estimation of an LTB or bridge buy (BB) lot size is problematic because there are uncertainties associated with calculating it. The uncertainties are the number of products to be produced and maintained, the time period over which production will be required, and the component quantity required to support repair and maintenance. Future production depends on future aircraft orders, the timings of aircraft discontinuance, major changes made to the avionics lineup, and any aircraft life extensions made by the aircraft manufacturer. Regulatory or legislative action may force the early withdrawal of a product. The repair and maintenance quantity depends on the equipment reliability, so estimating support needs is contingent on having the data collection systems in place that track repair consumption and enable forecasting of the expected failures.

The estimation of quantities and the timing of LTB and BB decisions cannot be made independently for one component alone because a component may be used in multiple products. A product marketing decision to EOL a product terminates the time horizon and affects the LTB or BB decision. This time horizon may also be set by expected future obsolescence of other components, regulatory actions, or legislation.

The LTB and BB estimation problem is, therefore, related to decision-making under uncertainty, which involves repairable system reliability, market forecasting, and obsolescence forecasting. Such problems are typically solved by the use of discrete event simulation models in a Monte Carlo framework. These models [85–87] represent the input uncertainties with sampled distribution functions whose functional form (i.e., equation and parameters) are derived by empirical means based on historical data and a wide range of assumptions. The model output is also a distribution function from which the mean and variance can be derived by distribution fitting. Such algorithms yield a probabilistic measure of the monetized risks of under- or over-provisioning associated with a given LTB or BB lot size. Recursive analysis then finds the lot size corresponding to the acceptable risk.

Another complication is that a particular component may be used for several products and, therefore, optimization must be completed across the manufacturer's product range rather than isolated to a product-by-product basis. Having considered all these uncertainties and made an LTB or BB, the avionics manufacturer must then ensure that the inventory is actively managed to

allocate the available stock, such that no one product is prematurely starved by demand from another. This requires that the manufacturer has robust materials-management infrastructure and manufacturing information systems that accurately track ordering, inventory, and consumption.

4.3 OPTIMUM RESOLUTION METHOD SELECTION

Methods for the implementation of change in avionics equipment to recover from obsolescence are well known [14]; these are the standard engineering design processes subject to all applicable airworthiness guidance and standards. All or many of the possible solutions may be technically feasible and achieve the desired aim of resolving the immediate obsolescence issue. These options will involve differing initial and recurring costs and time to implement so the optimum choice from among the technically feasible is arrived at by consideration of LCC and other less quantifiable considerations, such as market position and reputation.

It is important to note that the real cost of an obsolescence recovery action decreases with time because the real value of money usually decreases with time. The annual rate at which the value of money declines is termed the discount rate. The discount rate is the return on investment that could be obtained by investing the money rather than spending it immediately. This is an important modeling concept and the choice of discount rate has a strong influence on the selection decision. Most manufacturing organizations maintain a current rate within the corporate finance department because this rate factors into many investment decisions.

The choice is not simply which option to choose, but which sequence and timing of options yield a result that is optimum in some sense. An optimum solution may be, for example, to purchase a BB lot to take production and repair to a fixed future date, or an LTB to a planned EOL date or to when a redesign and upgrade is planned to be done. Therefore, some possible sequences are LTB only, LTB → EOL, BB → redesign, BB → redesign → LTB (different component) → EOL, and many other possible sequences.

The modeling required to compare the costs involved in various options and sequences is nontrivial. As with LTB and BB estimation, there are many uncertainties involved and many possible scenarios to consider, making a computer tool using algorithms, such as shown in reference [88], necessary. To date, such tools are not widely available and those few that are available [89] are not widely deployed.

4.4 THE PBL RISK ASSESSMENT

A supplier who writes a PBL (or power-by-the-hour) contract plans to maintain the equipment for a given period for a set price. Maintenance includes all steps necessary to maintain availability (e.g., repairs, quick reaction spares pool, and obsolescence resolutions, as required). All of these activities are subject to uncertainties and risks because exact needs cannot be predicted. To calculate a price for these services, the equipment supplier must estimate risk for a range of contracts and arrive at a pricing model that produces an acceptable risk and return ratio that is consistent with its risk management policies. Modeling techniques for repair needs and spare provisioning are well established by the logistics community, but the techniques for LTB, BB, and resolution selection are not typically part of those models. This item is suggested for future research in table 7.

4.5 DESIGN PATTERNS

The propensity for obsolescence vulnerability is, to some extent, set by the design. Designers may choose components that are nearing EOL but not yet the subject of a discontinuation notice. The design may lack change containment boundaries so that an obsolescence resolution requires consequential changes. To address these types of deficiencies, design patterns should include modular design patterns or rules that incorporate change containment in both the hardware and software supported by design analysis of multiple design options to obtain a measure of the risk associated with those options. Examples of design patterns are modularity enforced by modifiable IP blocks so that changes do not ripple out beyond the containing walls of the IP, and the use of a hardware abstraction layer (HAL) so that most hardware changes do not require changes to operational software and recertification. The most serious effect of obsolescence relates to processors, and a HAL is only partially effective in protecting against that. Some authors report specialized techniques for reducing the impact of processor obsolescence [45, 46, 48–50, 90–92] that depend on the use of IP.

The IP approach is attractive from an obsolescence protection viewpoint because IP is perpetual and can readily be ported to new, underlying hardware that is subject to the design assurance safeguards required by DO-254 [41] and the forthcoming EASA certification memorandum [93]. However, custom IP has a much higher initial cost relative to the cost of buying electronic components or licensing commercial off-the-shelf intellectual property (COTS IP). The use of COTS IP would be attractive for many of the common functions, such as processor, memory controller, input, and output functions that are readily available and sold to the commercial market for many types of consumer devices. Such an approach cannot presently be used in avionics because the current AEH design assurance guidance is process-based, requiring the applicant to develop a set of artifacts from each of the process steps. It is very difficult to use COTS IP because of the lack of these certification-process artifacts or safety assurance artifacts. Such guidance would open up a wide range of design options and help to mitigate obsolescence risks. An outline of a possible approach to the design assurance of COTS IP is given in section 9. This would require changes to current DO-254 AEH guidance, a research topic suggested in table 8.

4.6 CUSTOMER NOTIFICATION PERIOD OF SYSTEM EOL AND CONTINUED SUPPORT

Avionics manufacturers obsolete equipment for various reasons. Examples include regulatory and legislative action, declining market and loss of production capability, and unavailability of material. At the present time, manufacturers have no constraints regarding how much notice to give to customers to make a product LTB or whether to continue to offer support. Such notice periods are purely at the discretion of the manufacturer and driven by the normal competitive pressures. A code of practice similar to the JEDEC code of practice largely followed by component manufacturers would benefit customers [72].

4.7 MAINTAINING SOFTWARE AND HDL TOOLS AND PLATFORMS

There is currently no guidance regarding retaining the capability to modify and requalify the software and HDL, which may be required as part of an obsolescence resolution. Software tools

and platforms must be archived along with the source files and verification, and test programs must be retained and maintained. An alternative is to migrate the source code to new tools and platforms as the old ones are disposed of. The FAA CAST Position Paper CAST-3 [76] discusses the software implications of hardware obsolescence.

4.8 MAINTAINING MANUFACTURING AND REPAIR CAPABILITY

Sections 3.8 and 3.9 described the issues surrounding maintaining design, production, maintenance processes, and tooling so products can continue to be modified, produced, and repaired throughout the life cycle. There is currently no published guidance regarding retaining these production capacities or facilities to continue production over a long period or for the continuation of repair capabilities beyond EOL. A recommendation that such guidance would be helpful and should be considered is given in section 12.

4.9 COMPLIANCE AUDITING

Some avionics manufacturers have developed internal obsolescence management processes that vary from informal to documented-reactive and also the supporting tools to manage individual cases. Emerging standards and guidance on best practices defines some minimum requirements for these processes [3 and 75]. An independent validation should be made when avionics manufacturers claim their processes are compliant with this guidance. This is now the case with electronic component management (as shown in reference 74) for which independent auditors (e.g., International Electrotechnical Commission Quality Assessment System For Electronic Components [IECQ], BSI, and Underwriters Laboratories [UL]) carry out an assessment to the standard and provide a certificate of conformance. This audit mechanism could be extended to include obsolescence management processes.

4.10 PCN PROCESSING

Component manufacturers send out PCNs in document format (usually PDF) to the PCN distribution services and to their known customers. Avionics manufacturers who subscribe receive many of these every day. Some are routine manufacturing changes and some are for EOL. Each one has to be assessed for importance, relevance, and identification of products that are affected. A single PCN often includes many different component part numbers, only some of which are relevant to the recipient. Presently, this is mostly a manual process of reviewing each one and creating a tracking tool entry for further actions. The labor-intensive nature of this process could be reduced by the development of standardized B2B data items, fields, and formats to directly place PCN information into the avionics manufacturers' tracking tool by electronic transfer, therefore eliminating much of the transcription effort and allowing the tool to automatically flag the products affected. An effort is underway by the Edifice nonprofit organization to develop standards and guidance for electronic PCN delivery.

4.11 SECURITY

Avionics have not suffered significantly from cyber-attack since the networking has been limited to on-aircraft. The NextGen-enabled avionics will be more susceptible to cyber-attack than current systems because of the networking of ground and air segments. The networking enables

an increased degree of control by the ground segment of the aircraft state and trajectory, thereby introducing additional risk. This potential problem has been recognized for some time, and the development of new guidance began in 2007 with the Radio Technical Commission for Aeronautics (RTCA) Special Committee 216 on Aeronautical Systems Security.

The NextGen systems will be designed to detect and protect against attacks from known threats, but will remain susceptible to new threats. Therefore, the NextGen systems will incorporate inoculation systems by means of firewalls, antivirus capability, and continual software upgrades in much the same way that PCs do. Whether or not such changes will also require hardware changes with consequent obsolescence of the old is unknown at present. Current design assurance guidance requires extensive requalification following change that could become unsustainable. There is a need to design software so defensive upgrades can be incorporated without needing to requalify all software. Guidance on software architectures (i.e., design patterns) that implement such change containment would be very helpful. Cybersecurity is an area for which regulation to require inoculation may induce systems, software, and hardware obsolescence.

5. EXISTING R&D

This section describes obsolescence and related research that have been reported in the public domain literature. The main sources are journals, conference papers, and some publicly released reports and student theses.

The current research canon for obsolescence primarily covers methods for the creation of stochastic models to: 1) estimate a future cost-distribution function and 2) compute the model parameters for constrained minimization of this function. Such methods can be used to estimate LTB/BB quantities, compare design and component choice alternatives, evaluate make/buy decisions, and derive an optimal redesign schedule. Such methods ultimately depend on how obsolescence of components is forecast prior to the receipt of an obsolescence notice. Forecasting obsolescence is not well developed. Research that has investigated design patterns and methods that are compliant with the current airworthiness regulations is also very limited.

The majority of this research involves numerical assessments of cost and risk under various scenarios using stochastic models. Stochastic cost models are necessary because many or most of the model inputs cannot be known precisely; they have a range of uncertainty that may be represented by a distribution function. The general objective is to find the sequence and timing of actions and the model parameters that minimize either the TOC or the LCC. Obsolescence of components or equipment is certain to occur at several unknown points in the life cycle of equipment or aircraft, therefore exposing both the supplier and the customer to risk of loss. Risk minimization has some present cost. Therefore, it devolves to optimizing the trade between present and future costs according to the chosen optimization criteria, therefore minimizing the chosen criteria (LCC or TOC).

The research was divided into two broad categories: LCC/TOC modeling and design methods. The largest group is LCC modeling; design methods have received little attention. In practice, the TOC and LCC models are needed to assess the benefit that could be derived from the design

methods and whether any extra expense arising from using those methods is justified according to some measure of return on investment.

5.1 ECONOMIC AND LIFE-CYCLE MODELING

This category of research aims to find optimal strategies for obsolescence management for minimum LCC or TOC. Such methods depend on the creation of mathematical cost models. These can be used either as objective functions in classical function-minimization algorithms or executed within a Monte Carlo framework to iteratively converge on a minimum cost solution. The common factor in all these models is a dependence on forecasts of future demand and obsolescence of components. Both LCC and TOC models incorporate all costs incurred from initial design and deployment to phase out at EOL. Costs include those arising from engineering work and also those of the associated work to maintain the safety and design assurance of the product in accordance with the applicable regulations. The economic models can never be the only factor in decision making because the continued assurance of safety remains paramount; however, they can inform the debate and provide pointers in the right direction.

Obsolescence management devolves to repeatedly selecting the type and timing of product changes (i.e., the substitution of alternate components, LTB, or some level of redesign). Product change is controlled by the approved, documented QA standards of the avionics manufacturer that satisfy the airworthiness assurance regulations and guidance in the same way as for new product design. The safety risks associated with product change are, therefore, managed and mitigated in exactly the same way as for new product design; that is by conforming to the guidance in 14 CFR. There is, however, an opportunity to modulate the design-assurance activities according to the degree of change (discussed in section 6.2) to reduce the cost of compliance while retaining assurance that safety is not degraded by the change.

5.1.1 Estimating Lifetime Buy Quantity

A LTB or BB is a reactive strategy, made after an obsolescence notice has been received. Once the notice is received, a strategy must be determined to deal with it, such as LTB/BB or redesign, or some timed sequence of both. If an LTB or BB is the selected resolution option, the number of components to buy must be determined. Determination of the LTB/BB quantity depends on numerous factors, such as the expected production, the support demand profile, whether and when a redesign will be done, and whether the product will be declared obsolete (EOL) at some future time. Feng [85] describes the Life of Type Evaluation (LOTE) tool for estimating the LTB quantity that minimizes LCC. The underlying model is derived from the Teunter and Fortin EOL model [94–96]. The LOTE model extends this to a multicomponent assembly with a sequence of component EOL events and can include a redesign at some specified time.

Pourakbary [97] considers the case of the final stage of a product's life in which the product has a declining price, but repair cost either remains constant or increases. There comes a point at which repair is no longer economical, and it would be better for the manufacturer to replace the failed product with a new one rather than repair it and pay warranty costs. This model does not consider the rising price of components in a shortage situation, as is often the case for recently obsolete components that are temporarily available from a few sources.

Bradley [87] uses both stationary and nonstationary demand profits to consider the problem of an assembly of many components that sequentially become obsolete over the product lifetime. He concludes that manufacturers of long-life, low-growth products, as are typical in avionics, should attach more importance to lowering manufacturing costs, even if this requires increased initial design and sustainment costs.

5.1.2 LCC Estimation

Sandborn [98] describes the Mitigation of Obsolescence Cost Analysis (MOCA) tool to determine an optimum design refresh strategy based on LCC. Prabhakar [99] provides a model for estimating the TOC associated with the selection of a particular component. Prabhakar [100] uses the obsolescence forecasting method of Sandborn [79] to develop a model for determining the value of second sourcing components that accounts for the setup cost of qualifying additional suppliers. The general principles of LCC estimation are given in references 101 and 102.

5.1.3 Selection and Timing of Resolution Options

When an obsolescence notification is received, the avionics manufacturer must initiate a resolution-selection process to decide which of the available strategies is to be used and when it should be implemented. Options can range from simple part substitution to LTB/BB to redesign or some timed combination of both. The manufacturer may instead declare that the product has reached EOL if the contractual obligations originally agreed upon are satisfied. Even with an EOL declaration for which no further upgrades or design changes will occur, there still remains the choice of whether or not to continue to provide repairs to products already fielded. It is common practice for equipment procurement contracts to specify that service will be maintained while two or more aircraft remain in service. This may prove to be an impossible condition to satisfy if all sources of supply are exhausted. In addition, the timing and sequence of these activities must be decided.

One possible model for resolution selection is the multi-arm bandit (MAB) model. The available strategies are represented by arms on a slot machine that produce differing rewards when pulled. Arms may be pulled (i.e., strategies adopted) in any sequence and timing; therefore, the problem is to find the sequence and timing that produces the highest discounted reward. Rewards must be discounted because they occur at different times. Kumar [88] illustrates MAB using a two-arm MAB model for which the two arms represent periodic component buy and redesign. When the component becomes obsolete, only an LTB can be made, and redesign is the next choice. The technique is extensible to further resolution options.

Porter [103] describes a method for deciding the optimum time for redesign by considering the relative discounted costs of a BB and a redesign. He determines the optimum future time for redesign by comparing the holding cost of a BB with discounted future redesign cost.

During the warranty period, costs will be incurred for the provision of repair components. These may be obsolete by the time repair is needed, so it is necessary to compute the required number when making a LTB [104].

Any LTB or BB must procure as many components as needed to maintain fielded equipment in addition to new production. This may go beyond both the warranty period and EOL, depending on the support policy of the equipment manufacturer. Karyagina [105] describes a point process life-cycle model for repairable systems. Hong [106] describes a model for forecasting the demand for service (repair) components. These models have closed-form solutions for constant component failure rate, but require numerical evaluation if this assumption is not used. Constant failure rate is the common assumption, but other models can be used if there are validated failure data to support them.

Chiang [107] describes a model utilizing, in part, the newsvendor model that accounts for the amount of equipment in service and the rate of replacement, which is dependent on equipment age. This model is an analogy with a newsvendor who must minimize his loss from buying too many papers when set against the loss of scrapping the perishable excess inventory. Equipment or aircraft manufacturers face the same problem; they may have purchased more components or equipment than they eventually use by the time the product is at EOL, resulting in surplus inventory for which there is no remaining market. This inventory may continue to be drawn-on by service needs if the manufacturer elects to continue support until an end of support date is declared.

5.2 COMPONENT OBSOLESCENCE FORECASTING

The research on obsolescence forecasting may be split into demand-side and supply-side forecasting. Demand-side forecasting attempts to forecast the future obsolescence date of a component using a prediction model, such as one based on historical sales data or past obsolescence history of similar components. Supply-side forecasting considers the problem from the point of view of suppliers, who attempt to maximize their profits by discontinuing products with declining sales. Obsolescence forecasting is the central component of the economic modeling methods. To be proactive, it is not sufficient to wait for an obsolescence notice; therefore, some forecasting is required to predict the future costs of a range of present actions.

5.2.1 Demand-Side Methods

Demand-side methods forecast a future obsolescence date using historical data, such as sales profile, manufacturer product deletion history, and technology forecasts. Solomon [40] presents a model based on the observation that sales of a particular type of component or component family typically follow an approximation to a Gaussian growth curve, for which sales increase to a peak and then decline towards eventual obsolescence. Fitting the curve to sales data enables predicting when sales fall sufficiently low that obsolescence is imminent. The model is refined by separating the sales data of a component family by secondary attributes. Secondary attributes, such as operating voltage, memory size, or databus width, are specific to component families. Huang [78] applies this model to ASICs, using secondary attributes of the various types of ASICs on the market.

Sandborn [79 and 80] presents a model for forecasting obsolescence based on historical procurement lifetimes (the duration from introduction to EOL) for classes of components. Such models are useful when sales data is not available. Josias [108] describes a similar methodology based on fitting a linear regression equation to observed lifetime data for obsolete components

using component attributes as regression terms. The lifetime of a nonobsolete component can then be predicted by inserting the new component attributes into the regression equation. This methodology allows for dimensionality reduction in the regression equation by computing a significance value for each attribute so that insignificant ones can be disregarded.

Clay [109] describes a tool and method to calculate a material risk index (MRI) for a component. This method was originally described in reference 110. The methodology combines supplier risk, alternate-source risk, individual-component risk, and risk arising from semiconductor process technology evolution to produce an overall MRI. Presently, information on the underlying process technology for individual components is not widely available from the CISs; therefore, technology/process risk is currently difficult to assess. The index can be used to score a BOM, identify high-risk choices, and discriminate between alternative designs based on a rolled-up risk, as reflected in an LCC/TOC model at the product level.

5.2.2 Supply-Side Methods

A manufacturer discontinues production of a product (making it obsolete) because he perceives that the profit stream is soon expected to fall below a level that justifies using the capital resources necessary for its manufacture. This is true for manufacturers of components, equipment, and aircraft. Manufacturing costs may increase or decrease, depending on volume and realized manufacturing efficiencies, but the main driver of obsolescence is declining customer demand and, therefore, volume and income. Manufacturers of durable goods of all types use market forecasting models to predict sales over some chosen planning horizon and, therefore, inform their product EOL decisions. Such models are usually referred to in the literature as growth or technology diffusion models and have found wide application in diverse durable goods (such as washing machines and TVs) manufacturing industries. Component consumers could use the same type of models for insight into the future obsolescence risk associated with a particular component MRI and use that insight in a product risk-assessment process. Meixell [111] describes a model based on the observation that the future demand for a particular product can be predicted using to-date sales data for a class of similar products. A class is a group of items that share some characteristic, such as the underlying manufacturing technology. Such a characteristic is referred to as a leading indicator. The example given is for a semiconductor technology node (i.e., the basic feature size for that node) as a leading indicator. Because new sales data are continually being collected, the model uses standard Bayesian updating to update the forecast. There are many underlying technology growth models reported in the literature and a summary is provided in Meade [112] with some discussion of the models' applicability bounds. One of the growth models often proposed is the Bass model [113] or one of several other variations [114–118]. All of them depend on fitting the model to observed data. Srinivasan [119] describes a nonlinear least-squares fitting algorithm and Schmittlein [120] describes a maximum likelihood technique. These models are fairly complex computationally and require data that are not readily available to component consumers. Because of the difficulty of obtaining the needed data, these are not known to have been used by component consumers to estimate their risk of obsolescence.

5.3 DESIGN METHODS FOR OBSOLESCENCE AND MITIGATION

This category of research is used to develop design and design-analysis techniques that drive down the risk of obsolescence occurring and making it easier (i.e., cheaper and quicker) to recover from the event when it does occur. Many architectural and detailed designs could satisfy the functional requirements. A requirement can be implemented in hardware, software, or IP combinations. All of these alternatives will result in differing TOC over the equipment lifetime because of differences in the manufacturing cost; the warranty and support cost; and the repeated costs associated with resolving the inevitable occurrences of obsolescence. An economic analysis of multiple design options and top-level architectural schemes at an early stage of design can assist in selecting the most promising to go forward. In support of these multiple options, Singh [89] provides a methodology to compare the obsolescence impact of multiple design options using the MOCA tool. Bradley [121] provides a similar model. The use of purchased or licensed commercial COTS IP in avionics is presently problematic because, unless alternate means are proposed, it is subject to the design assurance requirements of DO-254 [41]. These requirements cannot readily be satisfied because of the unavailability of the necessary certification artifacts, except in a few particular cases. A suggested approach to solving this problem is given in section 9, but cannot yet be considered mature.

5.3.1 Mitigating Software Obsolescence

Obsolescence of components may impact the airborne system software and require some change or update to accommodate the AEH changes necessary to resolve the obsolescence issue [35]. Airborne software changes carry a cost to requalify and recertify the system and must be factored in when considering both initial design choices and the optimum strategy for obsolescence resolution. Goswami [122] provides an extension to the MOCA model that accounts for the impact of obsolescence on embedded software.

Airborne software obsolescence most often occurs when the processor becomes obsolete. Several authors [45, 46, 48–50, 91, 123, and 124] describe a design approach using processor IP based on the proposition that the processor HDL code can readily be retargeted to a substitute host device. This approach can retain software object code compatibility and cycle accurate timing, and avoid or reduce requalification and recertification costs.

Airborne COTS software is not frequently used in avionics because of the certification process requirements, with the exception of cases in which the software manufacturer attempts to qualify the software product per DO-178B/C [38 and 125]. This is rarely the case for design and manufacturing tooling software and is most often purely COTS. Avionics manufacturers, therefore, must preserve such software and the associated platforms over the equipment life cycle to continue to maintain product and service capability.

6. STANDARDS AND ASSURANCE

This report provides some suggested topics for which the FAA could provide guidance for setting standardized approaches and minimum requirements for the management of obsolescence-induced change and ensuring that existing airworthiness is maintained as products evolve through many changes.

These suggestions pertain to: 1) the interface between the customer and supplier of avionics equipment, 2) continued airworthiness after modifications are made to resolve an obsolescence issue, and 3) the procedures to be followed by the FAA in adopting new rules, regulations, or guidance so that the economic consequences to owners and operators with installed equipment are fully considered.

Avionics companies may want to manage their internal obsolescence management processes, tools, models, design rules, and supplier relationships in customized ways. The details of the processes are closely held proprietary information and, therefore, cannot be constrained by or disclosed in standards documents. Aircraft manufacturers may similarly want to establish unique and confidential working relationships with suppliers, though some guidance on EOL visibility may be useful.

The FAA sponsors organizations such as RTCA and SAE International to publish standards that are ultimately incorporated into guidance material, such as ACs. The guidance assists applicants in meeting airworthiness requirements by providing detailed acceptable means of compliance to 14 CFR and a common understanding for the FAA and industry.

Because of the short market life of many of the components used in avionics equipment, avionics manufacturers constantly make design and construction modifications to retain production and support capability. This continues until they conclude that the continued investment is no longer technically or economically feasible. Such changes can vary from minor substitution of an exactly equivalent component to major redesign and software recertification.

The material presented in sections 6.1–6.3 is intended to assist the FAA in scoping the task and writing charter documents for standards and rulemaking bodies, but does not provide detailed language because this must be the result of FAA/industry consensus that is not subject to legal challenge.

6.1 PRODUCT SUNSET NOTIFICATION

Avionics manufacturers may declare that a product will be obsolete after a certain time. There are several possible causes of this, such as the inability to procure further production components and material because the demand has declined to the point where continued production lacks sufficient business justification or the production process capability is no longer available. There are many underlying reasons for these basic causes, and obsolescence problems cascade throughout the supply chain.

Avionics product EOL notifications are typically given in a SIL or SB that is sent out to all known customers and authorized service centers. In such cases, the manufacturer should provide a minimum set of information in the notification. The recommended minimum information content is provided in section 12 and appendix B.

6.2 MODIFICATIONS AND CONTINUED AIRWORTHINESS

In resolving an obsolescence event, the original design assurance must be maintained to provide assurance of continued airworthiness to the type certificate (TC) holder and certification

authorities. Current guidance, in the ACs and the associated standards, defines new product design assurance and safety assurance procedures, but does not adequately address how that guidance should be applied to modifications. A recommendation on this is given in section 12.

Though changes solely for the resolution of obsolescence will not result in a change of function, there exists the possibility that the changes could have unintended safety effects, particularly for critical systems, unless precautions are taken against that possibility. Such changes can vary in complexity from very low (e.g., equivalent or exact component substitution) to very high (e.g., processor change, software change, and recertification). Safety may be affected if, for example, the replacement components have lower reliability, are more susceptible to or generate more electromagnetic interference, require consequential software change, or have additional unused functions or modes that are not forcibly disabled. The application of current design assurance standards may detect these possible safety effects (but are not guaranteed to do so) if applied in full, but often do not because the change is not expected to compromise or negate the original design assurance.

The FAA issued a Final Rule (Docket No. FAA-2001-8994; Amendment Nos. 21-77A, 25-99A) in May 2001. This rule interprets 14 CFR 21 Subpart D (Changes to TCs) requirements. The FAA subsequently developed associated guidance material [126]. This rule and guidance discusses the applicability of, and requirements for, changes to aircraft TCs following changes to the aircraft. The regulation classifies aircraft changes as major or minor and a definition of major and minor is provided in 14 CFR 21 Subpart D, section 21.93. This regulation appears to apply to the aircraft as a whole and does not cover how the impact of the equipment change should be assessed. Changes to avionics equipment, from whatever cause, can potentially have consequences to aircraft performance or safety, and should therefore be assessed in a modification program.

The FAA has not provided any guidance on how avionics manufacturers should assess the airworthiness impact of changes to avionics systems or the circumstances under which changes would require an amendment to the TC or TSO. Additional guidance on avionics equipment changes is desirable to ensure that such possibilities are considered and mitigated so that the original design assurance is not lost. A recommendation to this effect is given in section 12.

Major changes would require the application of current design assurance guidance for a new design with the corresponding artifacts presented to the FAA in a modification project request. Minor changes would require a smaller subset to be performed with minimal FAA oversight. The FAA has developed a document that describes these considerations in the CAST Position Paper CAST-3 outline [76]. This document is primarily concerned with assessing the impact on software arising from obsolescence-induced hardware change. It recommends that a change impact analysis be performed, categorizing the change as significant/insignificant software impact. This document, though old, provides a good starting point for more formalized guidance.

There appears to be no formalized measure of complexity, so change classification must be a result of engineering judgment, in agreement with the FAA. This classification would also define the artifacts to be provided to the FAA and those which should be developed for inspection on request.

6.3 RULEMAKING PROCEDURES

The rollout of NextGen will likely result in the promulgation of a number of new procedural rules, such as those listed in the NextGen Concept of Operations [21]. Such rule changes may render an equipment-installed base inadequate for the new task, and therefore either unusable or usable only under limited operational circumstances. The FAA's rulemaking activities should consider the economic impact on the installed base of equipment when new operational rules are introduced. Ideally, new rules should maintain backwards compatibility of existing equipage for some period of time to allow users a reasonable period to re-equip. Recognizing that some incentive is needed to persuade operators to re-equip and conform to the new rules, the best-equipped–best-served principle could be applied, for which operators with compliant equipage may retain access to existing services or utilize additional services and capabilities. Guidance on the Notice of Proposed Rulemaking (NPRM) process should be written, giving due weight to economic impact on operators and bearing in mind the inherent limitations arising from the FAA mandate to consider the safety, security, and efficiency of the NAS.

Airspace rules affect the evolution of aircraft installed aircraft equipment and NAS capability. The effect of rulemaking goes beyond obsolescence and life-cycle maintenance and encroaches into new avionics product development in response to the imperative of improving the aircraft capability and the NAS capacity and efficiency. Because of the statutory need for public review, comment, and consensus, the rulemaking process is on a slow timescale that is commensurate with the typical lifecycle of aircraft equipment. Modification of equipment to comply with new and revised rules is, therefore, less likely than avionics manufacturers declaring equipment EOL and developing entirely new products. Operators must necessarily continue to replace noncompliant equipment, a burden which falls most harshly on GA owner-operators.

7. HIGH-VALUE APPROACHES

This section presents, in summary form (see table 2), the methods that have been previously described. These approaches are referenced back to the previous sections. The table has the following headings:

- Approach
- Type

    – Economic analysis (E)
    – Design methods (D)
    – Forecasting (F)
    – Regulation and standards (R)

- Description
- Value[1]
- Cost

Value and cost are coded with qualitative three-valued categories: high (H), medium (M), and low (L). These are merely the author's opinion and are not derived from any verifiable sources.

Although the following items are presented as discrete items, they are interdependent. For example:

- A product plan requires analysis of component obsolescence forecasts, future product demand, and anticipated regulatory actions to schedule redesigns, align them with customer roadmaps, and decide the eventual EOL date.
- An optimum redesign schedule and resolution method at discrete intervals depends on the product plan.
- The product plan may need to be adjusted and optimized according to the results of LCC analysis and the design decisions finally adopted.

In short, life-cycle planning is an iterative process with many feedback loops and with no clear stopping criteria. Furthermore, any such plans are subject to disruption by external events and invalid assumptions requiring replanning on a continuous basis.

General descriptions of the methods and specific references are given under the "Approach" heading in table 2. Recommendations on additional and changed guidance to implement these methods are given in section 12.

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[1] Value refers to value to the equipment supplier because it is expected that value to the supplier would be manifested as value to the customer through pricing and supportability, but this is difficult to quantify. Recurring (i.e., operating) cost is used as a measure of cost, but it should be understood that there are substantial (but not yet quantifiable) nonrecurring costs and technical and organizational hurdles to overcome associated with implementing these processes.

Table 2. High-value approaches

Approach	Type	Process Description	Value	Cost
LTB forecasting (section 4.2)	E	Calculating the number of components that should be bought in response to an LTB notification. This calculation includes those needed for continued production, repair requirements until the next redesign point, or product EOL for all affected products.	H	M
LCC estimation (section 5.1.2)	E	Calculating the profile of the expected discounted cost of manufacturing and supporting the product to EOL. This calculation includes manufacturer costs of production, warranty, support, and obsolescence management.	H	M
Optimum resolution selection (section 4.3)	E	Calculating the optimum choice between the available resolution options (e.g., substitution, redesign, product sunset, etc.) based on some measure of optimality (e.g., LCC).	H	H
Optimum redesign schedule (section 5.1.3)	E	Calculating the optimum timing and content of multiple redesigns through the product life cycle based on some measure of optimality (e.g., LCC).	M	M
Product life-cycle plan (appendix B - Generic Product Life-cycle Plan)	E	The expected production profile, timing and content of redesigns and upgrades, and the expected final EOL date.	H	L
Obsolescence forecasting (section 4.1)	F	Estimation of the probability or risk of obsolescence as a function of future time for components that have not yet been declared obsolete by the manufacturer.	H	H
MRI (section 5.2.1)	F	Calculation of a dimensionless and scaleless index number for an individual component representing the probability or risk that the component will become obsolete at some fixed future time. This calculation is a special case of obsolescence forecasting based on a fixed time horizon.	M	L
Product scorecard (section 5.2.1)	D	A product BOM annotated with: 1) an obsolescence risk measure for each component (e.g., MRI, YTEOL) and 2) a mitigation plan for components that fall below a documented and agreed threshold. The card would be used as a decision tool for production managers to accept or reject the design definition and transition to the manufacturing phase.	M	L

Table 2. High-value approaches (continued)

Approach	Type	Process Description	Value	Cost
Design patterns (section 4.5)	D	Design methods that seek to minimize the cost of resolving future obsolescence cases (e.g., design partitioning and change containment boundaries). This minimization of cost also includes strategic use of custom and COTS IP and the certification and design assurance methods necessary to permit their use.	M	L
Design selection (section 5.3)	D	Performance of a trade study to select from a set of alternative designs and select the one that minimizes future obsolescence management costs according to some selected optimality criteria (e.g., LCC. This minimization of cost also includes decision criteria for make/buy determination).	H	H
Product EOL notification (section 4.6)	R	Recommended minimum information content for a product EOL notice.	L	L
Continued airworthiness (section 6.2)	R	Recommendations and guidance defining the design assurance artifacts required for equipment modification modulated according to change significance, extent, and complexity, and in accordance with the applicable airworthiness regulations.	H	L
Rulemaking (section 6.3)	R	Recommendations and guidance for the Aviation Rulemaking Advisory Committee for: 1) consideration of the cost impact of proposed rules on the installed base and 2) allowing adequate time for the user community to comply by provision of a transition plan.	L	L
Manufacturing and design tooling (sections 4.7, 4.8)	D	Ensuring that required tooling is available to support manufacturing until product EOL and repair until the support end date declared in the product EOL notice.	M	H

8. SHARED ISSUES

Obsolescence issues, caused by the obsolescence of electronic components, touch on all those who make, buy, use, and certify avionics equipment. These and other peripheral entities may generally be described as electronic device organizations (i.e., those whose business depends on electronic components in a direct or indirect way). Electronic components exist as either piece parts for manufacturing and repair material or incorporated within finished equipment. In either form they flow around the entire aerospace ecosystem, originating with the part manufacturer and ending at disposal. The flow of parts between these electronic device organizations is illustrated in figure 5. Each arrow represents a flow of parts from one entity to another and, because each entity is a business, also represents that a commercial relationship exists between them. In addition to the physical parts flow, there is also an information flow of data about parts (e.g., part properties, characteristics, life-cycle stage, qualification data, and standards for proper application in equipment).
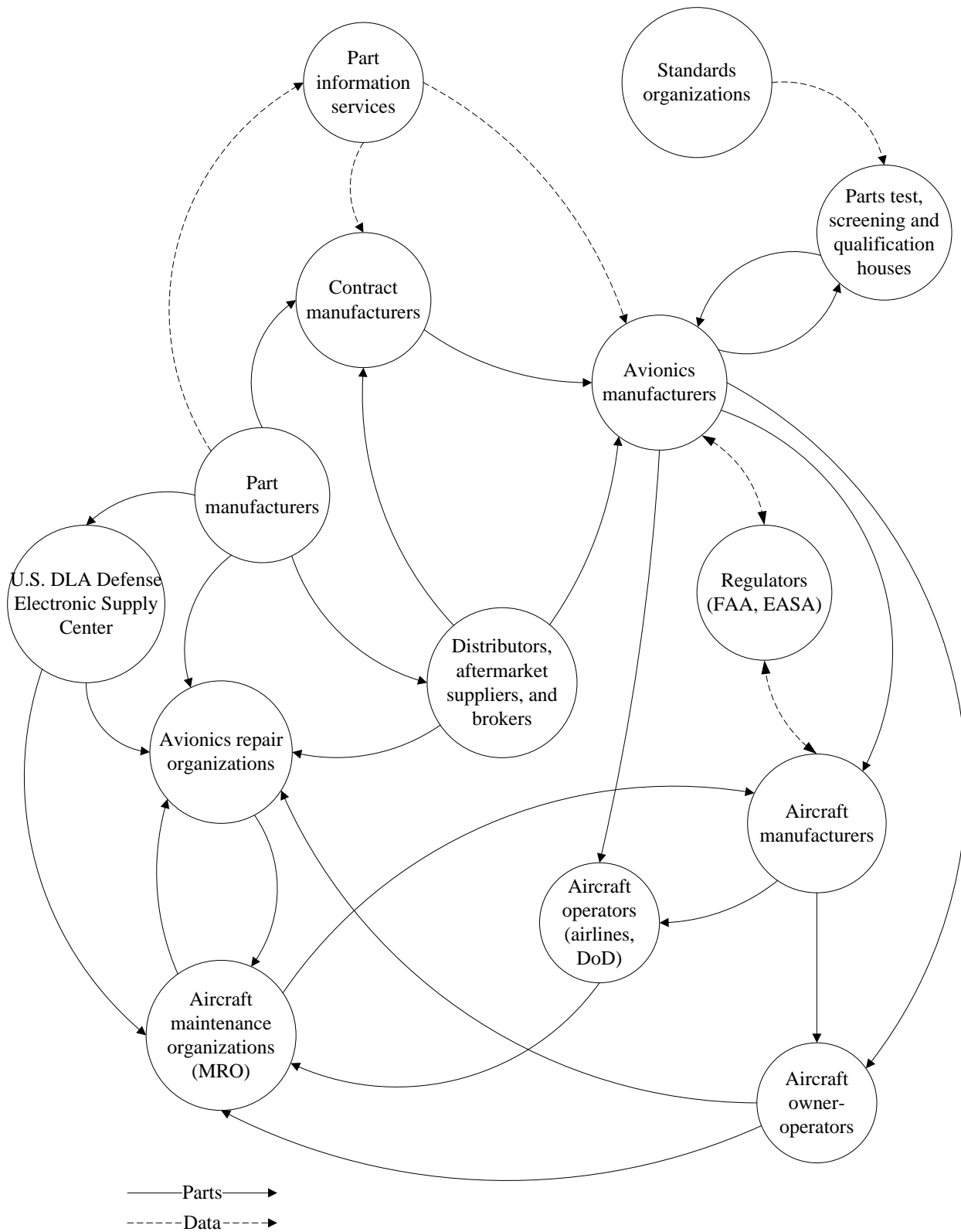
Figure 5. The flow of components between electronic device organizations

8.1 ELECTRONIC COMPONENT MARKET SEGMENTS

We characterize the electronic component market (i.e., buyers and users) into two broad segments. Segment 1 (which includes the aerospace industry) is characterized by:

- Long (20+ years) product life cycle and slow technology turnover
- High product complexity
- Low volume, high cost
- Severe environment
- Safety critical
- Strict regulation of design, production, and operation

These are characteristics that are shared to varying degrees by other industry segments, such as nuclear power generation, outdoor telecommunications, oil and gas exploration/extraction, industrial process control, automotive, and railways. Even when taken as a whole, in 2011 this segment accounted for less than 15% of the $300B annual semiconductor sales [127]. Military/aerospace is 1.1% and declining. This is the single most important factor for the obsolescence problem in aerospace.

Segment 2 (which includes consumer, computer, and communications) is characterized by:

- Short product life cycle and rapid technology turnover[2]
- High volume, low cost, and price sensitivity
- Benign environment
- Non-safety-critical
- Little regulation

Both segments share concerns about reliability and availability because these factors have a direct influence on safety and profitability. The 2011 market shares by industry segment is shown in figure 6 and the growth forecast by market segment is shown in table 3.

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[2] Network infrastructure and data center computing typically have long life cycles.

LEGEND
(%)
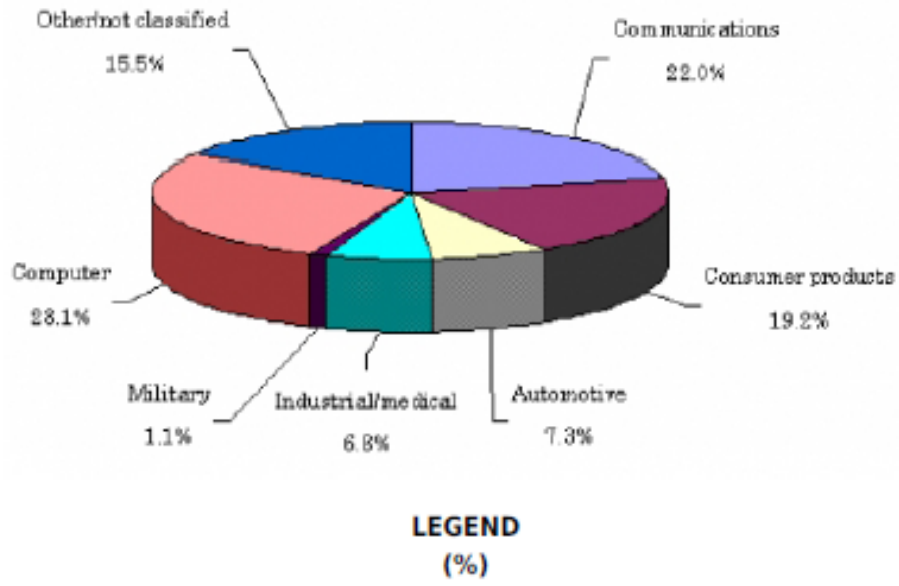
Market Sector	Percent
Computer	28.1
Communications	22.0
Consumer products	19.2
Automotive	7.3
Industrial/medical	6.8
Military	1.1
Other/not classified	15.5
Total*	100.0

Figure 6. Global semiconductor market share, 2011 (military includes aerospace) [127]

Table 3. Global market forecast for semiconductors ($billions) [127]

Type	2011	2012	2017	CAGR% 2012-2017
Computer	83.2	84.7	100.8	3.6
Communications	65.2	72.0	128.9	12.4
Consumer products	56.9	57.7	66.8	3.0
Automotive	21.5	21.8	22.7	0.8
Industrial/office	20.1	20.2	22.4	2.1
Medical	3.4	3.4	4.0	3.2
Military/aerospace	3.3	3.2	3.2	-0.2
Other/not classified	45.9	47.1	61.3	2.4
Total	299.5	310.1	410.1	5.8

CAGR% = compound annual growth rate

8.2 ELECTRONIC DEVICE ORGANIZATIONS

The obsolescence problem is intractable because there are many electronic device organizations involved, each of which, with the exception of regulators, are commercial self-supporting entities with differing concerns and motivating factors. In table 4 [127], electronic device organizations are categorized by type (the industry segment they primarily serve), and their primary concerns from an obsolescence perspective are listed.

Table 4. Electronic device organizations' primary concerns

Electronic Device Organization Type	Primarily Serving Segment	Primary Concerns
Parts manufacturers, semiconductor fabricators, and packagers	2	Manufacturing cost Technology cycle time Environmental legislation Raw material supply continuity
Parts distributors and brokers	2	Inventory cost
Aftermarket part suppliers	1, 2	Inventory cost
U.S. DoD Defense Electronic Supply Center	1	Technology cycle time Inventory cost
Avionics manufacturers and aircraft manufacturers	1	Regulation Design assurance Long life cycle
Operators (e.g., Bizjet, Airlines, and DoD)	1	Long life cycle Operating cost Support cost Operational environment Regulation
GA owner-operators	1	Long life cycle Acquisition cost Support cost Operational environment
Contract manufacturers	2	Line startup cost Recurring cost Production rate Material supply continuity Inventory cost Environmental legislation
Aircraft and avionics maintenance and repair organizations	1	Regulations Long life cycle
Regulators (e.g., FAA and EASA)	1	Aircraft, airspace safety, continued airworthiness, airspace usage efficiency
Parts test, screening and qualification houses	1	Technology cycle time, part testability, observability
Parts information services (e.g., IHS and GIDEP)	1, 2	Technology cycle time, source data feeds
Standards organizations (e.g., IECQ, IEC, UL, BSI, RTCA, and SAE)	1, 2	None

Table 3 shows that the common concern among parts users in aerospace (segment 1) is the long life-cycle requirement. The supply side (part distributors and manufacturers) does not have this concern because they are motivated primarily by consumer demand (85% of total demand). This forces a high rate of technology turnover and, therefore, obsolescence.

This variety of concerns leads to differing views and incentivizing factors among electronic device organizations on how the costs of obsolescence should equitably be distributed. Each organization will naturally seek to minimize its own costs. In commercial GA, regional, and large transport aerospace, the primary bearers of obsolescence costs are presently the avionics manufacturers, though all obsolescence costs find their way to the end users through purchase price and support cost. For military and space products, the end user is almost exclusively a government organization that directly bears the cost of obsolescence recovery.

9. USING COTS IP

Aircraft safety is not simply a matter of ensuring that the electronic components used are safe. Safety within a COTS electronic component or within COTS IP has no meaning because safety, like reliability, of an electronic component (including those that contain IP) depends entirely on the use, context, and the extent to which a design error or failure can contribute to a system hazard. Safety is a system property that must be assured by applying best practices at multiple levels.

This section suggests some approaches, methods, and processes by which an adequate measure of design assurance can be associated with COTS IP when used in airborne applications. This design assurance is one, but not the only, contributory measure to system safety. The intent is to outline methods and processes that can be modulated according to the criticality level of the airborne equipment.

COTS IP is available from many vendors implementing a variety of functions. It is incorporated in programmable devices (PD), such as an ASIC or FPGA, and used to provide many differing functions that have traditionally been implemented as COTS hardware components. Examples include processors, memory, and peripherals. COTS IP is delivered in various formats (e.g., source code HDL or as a precompiled and hardened macro targeted to a unique implementation process). It may also be encrypted to protect the underlying HDL source code.

This topic is important and relevant to obsolescence management because IP has some inherent technical and commercial advantages compared with hardware components. The advantages with respect to obsolescence are: 1) COTS IP can be bought or perpetually licensed and does not suffer from obsolescence directly, 2) if the target PD becomes obsolete, the IP can be ported to an alternative that need not be identical, and 3) IP modules can be linked by design tools to other IP to add and change functionality. These advantages are offset by increased difficulty in showing that adequate design assurance is provided to satisfy certification standards. In the remainder of this section, questions posed in reference [128] are addressed and a framework for future certification guidance on the use of COTS IP is developed.

In considering the use of COTS IP, avionics manufacturers must be cognizant of the product liability aspects because a majority of COTS IP, in common with COTS components, is sold

with a disclaimer that the buyer absolves the seller from any product liability when the product is used in safety-critical applications. A typical statement from Texas Instruments is shown below. This is taken from the data sheet for a Texas Instruments 54/74AHC00 Quad 2-input Positive NAND gate, but is a generic disclaimer:

> Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI.
>
> Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.
>
> In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.
>
> No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.
>
> Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have not been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.
>
> TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949." [129]

Statements such as this need not be inhibitors to the use of COTS IP and components since the avionics manufacturer and the aircraft manufacturer automatically assume the product liability risk when they choose to use such items and mitigate the risk through the verification and validation processes.

9.1 DEFINITION OF COTS IP

Though no single and generally accepted or common usage definition of COTS IP is known, this report considers COTS IP to be any IP with the following characteristics: 1) is widely available

for general sale or licensing and 2) high-level requirements (HLR); low-level requirements (LLR); detailed design; validation and verification artifacts; and documentation are not accessible to the avionics product designer and certification applicant. These characteristics have exact parallels in COTS electronic components.

This definition covers purchased hard, firm, and soft[3] format COTS IP that can be loaded by the applicant into a PD. This definition explicitly excludes any unique IP developed by the certification applicant because the applicant has complete design knowledge and control over all requirements and certification artifacts. Unique IP can be assured using the existing DO-254 processes. The assessment process proposed is the same whatever the method of delivery, though there are differences in the mechanics of loading the COTS IP into the PD.

The basic characteristic of COTS IP is that the user only knows the functional properties and has no knowledge of, or access to, the HLR, LLR, design, or verification. Functional properties are specified in manufacturer documentation (e.g., data sheet, application notes, user/programmers guide) that provides constraints that the user must observe in the application and the input/output relationships. The consequences of stepping outside those bounds are mostly unspecified. A further and important characteristic of COTS IP is that there is often a substantial user base that can contribute to confidence, but it is often difficult to quantify or discern what fraction of the usage base is actually relevant. One task is to determine a relevancy using the recommended updates to design assurance guidance, as discussed in section 12.

9.2 SIMILARITIES BETWEEN COTS IP ASSURANCE AND ASSURANCE OF COTS ELECTRONIC COMPONENTS

The approach presently used for COTS electronic components and modules is to determine whether the vendor has adequate processes in place for the qualification and QA of the component and to claim credit for wide usage. This approach is recommended in DO-254 [41]. Wide usage and service history are strong selection criteria and can typically be claimed for COTS components because they are developed for a wider market, often of much higher volume than aerospace. DO-254 section 11.3 provides some guidance on assessing and using product service experience to provide some degree of design assurance. The current guidance [130 and 131] for acceptable means of compliance with 14 CFR is built on the premise that no single failure can lead to a catastrophic system failure.

A review of the problems (but not the solutions) associated with COTS hardware use in safety critical systems is provided in [132]. Particular attention has been given to graphics processor devices [133 and 134] because of their potential to display hazardously misleading information to the crew. The difficulty of assuring the safety of COTS IP is not objectively different to that of assuring the safety of a complex COTS electronic component. Complex COTS component assurance is a topic of current research (e.g., microprocessors [135–139]).

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[3] Hard: technology specific physical layout format; firm: technology independent netlist format; soft: technology independent register transfer level or HDL format.

Aerospace vendors generally have an ECMP to describe the process followed for component selection and use that is in accordance with an international standard for preparing an ECMP, such as IEC TS-62239 or EIA-4899 [74, 75, 140]. For electronic components, compliance with the ECMP is usually accomplished by an audit of the vendor's component qualification process and results. It should be noted, however, that the audit process rarely extends to the design and verification of the component (i.e., design errors may be present; there have been some notable cases where this has occurred) [141]. In most cases, a vendor audit is performed using the STACK S-0001 specification [142] to determine the baseline quality requirements. This specification details the same general requirements for initial component qualification and ongoing QA of commercial integrated circuits that MIL-STD-883J provides for military components [143]. The second, and equally important, part of the ECMP is the requirement for the user to document the processes by which the components are used. The user's design and verification processes that fully account for the declared capabilities of the purchased component should be documented in the user's design and verification procedures system and documentation.

Acceptable means of compliance to current regulations and guidance for the selection and use of complex COTS electronic components is typically provided through a combined strategy of: 1) use of the ECMP, 2) system safety analysis, 3) assurance developed throughout the system hardware/software verification processes, and 4) architectural provisions to mitigate the possibility of common cause design errors. This methodology has been in use across the industry for more than 10 years and has proven to be very successful.

This report suggests that a similar process can be applied to the use of COTS IP, that the ECMP process offers a good model to extend to the COTS IP arena, and that much of the ECMP for the COTS components-related process is applicable.

9.3 COTS IP USAGE

Many companies have well-established processes to develop PDs (ASICs, programmable logic devices, and FPGAs, hereinafter referred to as PDs) that are compliant to DO-254 [41]. These processes typically depend on the availability of complete design information for the IP (e.g., requirements, codes, plans, verification results, and traceability matrices). Because complete design information is not generally available for purchased or licensed COTS IP, avionics vendors are not able to apply these processes and, therefore, are not able to use any of the wide variety of COTS IP available from vendors, therefore pushing up costs and time by developing custom IP and adding the risk of developing one-of-a-kind IP that does not benefit from a wide usage base.

The make-buy decision, being essentially an economic one, is altered by the availability of COTS IP. Therefore, design decisions that are not currently economically feasible become possible. This factor alone will help to drive down nonrecurring and recurring cost and also reduce LCC from the avoidance of obsolescence. The economic aspect influences the decision process regarding how to deal with an obsolescence event.

The only known COTS IPs that have an available DO-254 design assurance level (DAL) A package provided are the Altera NIOS-SC processor IP, the TTECH ARINC 664 controller in

Xilinx FPGAs, and ARINC-429 interface IP from BARCO and Ultra Electronics. The NIOS-SC is a relatively low-end processor with limited application areas. The small market size and high cost of developing a DO-254 support package are likely to discourage IP suppliers from entering the market to any significant degree. Therefore, the availability of functions is expected to remain low for the foreseeable future.

This section proposes how to define selection criteria as well as a process for assessing COTS IP and vendors for suitability for use in certified aerospace products of all DALs. In this case, suitability means not only that the COTS IP/PD combination performs its required functions under all the expected normal and abnormal operating conditions, but also that it has been developed within a structured and controlled process of assessed quality that is consistent with the DO-254 process-based design assurance philosophy. This process will provide high confidence that the IP is functionally correct and error free and that the target end-use equipment can be certified.

The possibility exists that any electronic component, whether containing IP or not, will include design errors. This possibility is recognized by the current guidance; however, the current 14 CFR guidance also recognizes that such errors should be mitigated by system design measures, such as redundancy and dissimilarity developed through the processes of ARP-4754A and ARP-4761, augmented through the process-based design assurance processes of DO-178C and DO-254.

DO-254 sets out a complete process for the specification, design, verification, and documentation of complex electronic hardware, such as PDs. Currently, DO-254 applies only to PDs that are programmed with avionics manufacturer-developed IP. This restriction is due to the limitations, guidance, and policy imposed by the FAA [144–149] because the impracticality of applying it to COTS hardware is recognized. DO-254 also defines the supporting infrastructure within which all design activities must be accomplished, such as QA, requirements traceability, configuration management (CM), and design and coding standards. This collection of design, verification, and infrastructure documentation is collectively referred to as life-cycle data. DO-254 is generic enough that user-defined data formats are acceptable, provided they meet the content requirements and are properly cross-referenced to the DO-254 hardware life-cycle data item descriptions, as described in section 9.3.2.

Because COTS IP is developed for wide usage in a range of applications, it often has multiple operating modes and features. When used in a particular application, some of these modes and features may never be invoked and, therefore, represent the hardware equivalent of dead code. Dead code can be a hazard because there are no corresponding requirements; therefore, it may not be tested. Guarding against erroneous invocation of dead code must be one of the objectives of verification; however, this assumes that the user knows what dead code exists in the COTS IP, which may not be the case. This issue is not confined to IP; a similar concern arises for software, electronic components, and modules for which modes are controlled by a configuration register or pin programming. This is a difficult problem, but may be explained by some of the advanced verification techniques discussed in section 9.4.1.

The major markets for COTS IP are in telecommunications, computers, and other non-aero sectors. There is no requirement to demonstrate design assurance to a certification authority, such as the FAA or EASA. In these markets, cost and time to market, rather than safety, are the principal drivers.

Aerospace application of COTS IP is constrained by the requirement to demonstrate design assurance. In the civil aircraft market, the FAA invokes design assurance requirements through AC 20-152 [144] associated policy [149], which in turn references DO-254 as an acceptable (but not the only) means of compliance. For military equipment, similar requirements are often levied by the customer on a contract-by-contract basis. AC 20-152 currently restricts the application of DO-254 to PDs, largely because of the recognized impracticability of obtaining the life-cycle data for COTS electronic components.

There is little experience regarding regulatory approval of systems that contain COTS IP and, therefore, there is no well-established process for doing so. Recent, but unofficial, guidance for the FAA certification process staff in conducting DO-254 reviews of PDs is provided in draft Order 8110.CEH [148 and 150] and in a more general DO-254 Job Aid [147]. These do not explicitly mention COTS IP. CAST position papers [146] provide some additional guidance, but do not specifically address how COTS IP should be certified.

9.3.1 A Suggested Approach to COTS IP Assurance

The demonstration of DO-254 compliance is difficult for COTS IP. The life-cycle data that is required by DO-254 is not generally provided. The proposition in this section is that much of the data exist in a well-managed COTS IP vendor, but may not be organized in a way consistent with DO-254. To what extent this is true is a research question suggested in sections 9.4.1.4 and 11. This section expands on the approach developed in reference 151. The initial assumption is that high-quality, well-managed COTS IP vendors have an interest in developing products that are free from design errors and correctly implement the design requirements set out for the product at the start of the development program. This assumption is based on the expectation that vendors who supply large volumes will not be prepared to risk design errors slipping through the validation and verification processes, causing defects in their products and a corresponding loss of customer confidence. COTS IP vendors have a strong incentive (commercially, not safety driven) to eliminate design errors from their products. This is because these errors lead to costly rework, recalls, and product liability penalties. They also have a broad customer and application base, allowing reports to be quickly fed back to the vendor. The IEEE Draft Standard P1734 [152] is intended to provide a unified view of quality measures for IP to facilitate the use and integration of this IP in electronic systems.

There is a strong similarity between the hardware-design process defined in DO-254 and the ISO-9001 philosophy of "say what you do -- do what you say." Avionics vendors must define their IP processes in great detail, show that these processes satisfy the objectives of DO-254, and support the processes with a QA function to ensure they are followed and can be demonstrated to have been followed. There is, therefore, an expectation that a prerequisite for vendors to be able to supply COTS IP of adequate quality is that they carry an ISO-9001 or equivalent approval. This approval is intended to assure that the vendor follows a well-defined and documented development process extending from requirements capture through to validation and verification,

with a supporting process for QA, CM, problem reporting, and resolution. For these types of vendors there will likely be a strong correlation between vendor process and documents as well as DO-254 process and life-cycle data items.

The general approach proposed is to set out a discovery process to map DO-254 life-cycle data items to the corresponding items of vendor data. This discovery process is a type of gap analysis in the vendor's processes, highlighting the additional costs to the user of creating the missing life-cycle data or developing mitigations in higher-level assemblies or software.

This process-oriented approach is based on a structured examination (through an audit) of whether the COTS IP vendor has established and followed a rigorous and structured approach to the specification, design, and verification of the COTS IP, and that it has been used in multiple applications with no unresolved problem reports outstanding. Furthermore, the process validates that the vendor operates adequate process assurance and QA controls that are able to assure CM of the delivered product, the supporting application documents, and the necessary supporting tools. That these processes are in place and operating correctly will be verified by an independent external certification body performing periodic audits to the top-level quality certificate (e.g., ISO-9001).

The intent is to gain assurance that the necessary processes exist, are followed, and are adequate, rather than reviewing the artifacts of each and every COTS IP. The vendor will be expected to provide minimum deliverable documentation sufficient for successful application, with references to the qualification documentation.

A suggested map of the proposed process is shown in figure 7. The audit elements may be based on the VSIA QIP tool [153].
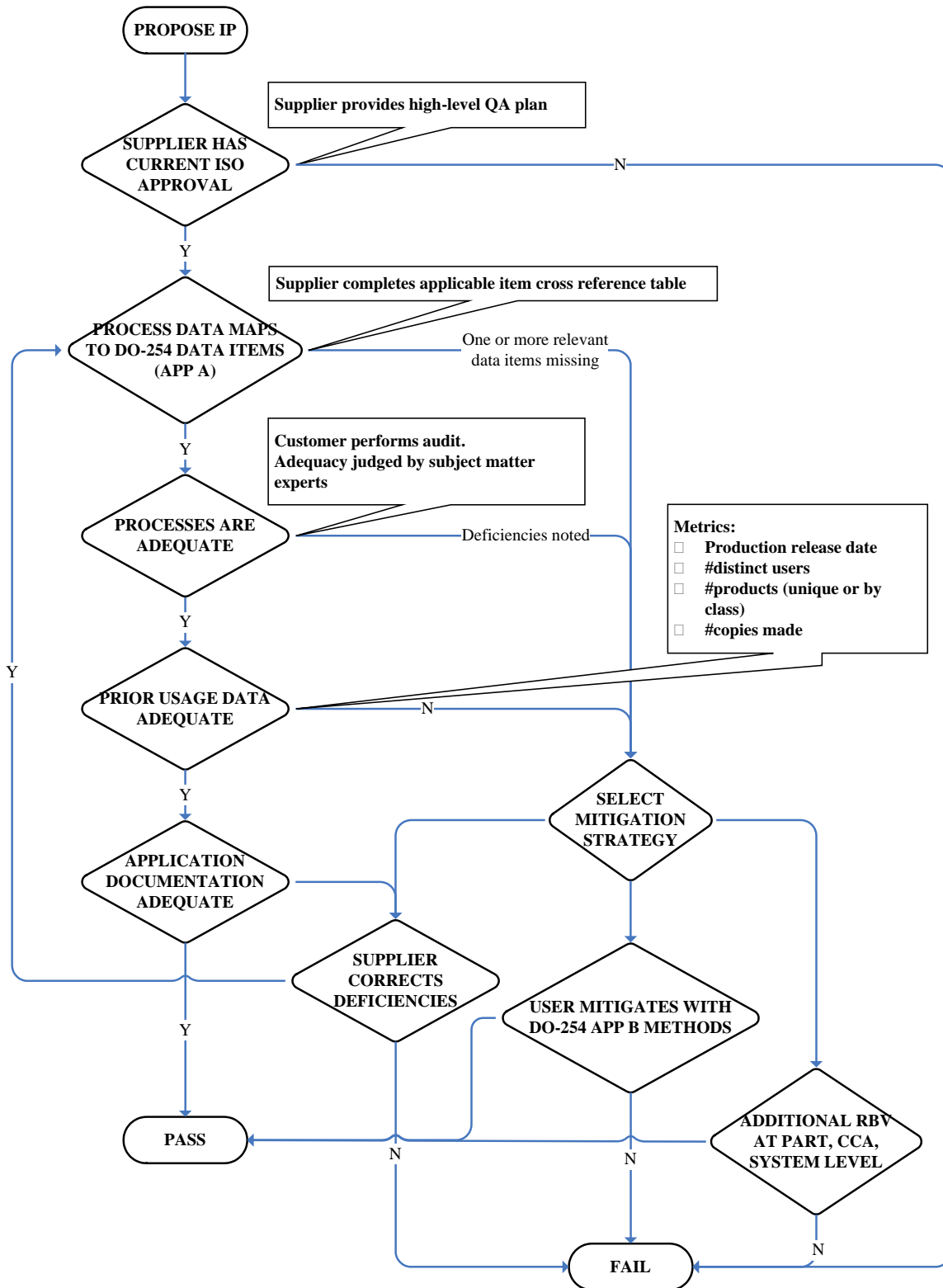
Figure 7. Process map

9.3.2 Representative Mapping of RTCA/DO-254 Data Items and Supplier Documents

Tables 5–7 are excerpted from DO-254 appendix A [41] as an example of templates to be used during the discovery process involved in selecting a COTS IP and supplier. These example templates are for a COTS IP that is intended for use in a DAL-A product. Lesser CM categories apply to lower DAL assignments, though this would imply that an assessment performed at a lower level could not later be used to establish approval of the IP for use in a product with a higher DAL.

During this assessment process, a cross-reference map linking DO-254 objectives to supplier process evidence would be completed either by prior submission or during an on-site supplier audit/review. This will involve substantial time and effort initially by both the customer and supplier, but is likely to be substantially repetitive during subsequent selections from the same supplier, because the requirements validation, IP design, and verification processes are largely independent of the actual product. The intent is to minimize the number of documents that need to be submitted, while ensuring that the supplier-processes closely follow the requirements-based verification paradigm of DO-254.

If the audit process highlights deficiencies, then the choices are for the COTS IP supplier to correct the deficiency (e.g., design data, verification results, and documentation), for the user to provide additional design and architectural mitigations, or for the supplier to be disapproved.

Table 5. The DO-254 [41] appendix A objectives/supplier evidence

Data section	DO-254 Hardware Life-Cycle Data	DO-254 Objectives	Submit	CM Category Table 5
10.1.2	Hardware Design Plan	4.1(1, 2, 3, 4)		HC2
10.1.3	Hardware Validation Plan	4.1(1, 2, 3); 6.1.1		HC2
10.1.4	Hardware Verification Plan	4.1(1, 2, 3, 4); 6.2.1(1)		HC2
10.1.5	Hardware CM Plan	4.1(5); 7.1(3)		HC1
10.1.6	Hardware Process Assurance Plan	4.1(4); 8.1(1, 2, 3)		HC2
10.2.1	Requirements Standards	4.1(2)		HC2
10.2.2	Hardware Design Standards	4.1(2)		HC2
10.2.3	Validation and Verification Standards	4.1(2)		HC2
10.2.4	Hardware Archive Standards	5.5.1(1); 7.1(1, 2)		HC2
10.3.1	Hardware Requirements	5.1.1(1, 2); 5.2.1(2); 5.3.1(2); 5.4.1(3); 5.5.1(1, 2, 3); 6.1.1; 6.2.1(1)		HC1
10.3.2.1	Conceptual Design Data	5.2.1(1)		HC2
10.3.2.2	Detailed Design Data	5.3.1(1); 5.4.1(2)		HC1
10.3.2.2.2	Assembly Drawings	5.3.1(1); 5.4.1(2); 5.5.1(1)	S	HC1
10.3.2.2.4	Hardware/Software Interface Data	5.3.1(1); 5.5.1(1)	S	HC1
10.4.1	Hardware Traceability Data	6.1.1; 6.2.1(1, 3)		HC2
10.4.2	Hardware Review and Analysis Procedures	6.1.1; 6.2.1(1)		HC1
10.4.3	Hardware Review and Analysis Results	6.1.1; 6.2.1(1)		HC2
10.4.4	Hardware Test Procedures	6.1.1; 6.2.1(1)		HC1
10.4.5	Hardware Test Results	6.1.1; 6.2.1(1)		HC2
10.5	Hardware Acceptance Test Criteria	5.5.1(3)		HC2
10.6	Problem Reports	5.1.1(3); 5.2.1(3); 5.3.1(3); 5.4.1(4); 5.5.1(4); 6.2.1(2)		HC2
10.7	Hardware CM Records	5.5.1(1); 7.1(1)		HC2
10.8	Hardware Process Assurance Records	7.1(2); 8.1(1, 2, 3)		HC2

HC = hardware control

Requirements for CM of the data items by the IP supplier and the definitions of HC1/2 are excerpted from DO-254 [41] Table 7-1 and reproduced below in table 6.

Table 6. CM hardware control categories (DO-254 Table 7-1 [41])

CM Activity	HC1	HC2
Configuration Identification	x	x
Baselines	x	
Baseline Traceability	x	x
Problem Reporting	x	
Change Control-integrity and identification	x	x
Change Control-records, approvals, and traceability	x	
Release	x	
Retrieval	x	x
Data Retention	x	x
Protection Against Unauthorized Changes	x	x
Media Selection, Refreshing, Duplication	x	

HC = hardware control

9.4 ADDITIONAL CONSIDERATIONS

There are no data items listed for DO-254 section 11 [41]. The additional data items listed in table 7 should be part of the documentation provided by the COTS IP supplier.

Table 7. Additional DO-254 objectives [41]

Hardware Life-Cycle Data	DO-254 Objectives	CM Category	Submit
Product Service Experience Data Acceptability Criteria	11.3.1(1, 2, 3)	HC2	S
Assessment of Product Service Experience Data	11.3.2(1, 2, 3, 4)	HC2	S
Product Service Experience Assessment Data	11.3.3(1, 2, 3, 4)	HC2	S

9.4.1 Advanced Methods

The COTS IP assurance methods in section 9.3 are essentially process-based and replace user processes with vendor processes of demonstrably equivalent rigor. While this is a minimum requirement, additional assurance methods could be used that operate at the functional level and do not require knowledge of the internals of the COTS IP. These methods depend on a formalized representation of the functional properties of the item that can be verified using

conventional directed (requirements based) test or randomized testing [154]. Functional properties can be captured in such tools as System Verilog.

9.4.1.1 Run-Time Methods

Run-time methods are architectural mitigations that add independent observer elements to monitor the IP function at run time and provide error detection. An error is any function output that results in a deviation from the output expected by the monitor or a hazardous situation. Expected outputs are developed from the functional properties of the hardware or software and expressed as a functional model, and hazardous situations are developed from the functional hazard and system safety assessments. For this to be effective, common cause (design) errors between the function and monitor must be eliminated by such techniques as hardware and software dissimilarity. Some work on this approach has been reported in references 155 and 156. Functional hazard and system safety assessment in conventional practice today typically considers only hardware failures as contributors to hazards. Recent work that derives hazards based on functional failures is exemplified in references 157 and 158. A new field of research called Software Health Management [159] offers some promising new techniques to detect hazards at run time. These techniques bear some resemblances to model-based techniques.

9.4.1.2 Model-Based Verification

Model-based design first creates executable, high-level, functional models that can be stimulated in a simulation environment. These types of tools are useful for exploring rare events (or corner cases) and developing HLR that can be tested during verification. One example of this type of tool is the Honeywell Integrated Lifecycle Tools and Environment [160], which is a proprietary Honeywell tool that generates test cases from a functional model of the function under test. The model is generated from the functional specification and, therefore, is implementation independent. Commercial tools, such as Simulink, System Verilog, or SCADE, can be used to generate the high-level models. In the context of COTS IP, model generation can only be performed according to the information provided by the supplier (i.e., the user guide, application notes, and data sheet). Test cases provided by this tool can be used for testing the IP in a simulator and the final FPGA. A subset of these tests may also inform the equipment verification plan.

9.4.1.3 Functional Failure Path Analysis.

Functional failure path analysis (FFPA) [161] was introduced in DO-254 Appendix B. The FFPA decomposes a design into paths of hardware elements that cause or contribute to the loss of a function identified by a functional hazard assessment. This process allows a correspondence between hardware elements, functional failures, and system hazards to be established so that the hardware as a whole need not be classified according to the highest level of design assurance required by any one function.

This method may be used to identify hardware elements (and, therefore, COTS IP) that do not contribute to identified hazards and elements for which design assurance is not required. The

method does not offer any assurance for COTS IP elements that do contribute to hazards because the foregoing limitations on the ability to analyze the design remain.

9.4.1.4 COTS IP Research Questions.

The development of a process to assure the safety of equipment using COTS IP is a technical problem and a consensus-building process. Design errors cannot be provably eliminated in any software, IP, hardware, or operating procedure design process (except in a small subset of cases that are amenable to formal methods); therefore, the exercise is, to some degree, about establishing a set of rules and best practices (i.e., acceptable means of compliance) that are adjudged by the industry and regulators to adequately assure safety.

The following are suggested research questions:

- How can the COTS IP usage base be discerned and filtered for relevant usage?
- Do COTS IP vendors who are willing and able to demonstrate their quality standards and internal design controls represent a sufficiently large class of applications and functions that prove to be useful?
- How should vendor standards and controls be assessed, both initially (for a new COTS IP product) and for update through declared EOL?
- What are the current constraints of DO-254 that confine or prevent the use of COTS IP?
- What, if any, amendments should be made to current guidance and standards to establish an industry/regulator consensus (i.e. revised acceptable means of compliance) on safe use practices?
- What architectural, design, or verification measures can be applied to mitigate the safety hazards that COTS IP might produce?
- Is it feasible to develop a set of metrics against which COTS IP could be scored?
- What would be the approval threshold for the metrics within the certification process?
- How can COTS IP unused functionality (dead code) be identified and shown to be permanently disabled or deactivated?
- What classes of functions and implementations are amenable to model-based verification?
- What is the effectiveness of the DO-254 advanced methods and to what classes of COTS IP are they applicable?

10. FINDINGS

Obsolescence is caused by both top-down regulatory and legal pressures and bottom-up supply chain pressures. GA owner-operators and manufacturers of all types of avionics and aircraft have no control over either, but are nonetheless required to respond.

The present state of obsolescence management in commercial and military aerospace, and in the GA industry is focused on getting the maximum forewarning of obsolescence and reacting to it.

The obsolescence problem has been around for many years. Because of its difficulty and changing market dynamics, it has been, and continues to be, an evolutionary process to develop

mitigation methods. The Part 25 aircraft manufacturers are taking the lead in developing and promoting standardized requirements through bodies such as the IEC with the support of the avionics manufacturers. Part 23 aircraft manufacturers have, so far, not been involved to any large extent in these activities. Avionics manufacturers are moving steadily to improve their internal mitigation processes and these experiences are being incorporated in the standardization activities. This is necessarily a slow process because the underlying business problem is that of the equitable distribution of obsolescence costs in an open, competitive market. Consequently, mutually agreeable and acceptable policies between suppliers and customers have to be pursued. The internal processes for obsolescence management used by avionics manufacturers are largely the same for all types of products, GA or otherwise. The differences arise mostly in the resolution option selection, which is driven mostly by the differing economics of the target markets.

The rate of progress on process development and maturity level is constrained by the high costs involved in setting up and operating the infrastructure; keeping up with new obsolescence issues; lack of obsolescence-aware design patterns; and lack of economic analysis and forecasting tools to select the resolution option that is most likely to be the most cost effective. The costs of obsolescence-management efforts must eventually find their way into product price, so the problem is essentially an economic one that rests on the ability to provide a compelling value proposition to the customer that long-term savings can be realized in return for short-term costs. The further progression of obsolescence management maturity is likely to be through the development of obsolescence-aware design patterns and economic modeling and forecasting methods from which product life-cycle plans and customer value propositions can be derived.

Obsolescence has marginal safety or security impact because: 1) the airworthiness regulations governing AEH apply to obsolescence-driven change as much as change to the original design—and also to change for any other reason, and 2) the regulations are technically adequate for assuring initial and continued airworthiness. Though poorly controlled obsolescence resolutions, redesign, or aviation rule changes could potentially result in the risk of some aircraft operating with obsolete or nonconforming equipment, that is an enforcement issue that cannot be easily mitigated through technical means.

There are numerous areas where obsolescence management practices and guidance could be improved. Most of these areas are ultimately dependent on methods for forecasting component obsolescence, market demand, and regulatory actions, which would allow for methods and algorithms for decision-making under uncertainty. Obsolescence management must be seen as a holistic risk-minimization activity because obsolescence will always exist and is subject to factors with a high degree of uncertainty.

11. FUTURE WORK

Several potential and promising research topics have been identified in this report. These are summarized in table 8. The suggested participants are categorized as:

- Industry – Avionics, aircraft manufacturers, industry trade associations, consultants
- Universities – University-based collaborative research centers
- Government – DoD, Department of Energy, FAA, EASA, NASA, federally funded research centers

Table 8. Possibilities for combined research topics

Research Topic	Participants		
	Industry	Universities	Government
Decision-support tools to aid management in selecting from the available choices of responses to an obsolescence event of either an electronic component or complete equipment EOL. Such tools will draw from research on economics and optimization algorithms.	X	X	X
The feasibility, cost/benefit tradeoff, and market acceptability of establishing a code of practice or enforceable regulations and contract terms to guarantee a minimum period of support for avionics equipment after discontinuance.	X		X
Develop auditable standards for obsolescence management processes and capabilities of equipment and aircraft manufacturers.	X		X
Develop new design-assurance techniques and regulatory guidance language that would permit the use of COTS IP. The IP can be perpetually licensed and therefore is immune to obsolescence. This solution is attractive to avoid the obsolescence of processors and other complex hardware, but is presently impossible because of the lack of DO-254 support artifacts, except in a few limited cases. A promising research avenue is to investigate whether adequate design assurance can be given by DO-254 to manufacturer process mapping.	X		X
Develop a means to calculate a probabilistic measure of obsolescence risk or forecast EOL for components that have not yet been reported as soon-to-be obsolete. This would provide a real-time obsolescence health index for currently used components. A health index could incorporate a variety of metrics, such as the present known state; indices produced by the obsolescence status tools; technology class or grouping; component technology roadmap forecasts (such as ITRS and National Electronics Manufacturers Initiative ; manufacturer product deletion history; the probability and timing of mergers and acquisitions; and fiscal health measures from business information sources.	X	X	
Develop a probabilistic LTB/BB estimation method. This is a difficult and unresolved problem because it depends on what future orders can be expected, the timescale for the future orders, and the number needed to support existing items in repair. These factors carry considerable uncertainty because market forecasts are inherently unreliable and future spares needs depend on both the number of items in service and the in-service failure rate.	X	X	
Develop standards, guides, and best practices for the preservation of manufacturing tools/processes and software/HDL tools and platforms.	X		X
Extend LCC models in the literature to TOC models for aircraft manufacturers (and possibly fleet owners) to enhance the fidelity of the construction of aircraft roadmaps and technology refresh plans.	X	X	
Develop a modulated list of the minimum artifacts needed to show continued airworthiness after equipment modification of varying degrees of complexity.	X		X
Develop reference material describing the principal components and structure of a product life-cycle plan. This material would serve as a guide to the evaluation of a product life-cycle plan.	X		X
Develop proposed modifications to the guidance for the NPRM processes to provide adequate response time to users who are affected by system obsolescence induced by rulemaking.	X		X

12. RECOMMENDATIONS

The FAA recommends deliberation to providing guidance to industry in the following areas:

- Recommend practices to ensure continued airworthiness following changes to the design of avionics, whether from obsolescence resolution or any other cause. The required level of design assurance should be tailored to the extent of the change and its probable impact on continued airworthiness (see section 6.2). It is recommended that the FAA should develop general equipment-change guidance to complement the existing aircraft-level change guidance. This would define the steps required to: 1) assess the impact of the changes on the aircraft TC and 2) maintain the original equipment design assurance and airworthiness under various degrees of modification. We recommend the following steps:

  – Determine the change(s) to be made to hardware and any consequential changes to software.

  – Classify the whole change package according to complexity as major or minor.

  – Document the changes and classification in a change impact analysis.

  – From the classification, determine the steps necessary for continued airworthiness of software and hardware and determine whether a TC amendment is required.

  – Open a modification project with the FAA if necessary to amend the instructions for continued airworthiness (ICA).

- Expand FAA internal ICA working guidance (Orders and Notices) to define the degree of involvement with the applicant when changes are made or a revised certification application is submitted.

- Expand existing design assurance guidance on modification procedures and requirements to provide a more detailed set of steps and considerations, according to the classification of the modification and to provide explicit requirements for artifacts.

- Control the aviation policy, guidance, regulation, and order-making process to allow adequate time for operators to spread the cost of upgrades (see section 6.3).

- Provide guidance on the minimum contents of a product life-cycle plan (see appendix B).

- Provide updated guidance for methods and processes for the selection and use of COTS IP to assure that adequate design assurance is obtained (see section 9).

- Recommend practices for manufacturers of avionics to notify customers of product EOL. These practices are not considered to impact safety assurance or certification. The intent of these guidelines is to ensure that avionics equipment users have adequate information and a reasonable amount of time to adapt their operations and procure alternative products if necessary. The minimum recommended information should be the following:

  – The latest date for LTB order (after this date no further orders can be accepted).

  – The latest date for shipment of LTB orders (after this date no further shipments will be made).

  – The name and address of the licensee if design authority, design approval holder, manufacturing rights, or support has been licensed or transferred to a third party.

  – A list of approved alternative products and approvals (if any) for each affected aircraft type.

  – The period of continued support after the warranty expires. During this period, maintenance support will be provided, possibly by a licensee.

  – The extent of continued support (e.g., provision of repair services by the manufacturer; licensee or approved repair stations; incorporation of airworthiness directives (AD) as required by the FAA; and updates to technical publications).

- Recommend practices to ensure that design, manufacturing, and support tooling are maintained and supported through the end of service life.

13. REFERENCES

1. Sandborn, P., "Strategic Management of DMSMS in Systems," *DSP Journal*, April/June 2008, pp 24–30.

2. Carbone, J., "Where Are the Parts?" *Purchasing*, December 2003, pp 44–47.

3. TechAmerica, "Standard for Preparing a DMSMS Management Plan," GEIA-STD-0016, TechAmerica (formerly GEIA), August 2011.

4. International ElectroTechnical Commission, "Process Management for Avionics – Aerospace Qualified Electronic Components (AQEC) – Part 1: Integrated Circuits and Discrete Semiconductors," TS 62564-1, IEC, Geneva, Switzerland, January 8, 2011.

5. United.States Department of Defense, "Diminishing Manufacturing Sources and Material Shortages (DMSMS) Guidebook," SD-22, September 1, 2010.

6.   Airbus, "Equipment - Design - General Requirements For Suppliers" Part 1 - Product, Chapter 14 - Issue: B," Airbus, Toulouse, France, Chapter 14, "Obsolenscence Management."

7.   Boeing, "Electronic Component Management Plan (ECMP)," D6-55583 Revision C, January 20, 2011.

8.   Gaillat, G., "Generic Tools and Methods for Obsolescence Control," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, October 23–25, 2000.

9.   Drake, Michael, "Sharing Obsolescence Information at Raytheon With the Component Obsolescence and Reuse Tool," *The International Symposium on Product Quality and Integrity; Transforming Technologies for Reliability and Maintainbility Engineering*, Tampa, Florida, January 27–30, 2003.

10.   Buratti, M. and Del Brusco, D., "Obsolescence Management Based on a 'Pro-Active' Approach in Conjunction With a 'Pre-Planned' Technology Insertion Route," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, October 23–25, 2000.

11.   Honeywell, "Service Information Letter: KLN94 GPS Navigation System (KLN94), PN 069-01034-0101, -0102; Discontinuance of End Item," Honeywell, April 14, 2010.

12.   Federal Aviation Administration, "Advisory Circular: US Terminal and En Route Area Navigation (RNAV) Operations," Washington, DC, AC 90-100A, March 1, 2007.

13.   Wilkinson, C. and Wasson, J., "Component Obsolescence Management for Military Electronics," *5th Annual Commercialization of Military and Space Electronics Conference,* Los Angeles, California, February 12–15, 2001.

14.   Pecht, M., Solomon, R., Sandborn, P., Wilkinson, C., and Das, D., *Life-Cycle Forecasting, Mitigation Assessment and Obsolescence Strategies*. College Park, Maryland: CALCE EPSC Press, 2002.

15.   Darling, D.R., Cirillo, T., Fuller, D., Herald, T., and Green, J., "Parts Obsolescence Management Technology Transition (POMTT)," AFRLML-WP-TR-2005-4012, August 2004.

16.   Regan, T., "Parts Obsolescence Management Tools (POMT)" TRW Electronic Systems Group, Dayton, Ohio, March 2001.

17.   Sandborn, P., "Trapped on Technology's Edge," *IEEE Spectrum,* Vol. 45, No. 4, 2008, pp. 42–58.

18. JEDEC, "Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices," IPC/JEDEC J-STD-020A, April 1999.

19. Fukuda, Y. and Osterman, M., "Tin Whiskers: What's the Risk?," *Lead Free Electronics*, June 2005, pp. 2.

20. Universal Avionics, "Service Information Letter - UNS-1( ) Product Support, Repair and Navigation Database Service ," available at http://uninet.uasc.com/documents/techpubs/ FMS_1(_)_Disc_of_Service_sl2843.pdf, accessed April 18, 2011.

21. Joint Program Development Office, "Operational Concept for the Next Generation Air Transportation System (Nextgen) Version 3.0," October 1, 2009.

22. Joint Program Development Office, "NextGen Avionics Roadmap," October 24, 2008.

23. European Union and EUROCONTROL, "European ATM Master Plan Edition 2," October 2012.

24. bin Salam, S., "NextGen: Aligning Costs, Benefits and Political Leadership," Eno Center for Transportation, April 2012.

25. "Cost Estimate, H.R 658 FAA Reauthorization and Reform Act of 2011 Report," Congressional Budget Office, Washington, DC, March 2011.

26. EuroControl, "Mandates ," available at http://www.eurocontrol.int/ses/public /standard_page/sk_mandates.html, accessed November 5, 2012.

27. "Draft Rule for Data Link Services for the Single European Sky," EUROCONTROL, 2007.

28. Seidenman, P. and Spanovich, D. J., "Airlines Seeking Software Solutions For Avionics Upgrades," available at http://www.aviationweek.com/Article.aspx?id=/article-xml/AW_11_05_2012_p08-504939.xml, accessed November 15, 2012.

29. "Automatic Dependent Surveillance-Broadcast (ADS–B) out Equipment and Use", FAA Title 14-CFR §91.225.

30. "Automatic Dependent Surveillance-Broadcast (ADS–B) Out Equipment Performance Requirements.," FAA Title 14-CFR §91.227.

31. Federal Aviation Administration, "Advisory Circular: Automatic Dependent Surveillance-Broadcast (ADS-B) Operations," AC 90-114 Change 1, Washington, DC.

32. "14 CFR Part 91 Automatic Dependent Surveillance - Broadcast (ADS–B) out Performance Requirements to Support Air Traffic Control (ATC) Service; Final Rule," Federal Aviation Administration, 2010.

33. European Union Directorate-General for Climate Action 2012, "Reducing Emissions From the Aviation Sector," available at http://ec.europa.eu/clima/policies/transport/aviation/index_en.htm, accessed November 21, 2012.

34. SESAR Joint Undertaking, "Partnership With AIRE Programme," available at http://www.sesarju.eu/environment/aire, accessed November 21, 2012.

35. Sandborn, P.A., "Editorial Software Obsolescence: Complicating the Part and Technology Obsolescence Management Problem," *IEEE Transactions on Components and Packaging Technologies,* Vol. 30, No. 4, 2007, pp. 886–888.

36. Audsley, N., Bate, I., and Grigg, A., "Portable Code: Reducing the Cost of Obsolescence in Embedded Systems," *Computing and Control Engineering Journal,* Vol. 10, No. 3, 1999, pp. 98–104.

37. Audsley, N.C., Grigg, A., Fletcher, M., and Wake, A., "Portable Code in Future Avionic Systems," *Proceedings of the 1998 IEE Colloquium on Real-Time Systems*, April 21, 1998.

38. Radio Technical Commission for Aeronautics, "DO-178B - Software Considerations in Airborne Systems and Equipment Certification," DO-178B, Washington, DC, December 1, 1992.

39. Electronic Industries Alliance, "Product Life Cycle Data Model," EIA-724, January 9, 1997.

40. Solomon, R., Sandborn, P.A., and Pecht, M.G., "Electronic Part Life-Cycle Concepts and Obsolescence Forecasting," *IEEE Transactions on Components and Packaging Technologies,* Vol. 23, No. 4, 2000, pp. 707–717.

41. Radio Technical Commission for Aeronautics, "DO-254 - Design Assurance Guidance for Airborne Electronic Hardware," DO-254, Washington, DC, April 19, 2000.

42. Pecht, M. and Das, D. "The Electronic Part Life Cycle," *IEEE Transactions on Components and Packaging Technologies,* Vol. 23, No. 1, 2000, pp. 190–192.

43. Freescale, Inc., "Life Cycle Stage Codes," available at http://www.freescale.com/webapp/sps/site/eialink.jsp, accessed June 17, 2013.

44. Peters, L.S., "GEM: Technology for Improved Logistics Support," *Proceedings of the IEEE 1993 National Aerospace and Electronics Conference, NAECON*, Dayton, Ohio, May 24–28, 1993.

45. Carayon, J.L., "Emulation Techniques for Solving Processor Obsolescence," *DASIA 2007: DAta Systems In Aerospace Conference*, Naples, Italy, May 29–June 1, 2007.

46.   Abate, F. and Violante, M., "Coping with Obsolescence of Processor Cores in Critical Applications," *IEEE International Symposium on Defect and Fault Tolerance of VLSI Systems, DFTVS '08*, Boston, Massachusetts, October 1–3, 2008.

47.   Alcalde, A., Ortmann, M.S., and Mussa, S.A., "NIOS II Processor Implemented in FPGA: An Application on Control of a PFC Converter," *Power Electronics Specialists Conference, 2008. PESC 2008. IEEE*, 2008, Rhodes, Greece, pp. 4446–4451.

48.   Anghel, L., Velazco, R., Saleh, S., et al., "Preliminary Validation of an Approach Dealing With Processor Obsolescence," *18th IEEE International Symposium on Defect and Fault Tolerance in VLSI Systems*, Boston, Massachusetts, November 3–5, 2003.

49.   Broadbent, M., "Use of FPGA for Emulation of Obsolete Processors in Safety Systems," June 8, 2005.

50.   Guzman-Miranda, H., Sterpone, L., Violante, M., Aguirre, M., and Gutierrez-Rizo, M., "Coping With the Obsolescence of Safety - or Mission-Critical Embedded Systems Using FPGAs," *IEEE Transactions on Industrial Electronics,* Vol. 58, No. 3, 2010, pp. 814–821.

51.   Bastia, S., "Next Generation Technologies to Combat Counterfeiting Of Electronic Components," *IEEE Transactions on Components and Packaging Technologies,* Vol. 25, No. 1, 2002, pp. 175–176.

52.   Livingston, H., "Avoiding Counterfeit Electronic Components," *IEEE Transactions on Components and Packaging Technologies,* Vol. 30, No. 1, 2007, pp. 187–189.

53.   Pecht, M. and Tiku, S., "Bogus: Electronic Manufacturing and Consumers Confront a Rising Tide of Counterfeit Electronics," *IEEE Spectrum,* Vol. 43, No. 5, 2006, pp. 37–46.

54.   Pecht, M. and Tiku, S., "Spectral Lines: Counterfeiting and You," *IEEE Spectrum,* Vol. 43, No. 5, 2006, pp. 10.

55.   Stradley, J. and Karraker, D., "The Electronic Part Supply Chain and Risks of Counterfeit Parts in Defense Applications," *IEEE Transactions Components and Packaging Technologies,* Vol. 29, No. 3, 2006, pp. 703–705.

56.   Tomczykowski, W., "DMSMS Acquisition Guidelines - Implementing Parts Obsolescence Management Contractual Requirements Rev 3.0," *Defense Micro Electronics Activity (DMEA)*, McClellan, California, 2001.

57.   United Kingdom Ministry of Defence, "A Guide to Managing Obsolescence," DEF-STAN 00-71, May 14, 1998.

58.   United States Air Force Materiel Command (DMSMS Program) and United Technology Corporation, "Case Resolution Guide," Dayton, Ohio, July 15, 1998.

59.   United States Army Materiel Command (DMSMS Program), "Case Resolution Guide," May 17, 2001.

60.   United States Defense Microelectronics Activity, "Diminishing Manufacturing Sources and Material Shortages: A Guidebook of Best Practices and Tools for Implementing a DMSMS Management Program," Report A095115, McClellan, California, September 2009.

61.   United States Naval Sea Systems Command, "Case Resolution Procedures Guide," August 2, 1999.

62.   United States Defense MicroElectronics Activity, "Resolution Cost Factors for Diminishing Manufacturing Sources And Material Shortages," Defense Microelectronics Activity, McClellan AFB, California, May 1999.

63.   United States Department of Defense and Kunesh, N., "Diminishing Manufacturing Sources and Material Shortages Management Guidance," April 2005.

64.   Tomczykowski, W., Fritz, A., and Scalia, R., "Program Managers Handbook – Common Practices to Mitigate the Risk of Obsolescence," May 31, 2000.

65.   Tomczykowski, W.J., "A Study on Component Obsolescence Mitigation Strategies and Their Impact on R&M," *Reliability and Maintainability Symposium*, Tampa, Florida, 2003.

66.   Bumbalough, A., "USAF Manufacturing Technology's Initiative on Electronic Parts Obsolescence Management," *44th International SAMPE Symposium*, Long Beach, California, May 23–27, 1999.

67.   QinetiQ and Arinc, "Ministry of Defence Component Obsolescence Resolution Cost Metrics Study," March 2004.

68.   ARINC, "Strategies to Address Electronic Component Obsolescence in Commercial Aircraft," ARINC Report 662, Annapolis, Maryland, June 1999.

69.   British Standards Institute, "Obsolescence Management – Guide to the Substitution of Components in Electronic Equipment," PD-6614, June 2002.

70.   British Standards Institute, "Obsolescence Management – Code of Practice for Obsolescence Notification and Support From Suppliers of Electronic Components," PD-6667, December 2000.

71.   British Standards Institute, "Design Management Systems – Part 5: Guide to Managing Obsolescence," BS7000-5, October 15, 2001.

72.   JEDEC, "Product Discontinuance," JESD48B, May 2005

73.   International ElectroTechnical Commission, "Obsolescence Management – Application Guide," DSF/PREN 62402, September 4, 2006.

74.   International ElectroTechnical Commission, "Preparation of an Electronic Components Management Plan," TS 62239, May 2003.

75.   International ElectroTechnical Commission, "Process Management for Avionics – Management Plan – Part 1: Preparation and Maintenance of an Electronic Components Management Plan (draft)," IEC-62239-1 TS Ed.1.

76.   Federal Aviation Administration, "Guidance for Assuring the Software Aspects of Certification When Replacing Obsolete Electronic Parts Used in Airborne Systems and Equipment," CAST-3, Washington, DC, June 1999.

77.   Balwally, N.M., "Forecasting Digital Microcircuit Obsolescence," Defense Electronics Supply Center, DLA-91-P00177, Alexandria, Virginia, March 1991.

78.   Huang, Z., Sandborn, P., Pecht, M., and Solomon, R., "Life Cycle Forecasting of ASICs," *Future Circuit International,* No. 7, 2001, pp. 101–107.

79.   Sandborn, P., Prabhakar, V., and Ahmad, O., "Forecasting Technology Procurement Lifetimes for Use in Managing DMSMS Obsolescence," *Microelectronics Reliability,* Vol. 51, No. 2, 2011, pp. 392–399.

80.   Sandborn, P.A., Mauro, F., and Knox, R., "A Data Mining Based Approach to Electronic Part Obsolescence Forecasting," *IEEE Transactions on Components and Packaging Technologies,* Vol. 30, No. 3, 2007, pp. 397–401.

81.   ITRS, "International Technology Roadmap for Semiconductors 2011 Edition Executive Summary."

82.   LaPedus, M., "Node Skipping Reaches New Heights," available at http://semimd.com/blog/2012/11/15/node-skipping-reaches-new-heights, accessed November 21, 2012.

83.   King, I. and Kucera, D., "Texas Instruments Eliminating 1,700 Jobs to Cut Expenses," available at http://www.bloomberg.com/news/2012-11-14/texas-instruments-eliminating-1-700-jobs-in-cost-cutting-drive.html, accessed November 21, 2012.

84.   "EASA Approves Jetstream 32 Life Extension Program," available at http://www.aero-news.net/aNNTicker.cfm?do=main.textpost&id=6207b89e-64e2-4c28-9566-97205c98b247, accessed November 21, 2012.

85.   Feng, D., Singh, P., and Sandborn, P., "Optimizing Lifetime Buys to Minimize Life-Cycle Cost," *Aging Aircraft Conference*, Palm Springs, California, April 2007.

86. Sandborn, P., Prabhakar, V., and Feng, D., "DMSMS Lifetime Buy Charcterization via Data Mining of Historical Buys," *DMSMS Conference*, Orlando, Florida, November 2007.

87. Bradley, J.R. and Guerrero, H.H., "Lifetime Buy Decisions With Multiple Obsolete Parts," *Production and Operations Management,* Vol. 18, No. 1, 2009, pp. 114–126.

88. Dinesh, K.U. and Saranga, H., "Optimal Selection of Obsolescence Mitigation Strategies Using a Restless Bandit Model," *European Journal of Operational Research,* Vol. 200, 2010, pp. 170–180.

89. Singh, P. and Sandborn, P., "Obsolescence Driven Design Refresh Planning for Sustainment-Dominated Systems," *Engineering Economist,* Vol. 51, No. 2, 2006, pp. 115–139.

90. Amendt, A.J., "The Obsolescence of the Microprocessor," *Microelectronics Reliability,* Vol. 16, 1977, pp. 323–332.

91. Anghel, L., Sanchez, E., Reorda, M.S., Squillero, G., and Velazcol, R., "Coupling Different Methodologies to Validate Obsolete Microprocessors," *19th IEEE International Symposium on Defect and Fault Tolerance in VLSI Systems*, Cannes, France, October 13, 2004.

92. Tong, J.G., Anderson, I.D.L., and Khalid, M.A.S., "Soft-Core Processors for Embedded Systems," *International Conference on Microelectronics, 2006.*, 2006, pp. 170–173.

93. European Aviation Safety Agency, "Notification of a Proposal to Issue a Certification Memorandum: Development Assurance of Airborne Electronic Hardware," EASA SWCEH – 001 No: 01, February 10, 2011.

94. Teunter, R.H. and Fortuin, L., "End-of-Life Service," *International Journal of Production Economics,* Vol. 59, 1999 pp. 487–497.

95. Teunter, R.H. and Fortuin, L., "End-of-Life Service: A Case Study," *European Journal of Operational Research,* Vol. 107, 1998, pp. 19–34.

96. Teunter, R.H. and Klein Haneveld, W. K., "The 'Final Order' Problem," *European Journal of Operational Research,* Vol. 107, No. 1, 1998, pp. 35–44.

97. Pourakbary, M., Frenkz, J.B.G., and Dekker, R., "End-of-Life Inventory Decisions for Consumer Electronics Service Parts," Econometric Institute EI 2009-48, February 24, 2010.

98. Sandborn, P. and Singh, P., "Electronic Part Obsolescence Driven Design Refresh Optimization," *Proceedings of FAA/DoD/NASA Aging Aircraft Conference*, San Francisco, California, September 2002.

99.   Prabhakar, V. and Sandborn, P., "A Part Total Cost of Ownership Model for Long Life-Cycle Electronic Systems," *International Journal of Computer Integrated Manufacturing,* Vol. 25, No. 4-5, 2012, pp. 384–397.

100.   Prabhakar, V. and Sandborn, P., "A Model For Making Part Sourcing Decisions For Long Life-Cycle Products," *ASME International Design Engineering Conferences & Computers and Information in Engineering Conference*, DFMLC 11, Washington, DC, August 28–31, 2011.

101.   van Noortwijk, J.M., "Explicit Formulas for the Variance of Discounted Life-Cycle Cost," *Reliability Engineering & System Safety,* Vol. 80, No. 2, 2003, pp. 185–195.

102.   Woodward, D.G., "Life-Cycle Costing – Theory, Information Acquisition and Application," *International Journal of Project Management,* Vol. 15, 1997, pp. 335–344.

103.   Porter, Z. G., "An Economic Method for Evaluating Electronic Component Obsolescence Solutions," The Boeing Company, May 1998.

104.   Martin, G.E. and Wang, M-C, "Estimation Technique for Non-Stationary Parameters With Application to Disposal of Inventories Subject to Obsolescence," *International Journal of Systems Science,* Vol. 21, 1990, pp. 1855–1868.

105.   Karyagina, M., Wong, W., and Vlacic, L., "Life Cycle Cost Modelling Using Marked Point Processes," *Reliability Engineering & System Safety,* Vol. 59, No. 3, 1988, pp. 291–298.

106.   Hong, J.S. , Koo, H-Y, Lee, C-S, and Ahn, J., "Forecasting Service Parts Demand for a Discontinued Product," *IIE Transactions* Vol. 40, No. 7, 2008, pp. 640–649.

107.   Chiang, D., Guo, R-S, Chen, Y-S, and Chen, J-Y, "The Final Order Model for Auto Service Parts Considering the End of Product Life-Cycle," *Asia Pacific Industrial Engineering & Management Systems Conference*, Kitakyushu, Japan, December 14–16, 2009.

108.   Josias, C., Terpenny, J.P., and McLean, K.J., "Component Obsolescence Risk Assessment," *IIE Annual Conference and Exhibition 2004*, Houston, Texas, May 15–19, 2004.

109.   Clay, W.S., Sykora, R.A., and Morrison, J.R., "Systems and Methods for Automatically Determining and/or Inferring Component End Of Life (EOL)," United States Patent US 7,672,921 B1, 2010.

110.   Robbins, R.M., "Proactive Component Obsolescence Management," *A-B Journal,* Vol. 10, No. 4, 2003, pp. 49–54.

111.   Meixell, M.J. and Wu, S.D., "Scenario Analysis of Demand in a Technology Market Using Leading Indicators,"*IEEE Transactions on Semiconductor Manufacturing,* Vol. 14, No. 1, 2001, pp. 65–75.

112.   Meade, N. and Islam, T. "Technological Forecasting – Model Selection, Model Stability, and Combining Models," *Management Science,* Vol. 44, No. 8, 1998, pp. 1115–1130.

113.   Bass, F.M., "New Product Growth for Model Consumer Durables," *Management Science,* Vol. 50, 2004, pp. 1825–1832.

114.   Kurawarwala, A. and Matsuo, H., "Forecasting and Inventory Management of Short Life-Cycle Products," *Operations Research,* Vol. 44, No. 1, 1996, pp. 131–150.

115.   Kurawarwala, A. and Matsuo, H., "Product Growth Models for Medium-Term Forecasting of Short Life-Cycle Products," *Technological Forecasting and Social Change,* Vol. 57, No. 3, 1998, pp. 169–196.

116.   Mahajan, V. and Muller, E., "Innovation Diffusion and New Product Growth Models in Marketing," *Journal of Marketing,* Vol. 43, No. 4, 1979, pp. 55–68.

117.   Mahajan, V., Muller, Eitan, and Bass, F.M., "Diffusion of New Products: Empirical Generalizations and Managerial Uses," *Marketing Science,* Vol. 14, No. 3, 1995, pp. G79.

118.   Mahajan, V., Muller, E., and Bass, F. M., "New Product Diffusion Models in Marketing: A Review and Directions for Research," *Journal of Marketing,* Vol. 54, No. 1, 1990, pp. 1–26.

119.   Srinivasan, V. and Mason, C. H., "Nonlinear Least Squares Estimation of New Product Diffusion Models," *Marketing Science,* Vol. 5, No. 2, 1986, pp. 169–178.

120.   Schmittlein, D. and Mahajan, V., "Maximum Likelihood Estimation for an Innovation Diffusion Model of New Product Acceptance," *Marketing Science,* Vol. 1, No. 1, 1982, pp. 57–78.

121.   Bradley, J.R. and Guerrero, H.H., "Product Design for Life-Cycle Mismatch," *Production and Operations Management,* Vol. 17, No. 5, 2008, pp. 497–512.

122.   Goswami, A., "Impact of Hardware Obsolescence on System Software for Sustainment-Dominated Electronic Systems," Master of Science Masters, Department of Mechanical Engineering, University of Maryland, College Park, Maryland, 2004.

123.   Parnell, K., "Could Microprocessor Obsolescence Be History?," *Xcell Journal*, Spring 2003.

124. Velazco, R., Anghel, L., and Saleh, S., "A Methodology for Test Replacement Solutions of Obsolete Processors," *9th IEEE On-Line Testing Symposium*, July 7–9, 2003.

125. Radio Technical Commission for Aeronautics, "DO-178C – Software Considerations in Airborne Systems and Equipment Certification," DO-178C, Washington, DC, December 13, 2011.

126. Federal Aviation Administration, "Advisory Circular: Establishing the Certification Basis of Changed Aeronautical Products," Federal Aviation Administration, AC 21.101A, Washington, DC, September 3, 2010.

127. McWilliams, A., "Electronic Chemicals and Materials: The Global Market," BCC Research, Wellesley, Massachusetts, SMC043C, January 2013.

128. Bartley, G., "The Flying Elephant: Open Forum on some impolite questions regarding complex COTS in critical airborne systems," *2007 National Software and Complex Electronic Hardware Conference*, New Orleans, Louisiana, July 24–26, 2007.

129. Texax Instruments, "Quadruple 2-Input Positive-Nand Gates," available at http://www.ti.com/lit/ds/scls227j/scls227j.pdf (last accessed September 2015), May 2013.

130. Federal Aviation Administration, "Advisory Circular: System Design and Analysis," AC 25.1309-1A, Washington, DC, June 21, 1988.

131. Federal Aviation Administration, "Advisory Circular: Equipment, Systems and Installations in Part 23 Airplanes," AC 23.1309-1D, Washington, DC, January 16, 2009.

132. Thornton, R.K., "Review of Pending Guidance and Industry Findings on Commercial off-the-Shelf (COTS) Electronics in Airborne Systems," Federal Aviation Administration report DOT/FAA/AR-01/41, Washington, DC, August 2001.

133. Fulton, R., "RTCA/DO-254 Data Package for Commercial Off-the-Shelf Graphical Processors," *2006 IEEE/AIAA 25th Digital Avionics Systems Conference (IEEE Cat No. 06CH37804)*, Portland, Oregon, 2006, pp. 6.

134. Federal Aviation Administration, "Use of COTS Graphical Processors (CGP) in Airborne Display Systems," Federal Aviation Administration, CAST-29, Washington, DC, February 2007.

135. Mahapatra, R.N. and Ahmad, S., "Microprocessor Evaluations for Safety-Critical, Real-Time Applications: Authority for Expenditure No. 43 Phase 1 Report," Aerospace Vehicle Systems Institute, DOT/FAA/AR-06/34, December 2006.

136. Mahapatra, R.N., Bhojwani, P., and Lee, J., "Microprocessor Evaluations for Safety-Critical, Real-Time Applications: Authority for Expenditure No. 43 Phase 2 Report," Aerospace Vehicle Systems Institute, DOT/FAA/AR-08/14, June 2008.

137. Mahapatra, R.N., Bhojwani, P., Lee, J., and Kim, Y., "Microprocessor Evaluations for Safety-Critical, Real-Time Applications: Authority for Expenditure No. 43 Phase 3 Report," Aerospace Vehicle Systems Institute, DOT/FAA/AR-08/55, February 2009.

138. Mahapatra, R.N., Lee, J., Gupta, N., and Manners, B., "Microprocessor Evaluations for Safety-Critical, Real-Time Applications: Authority for Expenditure No. 43 Phase 5 Report," Aerospace Vehicle Systems Institute, DOT/FAA/AR-11/5, May 2011.

139. Mahapatra, R.N., Lee, J., Gupta, N., and Manners, B., "Microprocessor Evaluations for Safety-Critical, Real-Time Applications: Authority for Expenditure No. 43 Phase 4 Report," Aerospace Vehicle Systems Institute, DOT/FAA/AR-10/21, TAMU-CS-AVSI-72005, February 2009.

140. Electronic Industries Alliance, "Standard for Preparing an Electronic Components Management Plan," Electronic Industries Alliance, EIA-4899, Arlington, Virginia, 2002.

141. Intel, "FDIV Replacement Program: White Paper: Statistical Analysis of Floating Point Flaw," Intel Corporation, 1994, available at http://www.intel.com/support/processors/ pentium/fdiv/wp/, accessed June 30, 2010.

142. Stack International, "General Requirements for Integrated Circuits, Edition 12.2 Notice 2," UK S-0001, St Albans, November 1999.

143. United States Department of Defense, "Test Method Standard Microcircuits," MIL-STD-883J, June 7, 2013.

144. Federal Aviation Administration, "Advisory Circular: Document RTCA DO-254, Design Assurance, Guidance For Airborne Electronic Hardware," AC 20-152, Washington, DC, June 30, 2005.

145. Federal Aviation Administration, "Clarifications on the Use of RTCA Document DO-254 and Eurocae Document ED-80, Design Assurance Guidance for Airborne Electronic Hardware," Position Paper CAST-27, Washington, DC, June 2006.

146. Federal Aviation Administration, "Frequently Asked Questions (FAQs) on the Use of RTCA Document DO-254 and EUROCAE Document ED-80, Design Assurance Guidance for Airborne Electronic Hardware," CAST-28, Washington, DC, December 2006.

147. Federal Aviation Administration, "Job Aid: Conducting Airborne Electronic Hardware Reviews," Washington, DC, February 28, 2008.

148. Federal Aviation Administration, "Order 8110.105 - Simple and Complex Electronic Hardware Approval Guidance (Change 1)," Order 8110.105, Washington, DC, September 23, 2008.

149. Federal Aviation Administration, "Final Policy Statement on Applying Advisory Circular 20-152, *RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware*, to Title 14 Code of Federal Regulations, Part 23 Aircraft; PS-ACE100-2005-50001," Washington, DC, January 26, 2007.

150. Federal Aviation Administration, "Order 8110.xxx - Simple And Complex Electronic Hardware Approval Guidance GAMA Briefing," 8110.CEH, Washington, DC, May 30, 2008.

151. Forsberg, H., Bjureus, P., Soderquist, I., Lamaty, P., and Maufroid, D., "Next Generation COTS-Commercial IP Blocks in Avionics," *23rd Digital Avionics Systems Conference*, 2004.

152. IEEE, "Standard for Electronic Design Intellectual Property (IP) Quality," P1734, June 11, 2010.

153. Kobylecky, J., "QIP Quality Metric User Guide v. 4.0," VSIA, 2007, available at http:\\www.vsia.org.

154. Godefroid, P., Klarlund, N., and Sen, K., "DART: Directed Automated Random Testing", *Sigplan Notices.,* Vol. 40, No. 6, June 2005, pp. 213–223.

155. Goodloe, A. and Pike, L., "Toward Monitoring Fault-Tolerant Embedded Systems (Extended Abstract)," *1ST INTL. WORKSHOP ON SOFTWARE HEALTH MANAGEMENT*, Pasadena, California, July 21, 2009.

156. Goodloe, A. and Pike, L., "Monitoring Distributed Real-Time Systems: A Survey and Future Directions," February 2010.

157. Leveson, N.G., Reese, J.D., and Heimdahl, M.P.E., "SpecTRM: A CAD System for Digital Automation," *Proceedings 17th Digital Avionics Systems Conference*, November 1998

158. Leveson, N., "A Systems Theoretic Approach to Safety Engineering," *IEEE Transactions on Dependable and Secure Systems,* Vol. 1, No. 1, 2004, pp. 66–86.

159. Dubey, A., Karsai, G., Kereskenyi, R., and Mahadevan, N., "Towards a Real-time Component Framework for Software Health Management," *16th IEEE Real-Time and Embedded Technology and Applications Symposium*, Stockholm, Sweden, April 12–15, 2010.

160. Bhatt, D. , Hickman, S. , Schloegel, K. , and Oglesby, D., "An Approach and Tool for Test Generation from Model-Based Functional Requirements," *Workshop on Aerospace Software Engineering, International Conference on Software Engineering*, May 17, 2007.

161. Beland, S.C. and BonJour, B., "Functional Failure Path Analysis of Airborne Electronic Hardware," *19th Digital Avionics Systems Conferences, DASC 19th*, Philadelphia, Pennsylvania, October 2000, pp. 1A3/1–8.

APPENDIX A—OBSOLESCENCE CAPABILITY SELF-ASSESSMENT

The following questionnaire is intended to assist avionics and aircraft manufacturers in self-assessing their obsolescence and life-cycle management maturity levels:

1.   Does obsolescence have a net negative impact on profitability (consider not just cost, but also new market opportunities created by obsolescence of one's own and competitor's older products)?

2.   Do you devote engineering and other financial resources to obsolescence management?

3.   Do you incorporate terms in procurement contracts for product obsolescence?

4.   How much notice of product discontinuance (i.e., no further order acceptance) do you typically provide to customers?

   a.   Is this a formalized company policy?
   b.   What notification mechanism do you use?

5.   Do you ever discontinue maintenance and support for obsolete products?

6.   Have you experienced cases for which regulation, rulemaking, or legislation has forced you to obsolete a product?

7.   Do your customers expect you to manage obsolescence transparently and at no direct cost?

8.   Do your design processes consider obsolescence risk or susceptibility as a discriminator between design choices (e.g., make/buy, software/hardware implementation)?

9.   Do you use decision-support tools and processes to assist in choosing between resolution options (e.g., last time buy, re-design, emulation, etc.)?

10.   Do you have a defined, formalized obsolescence management plan?

   a.   Is this a general plan, several product specific plans, or both?

11.   Do you create and maintain product life-cycle plans for each product?

12.   Do your product life-cycle plans include planning for:

   a.   Expected obsolescence of supplies?
   b.   Demand variation?
   c.   Support needs?
   d.   Product upgrades?
   e.   Product end of life?

13. Do you regard obsolescence as a shared problem, a problem you expect your suppliers to take care of, or entirely your problem?

14. What is the customer value proposition for obsolescence management?

   a. Are you willing to pay a premium on the product price or on a support contract to assure that fleet procurement, repair, and upgrade are managed for you transparently for a given period?
   b. Are such arrangements contractually feasible?
   c. How should such contracts be priced?

15. Do you get adequate notice that a supplier has obsoleted a product you need?

   a. How do you get that notification?
   b. What tools are used to track it through to a resolution?

16. Have you bought fake components or otherwise unapproved parts?

   a. Do you have formalized controls to detect/prevent that?

17. Do you maintain an approved parts and supplier list?

   a. Is component selection outside of that subject to special controls or approvals?

18. What metrics do you use for obsolescence health status?

19. Is obsolescence health status used as a selection criterion during design?

20. Is an obsolescence health assessment of a bill of materials required prior to and as a condition of transition to production?

21. Do you archive the design tools and platforms required to update hardware or software throughout the life cycle?

22. Do you have a defined, formalized process to classify changes (for obsolescence or any other reason) as major/minor from a continued airworthiness perspective?

23. From your answers above, where would you grade your obsolescence management capability/maturity in the scale in figure A-1 (intensity level of 1 to 3+)?

Table A-1. Intensity level of obsolescence

Intensity Level 1	Intensity Level 2	Intensity Level 3	Intensity Level 3+
DMSMS[1] Focal Point	Awareness Training	Circuit Design Guidelines	Technology Road Mapping
Awareness Briefing	DMSMS Prediction	VHDL[2]	Planned System Upgrades
Internal Communications	DMSMS Steering Group	Technology Assessment	Technology Insertion
External Communications	COTS[3] List	EDI[4]	Technology Transparency
DMSMS Plan	DMSMS Solution Database	Technology Insertion	VHDL
Parts List Screening	Opportunity Index		Programmable Logic Devices
Parts List Monitoring	Website		
Resolution of Current Items	Operations Impact Analysis		
Supportability Checklist			

1. DMSMS: Diminishing manufacturing sources and material shortages
2. VHDL: Very High Speed Integrated Circuit Hardware Definition Language
3. COTS: Commercial off-the-shelf
4. EDI: Electronig Data Interchange

APPENDIX B—GENERIC PRODUCT LIFE-CYCLE PLAN

This appendix sets out a generic product life-cycle plan template (hereinafter referred to as "the template") to guide the development of a product-specific product life-cycle plan (hereinafter referred to as "the plan"). The manufacturer of an avionics product in series production is expected to maintain a plan for each product throughout the life cycle as the hardware design evolves for any reason. Modifications may occur for a variety of reasons (e.g., functional upgrade, obsolescence recovery, and reliability improvement). Given the dynamic nature of both the product market and the supply base, it may be advantageous for the plan owner to implement it as a data or web-based computer application using live data feeds from various engineering and manufacturing IT infrastructure assets, but this is not a requirement.

B.1   PURPOSE

Avionics products are in a constant state of evolution as the availability of manufacturing facilities, material, and customer demand changes over time. Current life-cycle management processes mostly react to changes in order backlog or end of life (EOL) notices issued by component suppliers. One available action (e.g., bridge buy [BB], Last Time Buy [LTB], redesign, or EOL) is then selected and the process repeats until EOL. The reactive approach typically provides only 6–12 months of reaction time. This is insufficient for the longer-term planning that is necessary to implement and certify complex design change and to efficiently manage the wider portfolio of multiple product life cycles that share common components. Efficient management of the life cycles requires that a product plan be established for each product early on so that investment and recurring cost-optimized decision points can be planned for, and so the necessary materiel, budget, and staffing can be prioritized among competing demands. A product life-cycle plan shows the expected substance and timing of life-cycle events that would impact the avionics supplier's ability or willingness to continue with production and support of a particular product and to decide which actions are to be taken at those events.

It is assumed that product design and modification will be accomplished in satisfaction of the currently applicable Title 14 Code of Federal Regulations (CFR) airworthiness assurance regulations, standards, and guidance, and that the supplier will maintain documented processes and procedures to accomplish this.

The template defines a set of objectives to be met by the plan, categorized under various headings. The template does not specify or define how those objectives will be satisfied. Activities to satisfy the objectives and the resulting artifacts will be defined in the plan or will be incorporated by reference to managed and documented standards and procedures.

It is expected that:

- The referenced internal company standards and procedures will be controlled under the manufacturer's approved configuration management and quality system.

- This template will be available to regulators and customers to guide their evaluation of a plan offered or proposed by an avionics supplier.

- The avionics product manufacturer will develop a plan, for internal use only, according to the provisions of this template.

- The plan is not required to be publicly available, but may be, because it may contain proprietary information.

- Disclosure of the plan may be subject to the terms of a proprietary information agreement if so desired by the manufacturer.

- The avionics product manufacturer will provide regular evidence of continued plan compliance.

There is no expectation that the plan will be provided to regulators or customers because it may include confidential, proprietary, or competition-sensitive information. For plan compliance, see section B-5.

The manufacturer may choose to minimize product life-cycle costs by using optimization methods for the selection and timing of upgrades, obsolescence recoveries, and EOL or end of support (EOS) notification. Manufacturers are free to optimize a product plan atomically or globally across a portfolio of products.

Explanatory notes are given in *italicized text*. These are intended for guidance only; they are not intended to be plan objectives. The plan owner may use any suitable, documented methods and processes to accomplish the objectives.

B.2   SCOPE

This template is applicable to a product life-cycle plan for any avionics product.

No other references are provided. It is expected that all activities associated with life-cycle management will satisfy the current and applicable 14 CFR Regulations, Guidance, Policy, and Standards.

Table B-1 lists definitions of terms used in this appendix.

Table B-1. Definitions

Term	Definition
Product	An avionics product whose design authority is held by the plan owner.
Plan owner	The holder of the product design authority.
Component	A COTS electronic component, material, non-repairable sub-assembly, software code version, software license, IP version, or IP license listed in the product bill of materials. A component carries a unique component manufacturer part number recorded in the user's component information database that is linked to the AEH product manufacturer's internal unique part number.
LTB date	Date by which a LTB of a product should be made. No further orders can be entered after this date.
BOM	Bill of materials for a product comprising a list of components used for product manufacture, test, and release.
EOL	End of life of a component or product. The product will no longer be manufactured.
EOS	End of Support • of a product – will no longer be maintained or supported by the plan owner. • of a repairable subassembly – will no longer be maintained or supported by the subassembly manufacturer or his licensed designees.
EOL Notice	A document detailing any or all of a product EOL date, EOS date, or LTB date.
Functionally obsolete	Forecast demand is zero or small.
Obsolete	A component is not manufactured by any source. Diminishing stock may continue to be available from holdings or the market.
Licensing	Transfer of product design authority, production drawings, tooling, test procedures, test software, and technical documentation to a third party.
Product life cycle	Extends from initial product type sale to the later of EOL or EOS date.
Product life-cycle plan template	A document detailing the contents of a product life-cycle plan (this document).
Product life-cycle plan	A detailed plan for the management of a product life cycle in accordance with the provisions of this template.
Regulator	Internationally recognized aviation safety organization that approves certification applications, e.g., FAA, EASA

AEH = airborne electronic hardware; COTS = commercial off-the-shelf; IP = intellectual property; FAA = Federal Aviation Administration; EASA = European Aviation Safety Agency

B.4   PLAN OBJECTIVES

In the subsections that follow, 25 plan objectives in seven groups are defined. A product plan will show how each of these objectives is satisfied. Mandatory requirements are indicated by the word "shall."

NOTE: *manufacturers may show satisfaction by any suitable means, including by reference to other controlled company documents or data sources.*

A.   PLAN SCOPE AND MAINTENANCE

Objective-01: Each certified avionics product currently in production, maintained, or supported by the plan owner shall have a plan.

Objective-02: The plan shall be revised with significant events to reflect new or updated information.

NOTE: Manufacturers should define appropriate significant events (e.g., component EOL notices, change in product demand, and product upgrades).

Objective-03: The plan shall cover the planned life cycle up to the later of EOL or EOS.

Objective-04: The plan owner shall manage the plan under an approved configuration control system.

Objective-05: The plan shall identify the plan owner organization responsible for maintenance of the plan.

Objective-06: The plan shall identify the documented implementation procedures that assure conformance to this template.

Objective-07: The plan shall identify exceptions to this template.

NOTE: *It is expected that products will be in a continual state of evolution through functional upgrades and obsolescence recovery actions throughout the life cycle. The plan will, likewise, be in a constant state of evolution.*

B.   PRODUCT DEMAND

Objective-08: The plan shall identify the expected product demand profile showing the expected volume for each planning period over the planned product life cycle.

NOTE: Manufacturers may use any planning period, typically 1 year; however, significant events may prompt a plan revision.

NOTE: Manufacturers may elect to EOL a product if the forecast demand falls below an economic rate of production.

C.   PRODUCT REPAIR

<u>Objective-09:</u> The plan shall identify the expected repair component demand profile over the product life cycle for each component on the bill of materials (BOM) for each planning period.

NOTE: Manufacturers may use any planning period, typically 1 year.

D.   PRODUCT MODIFICATION

<u>Objective-10:</u> The plan shall identify the dates when product modifications are intended to be performed.

<u>Objective-11:</u> The plan shall identify the manufacturers' documented procedures and processes applicable to modifications.

NOTE: Product modifications may occur when performing obsolescence recovery or for a variety of other reasons

E.   PRODUCT EOL OR EOS

<u>Objective-12:</u> The plan shall identify planned product EOL and EOS dates, if any.

<u>Objective-13:</u> The plan shall identify if and when the product is planned to be licensed.

<u>Objective-14:</u> Plan ownership shall be transferred to the licensee when the product is licensed.

<u>Objective-15:</u> A Service Bulletin or Service Information Letter shall be issued to known users and customers within a reasonable amount of time, identifying the announced product EOL or EOS dates.

NOTE: The product manufacturer may opt to license the product at any time.

NOTE: It is normally expected that EOL will precede EOS, but this is not necessarily true.

NOTE: Product manufacturers may elect to obsolete a product through an EOL Notice if the necessary modifications would be technically or economically infeasible.

F.   COMPONENT OBSOLESCENCE, SELECTION, AND USE

Objective-16: The plan shall maintain a current estimate of the expected obsolescence date of all components on the BOM.

Objective-17: The plan shall forecast the dates and quantity of component LTBs.

Objective-18: The plan shall forecast the expected timing for the obsolescence of each component.

Objective-19: The plan shall identify the expected recovery action(s) for each forecast obsolescence event.

Objective-20: The forecast component obsolescence date shall be updated in the plan if a new or alternate component is added or substituted in the BOM.

Objective-21: The plan shall maintain a current forecast of run-out dates for LTB/BB stock holdings.

NOTE: *Components will be selected and used according to the supplier's documented processes. Typically these include an approved Electronic Component Management Plan compliant to International ElectroTechnical Commission TS 62239 [B-1].*

NOTE: *When the future obsolescence date is not known, as is the case prior to the issue of a component EOL Notice, the obsolescence date may be estimated by the plan owner's own methods or by using an estimated value provided by a commercial component information service.*

NOTE: *Manufacturers may choose to consolidate and align obsolescence recoveries with the use of BBs.*

G.   DESIGN AND MANUFACTURING TOOLS AND FACILITIES

Objective-22: The plan shall identify the tools and facilities necessary to design, modify, and verify product hardware and software.

Objective-23: The plan shall identify the procedures and processes used to preserve the availability of product hardware and software design facilities and tools until the later of the EOL or EOS dates.

Objective-24: The plan shall specify the actions necessary to preserve the availability of the product manufacturing process, materials, facilities, and tooling until the later of the EOL or EOS dates.

Objective-25: The plan shall identify the expected obsolescence date of the product manufacturing process, materials, facilities, or tooling.

NOTE: Manufacturers may elect to repeatedly subcontract manufacturing to an approved supplier while retaining design authority.

NOTE: Documentation on the instructions for use of tools and facilities will normally be managed within the normal product or process documentation.

B-5   PLAN COMPLIANCE

PLAN COMPLIANCE BETWEEN OWNER AND CERTIFICATE HOLDER

The plan shall be deemed accepted when the plan owner and the type certificate (TC) holder agree that the plan is acceptable to both parties, if the TC holder chooses to exercise the right of plan acceptance. Review within a certification process by a mutually acceptable and internationally recognized assessment body may be used as evidence that the plan satisfies the objectives of this document.

B-6.   REFERENCES

For dated references, the issue of the given date shall be applicable; otherwise the latest issue is applicable.

B-1.   IEC, "Preparation of an Electronic Components Management Plan," Geneva TS 62239, May 2003.

APPENDIX C—LITERATURE SEARCH RESULTS

The following obsolescence and life-cycle maintenance references are provided with abstracts, when available from the publication. The references primarily relate to hardware, but a few discuss software obsolescence. The literature is largely silent on obsolescence at the system level (e.g., that arising from changes in the operating environment or from regulatory action) and on the problems associated with maintaining tools and platforms for long periods.

The majority of references are generated within the aerospace industry, but some come from the nuclear/oil/gas/chemical industries that have many of the same concerns as aerospace (i.e., its regulated and safety-critical nature).

The economic modeling references are generated predominantly by universities. They are a largely self-contained group and do not appear to have had significant take-up because they are not cited in the other literature to any significant extent.

There are few references that deal with the specifics of industry internal processes. We attribute that to the protection of proprietary information and the desire to protect competitive position.

The sources for these references fall into four main classes:

1.   Engineering journals and conference papers
2.   National and international standards and other guidance material (e.g., military and regulatory documents)
3.   MSc. And PhD. university theses
4.   Economic modeling journals and conference papers

The references are listed in alphabetical order by first author.

Abate, F. and Violante, M.,"Coping With Obsolescence of Processor Cores in Critical Applications," *IEEE International Symposium on Defect and Fault Tolerance of VLSI Systems, DFTVS '08*, 2008, pp. 24–32.

> Critical applications are more and more relying on electronic components to provide the services they are designed for. The obsolescence of such electronic components has already been recognized as a critical issue that must be properly addressed. Among the different possibilities, FPGA-based emulation of obsolete digital components seems particularly interesting. This paper proposes an automatic approach for customizing the processor cores before they are implemented on the FPGA of choice, by removing the unnecessary instructions. The benefits stemming from this approach are cost savings thanks to the possibility of adopting smaller, less expensive, FPGA devices, the possibility of integrating both the processor and its companion chip on the same FPGA device, and the possibility of adopting hardware redundancy without incurring in high overheads. The approach has been evaluated on a case study, showing that a customized and hardened processor obtained from our design flow requires nearly the same area of the original, un-hardened, processor.

Abdel-Malek, L. and Wolf, C., , "Measuring the Impact of Lifecycle Costs, Technological Obsolescence, and Flexibility in the Selection of FMS Design," *Journal of Manufacturing Systems*, Vol. 13, No. 1, 1994, pp. 37–47.

> Selecting an appropriate FMS requires consideration of many factors for successful implementation and operation. Primary factors are the system's flexibility, lifecycle cost, and competitive ability over time. This paper proposes a quantitative measure for comparing alternative FMS designs with respect to these three criteria. The model captures the effect of these three factors in a single measure.

Air Force Science and Technology Board, "Aging Avionics in Military Aircraft," Washington, DC, National Academy Press, 2001.

> Questions about the readiness of U.S. military forces to go into battle have received widespread attention in recent years, and the issue was hotly debated in the 2000 U.S. presidential campaign. Partly as a result of a slowdown in purchasing of new material in the 1990s, many weapon systems are showing their age, and their lifetimes are being extended beyond their original design lifetimes. This has led to increased maintenance costs and reduced mission-capable rates. The problem is especially severe with electronics systems, such as aircraft avionics, which increasingly depend on commercially available components that have a technology refresh cycle as short as 18 months and an availability cycle of less than a decade.

Airbus, *Equipment - Design - General Requirements for Suppliers*, "PART 1 - Product, Chapter 14 - Obsolescence Management," Issue: B., Toulouse, France, 2006.

> No abstract available.

Alford, Jr., L. D., "The Problem With Aviation COTS", *IEEE Aerospace and Electronic Systems Magazine*, Vol. 16, No. 2, 2001,pp. 33–37.

> Commercial off the Shelf (COTS) has become a byword for acquisition reform, but there are significant risks associated with the use of COTS products in military systems. These risks are especially acute for aviation systems. This paper explains how COTS can negatively affect military acquisitions and gives ideas on how to plan and resolve COTS caused problems.

Al-Qahtani, A.M., Lourido, M.L., Dabbousi, R.M.O., and Al-Shahrani, O.O., "Management of Electrical Equipment Obsolescence at Oil Gas Industrial Facilities," *Industry Applications Society 57th Annual Petroleum and Chemical Industry Conference, PCIC 2010*, San Antonio, Texas, September 20–22, 2010, pp. 1–8.

> This paper presents the experience and lessons learned in the development and implementation of an electrical equipment obsolescence management program at a large oil gas company. A methodology was developed to identify obsolete equipment by a rational application of obsolescence criteria and ranking mechanisms. Major investment

in replacing aging electrical equipment is required to ensure operational continuity and reliability, and to assure the continued viability and cost-effectiveness of existing Company's assets. Key strategies to develop successful strategic planning for capital investments in existing facilities are outlined. The obsolescence management program is contributing to minimizing or deferring capital expenditures in replacements by cost-effective alternatives that will extend the economic life of electrical equipment, while maintaining the required operational safety and availability. 2010 IEEE.

Amendt, A.J., "The Obsolescence of the Microprocessor," *Microelectronics Reliability*, Vol. 16, 1977, 323–332.

A broad view of the usage spectrum is taken. Speculation as to whether the concept of the discrete micro-processor may soon be outdated and whether a definitive assessment of the thing will ever be feasible is studied. In the light of these considerations future development trends are discussed.

Anghel, L., Sanchez, E., Reorda, M.S., Squillero, G., and Velazco, R., "Coupling Different Methodologies to Validate Obsolete Microprocessors," *19th IEEE International Symposium on Defect and Fault Tolerance in VLSI Systems, DFT 2004,* Cannes, France, October 10–13, 2004, pp. 250–255.

The actual operating life time for many electronic systems turned out to be much longer than originally foreseen, leading to the use of obsolete components in critical projects. To skip microprocessor obsolescence problems, companies should have bought larger stocks of components when still available, or are forced to find parts in secondary markets later. Alternatively, a suitable low-cost solution could be replacing the obsolete component by emulating its functionalities with a programmable logic device. However, design verification of microprocessors is well known as a challenging task. This paper proposes a coupled methodology to generate test-programs, using complementary techniques: one pseudoexhaustive and one driven by an evolutionary optimizer. As a case study, the Motorola 6800 was targeted.

Anghel, L., Velazco, R., Saleh, S., Deswaertes, S., and El Moucary, A., "Preliminary Validation of an Approach Dealing With Processor Obsolescence," *18th IEEE International Symposium on Defect and Fault Tolerance in VLSI Systems*, Boston, Massachusetts, November 3–5, 2003, pp. 493–500.

Processor obsolescence is a big concern affecting most equipment involved in safely critical applications (automotive, aerospace, nuclear plants, military applications...). Indeed, such applications are active years longer than was originally anticipated. A method for validating the solution consisting in the replacement of a processor, not available any more in the market, by its emulated version by means of an FPGA is presented in this paper. The Motorola 6800 processor is used as a test vehicle to illustrate the key aspects of the explored validation plan. Significant experimental results and their impact on the HDL description are discussed.

Anwar, N. and Barrowclough, B., "Nuclear Power Plant Control Challenges," *The Institution of Engineering and Technology Seminar on Power Generation Control,* Austin Court, Birmingham, United Kingdom, November 28, 2006, pp. 81–82.

One of the biggest challenges faced by the nuclear power industry is obsolescence of C&I equipment. A lot of equipment used in many of the nuclear power stations has been designed as one-of-a-kind and replacement of such control systems is a real challenge. Engineering Division at British Energy's HQ in Gloucester is in the process of replacing one such system at the Hinkley Point B Power Station supported by SIEMENS PG. The first part presents an example of a control system replacement project of a boiler feed control system, the half unit valve control system. It highlights typical challenges faced by British Energy from producing specification to commissioning. The second part is presentation by SIEMENS PG, which focuses on SIEMENS experience of working with British Energy on this particular project and the choice of the particular solution offered to British Energy.

Arcelus, F.J., Pakkala, T.P.M., and Srinivasan, G., "A Myopic Policy for the Gradual Obsolescence Problem With Price-Dependent Demand," *Computers and Operations Research*, Vol. 29, No. 9, 2002, pp. 1115–1127.

The purpose of this paper is to develop a retailer's profit-maximizing myopic inventory policy for an item recognized as subject to gradual obsolescence. Demand is assumed to be a decreasing function of both the retailer's sale price and of time, up to a certain stochastic time point when obsolescence occurs and, as a result, the demand suddenly drops to zero. For each ordering cycle, the decision variables are the retailer's selling price and the order size. A stop-ordering rule is developed on the basis of finding the time point beyond which it is profitable to stop ordering, even if there is still some demand for the item. In addition, the sudden obsolescence problem is shown to be a limiting and non-trivial case of its gradual counterpart. The numerical example illustrates the main features of the model, including the importance of the vendor dropping the price charged to retailers, so as to provide the needed incentives for the retailers to drop the price charged to their own customers and thereby palliate as much as possible to negative effects of obsolescence. This paper develops a myopic policy to evaluate a retailer's decision process, when an item is recognized as subject to gradual obsolescence. The model considers demand to be a decreasing function of both the retailer's sale price and of time, up to a certain stochastic time point when obsolescence occurs and, as a result, the demand suddenly drops to zero. The retailer's profit-maximizing policy consists of an optimal selling price and an order size for each ordering cycle, as well as the time point beyond which it is profitable to stop ordering, even if there is still some demand for the item. This is in contrast to alternate formulations, where the stopping rule is based upon minimizing the cost of obsolescence, rather than evaluating the profitability of the item in question. Finally, the numerical example illustrates the need for vendor/retailer collaboration in the development of the pricing policies. Otherwise, the retailer has no incentive to keep prices low and thus counteract the normal decreases in demand that occur as time passes by and the probability of obsolescence increases. Crown Copyright 2002 Published by Elsevier Science Ltd. All rights reserved.

Arcelus, F.J., Pakkala, T.P.M., and Srinivasan, G., "The Instant Obsolescence Problem With Price-Dependent Demand," *INFOR*, Vol. 44, 2006, pp. 247–266.

> This paper develops ordering policies for a retailer confronted with a product subject to instant obsolescence, as a result of the imminent end to its economic lifetime, usually for technological, economic or change-in-fashion reasons. The retailer's objective function exhibits a profit maximizing rather than a cost minimising optimization objective to better reflect the profit-generating role of the retailer's merchandise. There is also a price-induced demand function to provide the retailer an additional profitability tool to handle the sudden loss of the product's income generating potential. Due to the highly complex nature of the model needed to solve the instant obsolescence problem, three heuristic solutions are proposed. The first exhibits orders of equal size. Such a feature is highly coveted in practice, but produces optimal solutions only under rather restrictive assumptions about the probability distribution of the product's economic lifetime. The second yields approximated solutions, valid for any probability distribution, regardless of whether an optimal solution can be derived. The third includes both features. A numerical example highlights the nature of the various heuristic solutions. This example also brings forward an important supply-chain characteristic, namely without any price incentive when purchasing the item in question, a profit-maximizing retailer may find it rational to discourage sales of the item or even to refuse to stock it at all.

ARINC, "Strategies to Address Electronic Component Obsolescence in Commercial Aircraft," Annapolis, Maryland, 24101-7465, 1999.

> The purpose of this document is to establish guidelines that should be observed during initial design, production and maintenance of avionics LRUs, and to present short term and long-term strategies to minimize the costs and impacts associated with decreasing availability of electronic components.

Asiedu, Y. and Gu, P., "Product Life Cycle Cost Analysis: State of the Art Review," *International Journal of Production Research*, Vol. 36, No. 4, 1998, pp. 883–908.

Audsley, N., Bate, I., Grigg, A., "Portable Code: Reducing the Cost of Obsolescence in Embedded Systems," *Computing and Control Engineering Journal*, Vol. 103, 1999, pp. 98–104.

> Embedded computer systems often remain in service long after part or all of the hardware has become obsolete, due to the high cost of replacement. This cost occurs as often software has to be rewritten for the new hardware. Portable code allows compiled software to be executed on any platform without change. This enables hardware to be replaced when it is obsolete, but software to be moved to the new hardware unchanged - so reducing the cost of obsolescence.

Avionic Systems Standardisation Committee Systems Engineering Subcommittee, "Processor Obsolescence in Avionics," 1999.

> This paper was written in response to a request to prepare a discussion paper on processor obsolescence issues. It reviews the reasons for processor obsolescence and the subsequent consequences. The paper considers briefly guidelines, which already exist, and how these fall short of the ideal. It then considers some of the techniques, which could be used to assist in mitigating against processor obsolescence. The report concludes that guidance is needed in two contexts, one associated with existing systems where processor obsolescence is likely to become an issue and the other in the context of making systems more proof against future changes.

Avlonitis, G.J., Hart, S.J., and Tzokas, N.X., "An Analysis of Product Deletion Scenarios," *Journal of Product Innovation Management,* Vol. 17, No. 1, 2000, pp. 41–46.

> Despite a flurry of attention during the early 1980s and the occasional article thereafter, product deletion continues to suffer from neglect, which is surprising given its role in aiding processes of innovation and change that are central to competitive survival. The aim of this article is to rejuvenate research interest in this field. In doing so, we review and organize the relevant literature in three key sets of factors and postulate that their interplay delineates the product deletion scenarios followed by a company. On the basis of this argument, we develop a typology of product deletions and outline how it increases our knowledge of this critical issue and leads to useful research directions.

Baker, J.H.A., "Integrating Reliability, Obsolescence and Integrity Management Into Life Cycle Management of Subsea Facilities," *Underwater Technology*, Vol. 30, 2011, pp. 35–41.

> This paper recommends that the reliability, obsolescence and integrity management processes related to subsea fields should be integrated into a single process, here termed 'life cycle management', because they all treat in a similar way with the same systems, the overall aim being to maintain system integrity and availability throughout field life. This paper asserts that all three processes should commence early in the design phase of a project and be carried through to decommissioning. It also discusses failure modes, effects and criticality analysis (FMECA) which, it is proposed, should be developed into an integrated system in support of life cycle management, reflecting the root causes of failure as a means of identifying effective and measurable mitigation activities.

Balwally, N.M.,"Forecasting Digital Microcircuit Obsolescence," Department of Defense, Defense Logistics Agency, Alexandria, Virginia, 1991.

> This report documents a procedure for forecasting digital microcircuit Obsolescence at the Defense Electronics Supply Center, Dayton, OH. Obsolescence is caused by rapid advancement in digital technology and decrease in commercial demand while military demand still continues. In logistics parlance, parts obsolescence is known as a Diminishing Manufacturing Source (DMS) problem. Continued supply of an obsolete DMS item is assured via substitution, alternate sourcing or a one time buy equal to the

lifetime requirements of the item. Emulation is a recent alternative which explores the possibility of replacing obsolete digital microcircuits with state of the art devices which can be manufactured and supplied on demand. The report recommends use of a statistical model which forecasts DMS items from a population of presently non-DMS items belonging to obsolete digital microcircuit technologies. The items forecast by the model should be evaluated for their emulation potential.

Barton, D.L. and Chawla, P., "Designing Systems for Future Obsolescence," *Digital Avionics Systems Conference, 22nd DASC*, Indianapolis, Indiana, 2003.

A methodology and a set of tools that can tremendously decrease the cost of complex system design and verification are proposed. Both the methodology and the tools are based on the SLDL Rosetta, which provides a semantic base to work with.

Baskak, M. and Kahraman, C., "Fuzzy Replacement Analysis," *1998 Conference of the North American Fuzzy Information Processing Society - NAFIPS,* August 20–21, 1998, pp. 77–81.

In an uncertain economic decision environment, an expert's knowledge about the defender's remaining life and its cash flow information usually consist of a lot of vagueness instead of randomness. To describe a planning horizon which may be implicitly forecasted from past incomplete information, a linguistic description like `approximately between 10 and 14 years' is often used. A fuzzy replacement analysis for a defender is examined in the paper. The life of the defender is given by a membership function that is an intersection of the membership functions regarding the physical impairment of the defender, its obsolescence, and external economic conditions. A fuzzy economic analysis for a replacement decision is also given.

Bass, F.M., "New Product Growth for Model Consumer Durables," *Management Science,* Vol. 15, No. 5, 1969, pp. 215–227.

A growth model for the timing of initial purchase of new products is developed and tested empirically against data for eleven consumer durables. The basic assumption of the model is that the timing of a consumer's initial purchase is related to the number of previous buyers. A behavioral rationale for the model is offered in terms of innovative and imitative behavior. The model yields good predictions of the sales peak and the timing of the peak when applied to historical data. A long-range forecast is developed for the sales of color television sets.

Bass, F.M., "New Product Growth for Model Consumer Durables," *Management Science*, Vol. 50, 2004, pp. 1825–1832.

Growth model for timing of initial purchase of new products was tested empirically against data for eleven consumer durables; basic assumption of model was that timing of consumer's initial purchase is related to number of previous buyers; behavioral rationale for model is offered; model yields good predictions of sales peak and timing of peak

when applied to historical data; long-range forecast is developed for sales of color television sets. (13972).

Bayruns, T., Glusman, B.J., and Hamberg, M., "The Feasibility of Applying Safety Certifiable Software Standards to Comanche Mission Processing," *The 22nd Digital Avionics Systems Conference, DASC '03*, October 12–16, 2003, pp. 6.C.1–61-12 Vol. 2.

The RAH-66 Comanche helicopter represents state of the art technology that provides interoperable reconnaissance and attack capabilities for the battlefield of the future. The program is currently in the Engineering Manufacture and Development (EMD) phase with first low rate initial production delivery scheduled for summer 2008. The current trend toward Integrated Modular Avionics (IMA) for mission processing in military programs has long been the fundamental enabling concept of the Comanche Mission Equipment Package (MEP). Operational requirements and aggressive performance specifications relative to weight size, processing power, and IO throughput necessitated use of IMA as well as many unique design and integrations solutions resulting in an early instance of Open System Architecture technologies and approaches. As work continues on the program, typical problems associated with component obsolescence and a desire to reduce total ownership costs have meant evaluation of new technology and its application for argumentation as well as replacement of components in the current MEP. As in the past, the program continues to maximize incorporation of Commercial-Off-the-Shelf (COTS) products and the use of standards-based solutions as development cost reduction measures. New capabilities, just now being incorporated into commercial real-time operating systems, offer the potential of considering a COTS replacement for the Comanche MEP OS. Over the last few years, advancements in COTS computer and telecommunications technologies are enabling broader acceptance of COTS OSA concepts. These concepts leverage commercial designs more closely, incorporate more modern commercial standards, and offer less costly obsolescence mitigation while meeting military rotorcraft integration challenges. This paper will give an overview of those unique MEP architectural considerations and highlight the recent advances in embedded partitioned processing driven by safety certifiable Operating Systems as potential solutions for these issues while preserving a large investment in legacy code. It will also discuss how insertion of these technologies can position the Comanche MEP to successfully deal with future requirements such as Global Air Traffic Management (GATM) compatibility and Multiple Independent Level Security.

Bayruns, T. and Koenig, J.R., "Proactive Open System Architecture Design Concepts for the V-22 Osprey Tiltrotor," *Proceedings of the 21st Digital Avionics Systems Conference,* 2002, pp. 5C1-1–5C1-10 Vol.1.

The V-22 Osprey tiltrotor is in low rate initial production with an avionics architecture designed in the late 1980's using state-of-the-art military designs. Even before full rate production begins, the aircraft has faced vendor hardware and software obsolescence issues compounded by rapidly growing interest in satisfying new requirements such as FAA DO-178B certification. This paper describes how open system architecture design concepts used by other military aircraft, such as the F-15, F/A-18, and other military

transports, maximizing off-the-shelf technology can be applied to the V-22 Osprey to consolidate avionics, mitigate obsolescence, reduce life cycle cost and support growth requirements. The approach presented focuses on the mission processing, display processing, and sensor processing subsystems and shows potential space, weight, cost, and power reductions with minimal deviation from any current aircraft requirements. Technology and standards for placing all three subsystems into a single unit are examined to determine the feasibility of the open systems approach. Being proactive today by applying open system concepts to the V-22 Osprey will allow future development of affordable new mission variants with reduced total ownership cost.

Bayus, B.L., "An Analysis of Product Lifetimes in a Technologically Dynamic Industry," *Management Science*, Vol. 44, No. 6, 1998, pp. 763–775.

The conventional wisdom that product lifetimes are shrinking has important implications for technology management and product planning. However, very limited empirical information on this topic is available. In this paper, product lifetimes are directly measured as the time between product introduction and withdrawal. Statistical analyses of desktop personal computer models introduced between 1974 and 1992 are conducted at various product market levels. Results indicate that (1) product technology and product model lifetimes have not accelerated and (2) manufacturers have not systematically reduced the life-cycles of products within their lines. Instead, the products of firms that have entered this industry in the more recent years tend to be based on previously existing technology, and, not surprisingly, these products have lifetimes that are shorter than those of established firms. Implications of these findings are discussed.

Beck, D.S., "Microelectronic Obsolescence Management," Naval Postgraduate School, Monterey, California, 2003.

The ability of the Department of Defense to execute its mission is directly dependent on the capability to produce and maintain weapon systems. Rapid advances in technology have been instrumental to the development of highly efficient and capable systems. However, they have also increased the rate electronic part manufacturers change product lines resulting in the Department of Defense's increasing dependence on obsolete electronic components. The objective of this thesis is to provide a viable tool for managers to eliminate, mitigate, and proactively manage the growing obsolescence problem. The thesis will define obsolescence, provide a comprehensive discussion of ongoing obsolescence initiatives, and provide a systematic approach to manage microelectronic obsolescence. The thesis will also explore and provide recommendations to address the increasingly common scenario where an ongoing weapon system production program receives little or no notification of a part going out of production.

Behbahani, A.R., "Achieving Afrl Universal Fadec Vision With Open Architecture Addressing Capability and Obsolescence for Military And Commercial Applications," *42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit*, Sacramento, California, July 9–12, 2006, pp. 17–29.

> The United States Air Force (USAF) has an inventory of over 24,000 aircraft with over 47,000 gas turbine engines. Aircraft systems are expensive and must be periodically modernized or upgraded to keep pace with changing threats, missions, and advancing technology. Controls and accessories comprise approximately 1/5 of the total cost of an engine. The main component of the controls system is the Full Authority Digital Engine Control (FADEC). Legacy FADEC systems are both unique and dedicated to a specific weapon system. Today, each FADEC design is unique within its application class. Developing a universal or common standard for engine controls and accessories which includes FADECs would significantly reduce development and support costs across DoD platforms. With engines representing up to 60% of the platform operating costs, modernizing them could provide significant return on investment and avoid the high cost of full system replacement. Obsolescence issues consume considerable funds and manpower and increase the risk to operational missions and the supply pipeline. To minimize the impact obsolesce, technology insertion can provide alternatives that leverage state-of-the art hardware and software to resolve the unavailability of critical parts, enhance performance and decrease cost. These alternatives will be developed through open system architectures with common or "universal" standardized inputs and outputs with improved reliability (reduce failures), common and advanced materials, reusable software, decreased number of components, high-reliability modules and improved manufacturing processes. The universal FADEC system for DoD engines will involve a family of common components. It will consist of a real-time operating system and partitioned application software (AS) structure. These components will significantly ease the strain on the supply and maintenance infrastructure. The universal FADEC vision is to develop a common input/output scheme, open hardware and software architecture, and generic circuit modules. A systems approach will be employed, considering sensors, cabling, connectors, and interface standards, as well as the FADEC electronic hardware and software.

Berg, R.M., J.C. Ruether, et al., "Methodology for Evaluating Maintainability and Obsolescence of Nuclear Plant Ic Systems," *Proceedings of the 56th Annual American Power Conference, Part 1 (of 2), April 25, 1994 - April 27, 1994*, Illinois Institute of Technology, Chicago, Illinois, Vol. 56, pp. 1256–1261.

> This methodology has been applied to several Prairie Island IC systems and subsystems, and is being used to substantiate resource allocations and priorities in planning. The methodology has been valuable in fostering a systematic approach and removing bias in the evaluation process. The methodology will be raised to incorporate experience gained at Prairie Island and other participating plants.

bin Salam, S, "NextGen: Aligning Costs, Benefits and Political Leadership," Eno Center for Transportation, 2012.

> The aviation system that is part of the life-blood of our economy is poised to face rising demand with limited additional capacity and outdated technology. This could put considerable stress on the system in terms of congestion and efficiency. The Next Generation Air Transportation System (NextGen) represents a series of incremental policies, procedures, and technological changes to modernize the air traffic control (ATC) system into a more efficient, state-of-the-art satellite-based system. On the technology side, NextGen is composed of two main components: aircraft based equipment that records and transmits the exact location of the aircraft using Global Positioning System (GPS), and ground based infrastructure that can receive and analyze the GPS data. Infrastructural improvements also entail devising more direct and fuel-efficient routes, and upgrading the computer and backup system used at 20 Federal Aviation Administration (FAA) air traffic control centers nationwide. The infrastructure implementation is currently in the hands of the FAA and funded by the Airport and Airway Trust Fund (AATF), while aircraft equipage is expected to be paid for by the operators.

Boeing, "Supplier Obsolescence Management Program," D6-82983, 2004.

> The intent of the Supplier Obsolescence Management Program (SOMP) is for the supplier to define, document and implement an obsolescence program throughout the lifecycle of electronic and Avionic Products subject to obsolescence. Although elements of suppliers' obsolescence program are subject to review by Boeing, the supplier is expected to establish internal management processes that address potential obsolescence events beginning with initial design, production and maintenance of electronic and avionic LRUs, and establish short term and long term strategies to minimize the customers cost of ownership associated with decreasing availability of electronic components through occurrences of obsolescence.

> BCA encourages all suppliers participating in the SOMP to be flexible in developing and implementing internal processes to accomplish these objectives. Each supplier is responsible to define, document and implement a SOMP that is tailored to their overall operation. BCA will expect the supplier to provide timely and credible data associated with obsolescence as defined above and in the body of this document.

Borgonovo, E., Marseguerra, M., and Zio, E., "A Monte Carlo Methodological Approach to Plant Availability Modeling With Maintenance, Aging and Obsolescence," *Reliability Engineering and System Safety,* Vol. 67, No. 1, 2000, pp. 61–73.

> In this paper we present a Monte Carlo approach for the evaluation of plant maintenance strategies and operating procedures under economic constraints. The proposed Monte Carlo simulation model provides a flexible tool which enables one to describe many of the relevant aspects for plant management and operation such as aging, repair, obsolescence, renovation, which are not easily captured by analytical models. The

maintenance periods are varied with the age of the components. Aging is described by means of a modified Brown-Proschan model of imperfect (deteriorating) repair which accounts for the increased proneness to failure of a component after it has been repaired. A model of obsolescence is introduced to evaluate the convenience of substituting a failed component with a new, improved one. The economic constraint is formalized in terms of an energy, or cost, function; optimization studies are then performed using the maintenance period as the control parameter.

Boucekkine, R., del Río, F, and Licandro, O., "Obsolescence and Modernization in the Growth Process," *Journal of Development Economics,* Vol. 77, No. 1, 2005, pp. 153–171.

In this paper, an endogenous growth model is built up incorporating Schumpeterian creative destruction and embodied technological progress. Under embodiment, long run growth is affected by two opposite effects: (i) obsolescence costs add to the user cost of capital, which have a negative effect on research efforts; and (ii) the modernization of capital increases the demand for investment goods, raising the incentives to undertake research activities. Applied to the understanding of the growth enhancing role of both capital and R&D subsidies, we conclude that the positive effect of modernization generally more than compensates the negative effect of obsolescence.

Bradley, J.R. and Guerrero, H.H., "Product Design for Life-Cycle Mismatch," *Production and Operations Management,* Vol. 17, No. 5, 2008, pp. 497–512.

Life-cycle mismatch occurs when the life cycle of a product does not coincide with the life cycles of the parts used in that product. This is particularly a problem with products that contain electronic components that sometimes have life spans of only two years. The cost of mitigating component obsolescence, which may require redesigning the product, is often considerable. Thus, prudent product design necessitates the selection of electronic components and product architecture, considering the cost of mitigating an obsolete design and other costs related to the design and manufacture of a product. Accordingly, we develop and analyze a model that shows how a product design can be effectively tailored to a particular product's life cycle.

Bradley, J.R. and Guerrero, H.H., "Lifetime Buy Decisions With Multiple Obsolete Parts," *Production and Operations Management,* Vol. 18, No. 1, 2009, pp. 114–126.

Life-cycle mismatch occurs when the life cycles of parts end before the life cycles of the products in which those parts are used. Lifetime buys are one tactic for mitigating the effect of part obsolescence, where a quantity of parts is purchased for the remaining life of a product. We extend prior work that determines optimal lifetime buy quantities for one product with one obsolete part by providing an analytic solution and two simple heuristic policies for the optimal lifetime buy quantities when many parts become obsolete over a product's life-cycle. We determine which of our two heuristics is most accurate for different product life cycles, which yields a metaheuristic with increased accuracy. That analysis also reveals critical perspectives in making lifetime buy decisions with nonstationary life-cycle demand patterns.

Bray, O.H. and Garcia, M.L., "Technology Roadmapping: the Integration of Strategic and Technology Planning for Competitiveness," *Innovation in Technology Management - The Key to Global Leadership, PICMET '97: Portland International Conference on Management and Technology*, Portland, Oregon, July 27–31, 1997, pp. 25–28.

> Technology planning is becoming critical with the rapid development and obsolescence of technologies. Technology roadmapping provides a tool for selecting which technologies to pursue in what timeframes. This paper provides a framework for technology roadmaps, describes the roadmapping process, and reviews its application.

Broadbent, M., "Use of FPGA for Emulation of Obsolete Processors in Safety Systems," QinetiQ, 2005.

> No abstract available.

BSI, "Obsolescence Management - Code of Practice for Obsolescence Notification and Support from Suppliers of Electronic Components," 2000.

> No abstract available.

BSI, "Design Management Systems - Part 5: Guide to Managing Obsolescence," 2001.

> No abstract available.

BSI, "Obsolescence Management - Guide to the Substitution of Components in Electronic Equipment," 2002.

> No abstract available.

Bumbalough, A., "USAF Manufacturing Technology's Initiative on Electronic Parts Obsolescence Management," *44th International SAMPE Symposium*, May 23–27, 1999, Vol. 44, 2044–2051.

> Parts obsolescence problems are prevalent in fielded and developmental systems where the service life or development cycle is longer than the manufacturing life of one or more of its components. With the typical manufacturing life of most electronic components today being two to four years it is expected that most defense systems will have obsolescence problems before fielding and certainly experience obsolescence during service life. The Manufacturing Technology Division has implemented a five year, 21 Million dollar initiative in parts obsolescence. The contractors are proving an additional 11 Million in cost share. Request for proposals were published in the Commerce Business Daily under the titles 'Parts Obsolescence Tools' BAA-97-11-MLKT, and 'Parts Obsolescence and the Application of Commercially Manufactured Electronics' BAA-98-14-MLKT. The resulting initiative consists of programs in the following areas: a) Commercially available obsolescence management decision and reverse engineering tools: The objectives are to take the most cost effective management decision and reduce

the cost of re-engineering. b) Application of Commercially Manufactured Electronics (ACME): The objective is to address key technology driven issues required to increase effective use of commercially manufactured electronics at the chip, board, and box level. This area includes efforts addressing Physics of Failure (PoF) reliability approaches and application-specific integrated circuits (ASICs) availability. c) Pilot Programs: These programs will establish improved business policies and obsolescence management processes utilizing the tools and technologies of the other areas. They will demonstrate and document the cost effectiveness of implementing the technology and processes into weapon systems.

Buratti, M. and Del Brusco, D., "Obsolescence Management Based on a 'Pro-Active' Approach in Conjunction With a 'Pre-Planned' Technology Insertion Route," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, 2000, **p**p.12-11–12-15.

Parts obsolescence was affecting all Alenia products/programs so that we had to identify a robust strategy to prevent uncontrolled effects. The design of products family has taken the obsolescence management issue as key basic requirement. The basic ideas on the back of our pro-active approach for obsolescence issues are: All products (in terms of equipment subsystem or systems) design shall offer a flexible open architecture which permits to change a specific functional block maintaining unchanged the overall architecture. The 'Open architecture' used shall facilitate any design changes into the defined functional blocks (caused by obsolescence issues) because of the high level of interface standardization. A product configuration for a pre-determined period of time shall be maintained by performing components buy for all expected production batches including logistic support, allowance and spares. There will be a defined periodic product enhancement which permits a pre-planned obsolescence removal activities and relevant design changes. There will be a high level of backward compatibility between the updated system configuration and the previous one. Technologies which support the Product enhancement will be consolidated and introduced at a point where the level of risk is considered acceptable (or obsolescence became a major issue).

Campbell, S.M., "On the Absence of Obsolescence," *IEEE Annals of the History of Computing,* Vol. 31, No. 4, 2009, pp. 118–120.

The paper talks about the history of computing that explored obsolescence. Computer technology had undergone the most dramatic progress of any technology in the second half of the 20th century, and thus also the most dramatic rate of obsolescence. At the root, obsolescence is a process that occurs when users chose to replace one technology with another, either because they need to. That newer technology is also better is almost an aphorism of the last few centuries.

Carayon, J.L., "Emulation Techniques for Solving Processor Obsolescence," *DASIA 2007: DAta Systems In Aerospace Conference*, Naples, Italy, 2007, European Space Agency.

Our Space projects often use specific radiation tolerant processors for executing flight software. The flight software represents a huge investment in design, coding and validation. When a processor becomes obsolete, and when instructions set is to be changed, this leads to port software to the new target and to validate it again on a new computer. This is a time and cost consuming task. A huge effort was undertaken by space agencies like ESA and CNES to standardize the SPARC instruction set and make technological advances on several chips from ATMEL or VHDL-IP cores, with an increasing processing power. The paper describes the approach taken at CNES for the replacement of the Transputer T805 used for Myriade OBC computer, before migrating for a new instructions set (SPARC for example) for a new line of micro and minisatellites common avionics.

Carbone, J., "Where Are the Parts?," *Purchasing*, 2003, pp. 44–47.

No abstract available.

Carlaw, K.I., "Optimal Obsolescence," *Selected Papers of the MSSANZ/IMACS 15th Biennial Conference on Modeling and Simulation,* Elsevier, Vol. 69, 2005, pp. 21–45.

Technological change is examined in a model of capital production to show that "creative destruction" can occur as an outcome of firm's optimizing behaviour, regardless of market structure. Capital systems are made up of components that are all necessary for each system to operate and each component has uncertainty with respect to its durability. For different types of technological change agents make a corresponding decision about whether to continue to use the original capital system (if it is still alive) or to scrap it and build a new capital system which embodies the new technology. Each system has transitional probabilities for scrapping that depend on the size of the present value of the vintage. As technology improves, the optimizing level of durability, and thus the optimal stock of embodied services increases for the new capital system. Yet simultaneously the probability of scrapping an old system over any given time interval increases. Thus, the larger is the improvement in technology, the greater is the chance of scrapping the old system before its physical service life has ended. Over some time horizon of unforeseen and rapid technological change investment in new capital systems could be increasing while at the same time old capital systems are scrapped at a faster rate. 2005 IMACS. Published by Elsevier B.V. All rights reserved.

Carruth, R.C. and Sotos, S.G., "Design Concepts for the Reactor Protection and Control Process Instrumentation Digital Upgrade Project at the Donald C. Cook Nuclear Plant Units 1 and 2," *1995 IEEE Nuclear Science Symposium and Medical Imaging Conference Record,San Francisco, California, October 21–28, 1995,* Vol. 2, pp. 890–894.

As the nation's nuclear power plants age, the need to consider upgrading of their electronic protection and control systems becomes more urgent. Hardware obsolescence

and mechanical wear out resulting from frequent calibration and surveillance play a major role in defining their useful life. At Cook Nuclear plant, a decision was made to replace a major portion of the plant's protection and control systems with newer technology. This paper describes the engineering processes involved in this successful upgrade and explains the basis for many decisions made while performing the digital upgrade.

Carruth, R.C. and Sotos, W.G., "Design Concepts for the Reactor Protection and Control Process Instrumentation Digital Upgrade Project at the Donald C. Cook Nuclear Plant Units 1 and 2." *IEEE Transactions on Nuclear Science,* Vol. 43, No. 3, 1996, pp. 1899–1902.

> As the nation's nuclear power plants age, the need to consider upgrading of their electronic protection and control systems becomes more urgent. Hardware obsolescence and mechanical wear out resulting from frequent calibration and surveillance play a major role in defining their useful life. At Cook Nuclear plant, a decision was made to replace a major portion of the plant's protection and control systems with newer technology. This paper describes the engineering processes involved in this successful upgrade and explains the basis for many decisions made while performing the digital upgrade.

Cattani, K., "Hewlett Packard Company: Managing Product End of Life," *Operations Management Education Review,* Vol. 1, 2005, pp. 67–86.

> No abstract available.

Cattani, K.D. and Souza, G.C., "Good Buy? Delaying End-of-Life Purchases," *European Journal of Operational Research,* Vol. 146, No. 1, 2003, pp. 216–228.

> We study the effects of delaying an end-of-life buy. Manufacturers sometimes are required to place a final, end-of-life buy for a component that the supplier will no longer provide. The manufacturer performs a newsvendor analysis with the possible result of significant expected overage and underage costs. If the decision can be delayed, the expected overage and underage costs can be reduced. We model the effects of a delay of the final purchase under various scenarios of remaining demand. We contrast the manufacturing benefits with the costs incurred by the supplier and show that the supplier, who benefits greatly from the end-of-life buy, likely will require an incentive to enact a delay. Our results provide an insight to the observation of increasing numbers of end-of-life buys and provides a framework for analysis as manufacturers strive to cope with the issue.

Chafee, S.S., "Fundamental Requirements of Life-Cycle Costing: Projecting Life-Cycle Costs for Electronic System Modernization," *Northcon/96*, 1996, pp. 41–46.

> Rapid advances in electronics technology with resultant obsolescence and nonavailability of currently used electronics components and devices force systems managers to continuously upgrade and modernize existing systems in order to ensure equipment

supportability. This paper examines the requisite attributes of Life-cycle Cost (LCC) analysis methods needed to effectively and flexibly project long term cost requirements, perform LCC versus performance tradeoff analyses, and accurately calculate time phased cost profiles during the planning and design of system upgrades. To be effective, an LCC analysis tool must facilitate modernization and upgrade planning by allowing the decision makers to rapidly analyze life-cycle economic impacts caused by front end technical and logistic decisions. Required accuracy of the estimate and the time and resources available to complete the analysis are important factors in selecting the analytical methods to be employed. When used as an integral part of the planning process, LCC analysis provides a tool for the systematic balancing of overall cost of systems ownership with system technical and schedule requirements.

Chestnutwood, M. and Levin, R., "Technology Assessment and Management Methodolog–An Approach to System Life Sustainment and Supportability Enhancement," *Proceedings from the 18th Digital Avionics Systems Conference,* 1999, pp. vol.1.

System Life Sustainment of electronic systems, especially Military Legacy Systems, have traditionally been a sequential set of processes and plans that are applied to the system based on what point of the life cycle curve the system happens to be in at any point in time. With Military systems, these processes are stretched to the limit as the life of the systems is artificially extended by the services (to as much as 30 years). Critical elements of proper life cycle management of Military systems and their associated product implementations are system integration, product replacements, upgrades, and technology insertions. Reduced Government funding and manpower levels have further emphasized the need to improve life cycle management processes. As legacy systems age, their associated sustainment costs can rise dramatically due to obsolescence, reliability and supportability problems while at the same time the performance of the system, as compared to state of the market or technology, decreases. Key decision points occur during the life cycle that will impact long term funding and performance profiles. Early detection of sustainment problems provides sufficient time for the decision making process to implement an analysis of viable alternatives and solutions. To be complete the analysis must include an evaluation of alternative sources and support concepts, technology infusion, re-engineering, commercial technology insertions and comparisons of life cycle costs. To be successful in the support and evolution of systems, programs must have a well defined approach and tool set to aid in the decision making process.

Chiang, D., Guo, R.-S., et al., "The Final Order Model for Auto Service Parts Considering the End of Product Life-Cycle," *Asia Pacific Industrial Engineering & Management Systems Conference*, Kitakyushu, Japan, 2009.

The importance of service parts is much emphasized as the competition in the market becomes severe. These service parts are not only providing product after-sale service, but also playing one of the important rules as competing with competitors in the future. Especially, the supplier of service parts may no longer manufacture the parts after certain period of time before the end of service period for considering economic production quantity. Therefore, the after service providers must place a final order to meet future

demand before the production of service parts is stopped. In this paper, we first combine an effective demand forecasting model by considering product sales and the rate of return with newsboy problem to determine the optimal final order quantity by a tradeoff of dead-stock cost and lost sale cost. Next, we use the real data provided by a local auto company to construct a simulation model to compare our model with current practices of this auto company. Results show that our model reduces the total cost significantly, and the auto company is suggested to apply the newly developed model to placing its final order and controlling its inventory policy more effectively.

Chiramal, M., "Application of Commercial-Grade Digital Equipment in Nuclear Power Plant Safety Systems," *Proceedings of the 20th IEEE Symposium on Reliable Distributed Systems*, 2001, pp. 176–178.

Due to obsolescence, increasing maintenance costs, and the lack of qualified spare parts for the equipment and components of the analog instrumentation and control (I&C) systems in operating domestic nuclear power plants, nuclear utilities are replacing equipment and upgrading certain I&C systems. These activities generally involve changing from analog to digital technology. In many cases commercial products offer practical solutions. Digital I&C systems have the potential to enhance safety, reliability, and availability of the plant systems and improve plant operation. However, the use of digital software-based equipment presents challenges and concerns to the U.S. nuclear industry and the Nuclear Regulatory Commission (NRC). The NRC's approach to the review and acceptance of design qualification for digital systems largely focuses on confirming that the applicant or licensee has employed a high-quality development process that incorporated disciplined specification and implementation of design requirements. Inspection and testing is used to verify correct implementation and to validate the desired functionality of the final product.

Clavareau, J. and Labeau, P.-E., "Maintenance and Replacement Policies Under Technological Obsolescence," *Reliability Engineering and System Safety,* Vol. 94, pp. 370–381.

The technological obsolescence of a unit is characterized by the existence of challenger units displaying identical functionalities, but with higher performances. This paper aims to define and model in a realistic way, possible maintenance policies of a system including replacement strategies when one type of challenger unit is available. The comparison of these possible strategies is performed based on a Monte Carlo estimation of the costs they incur. 2008 Elsevier Ltd. All rights reserved.

Clavareau, J. and Labeau, P.-E., "A Petri Net-Based Modelling of Replacement Strategies Under Technological Obsolescence," *Reliability Engineering and System Safety,* Vol. 94, pp. 357–369.

The technological obsolescence of a unit is characterised by the existence of challenger units displaying identical functionalities, but with higher performances. Though this issue is commonly encountered in practice, it has received little consideration in the literature. Previous exploratory works have treated the problem of replacing old-technology items by new ones, for identical components facing a unique new generation of items. This

paper aims to define, in a realistic way, possible replacement policies when several types of challenger units are available and when the performances of these newly available units improve with time. Since no fully generic model can exist in maintenance optimisation, a modular modelling of the problem, allowing easy adaptations to features corresponding to specific applications is highly desirable. This work therefore proposes a modular Petri net model for this problem, underlying a Monte Carlo (MC) estimation of the costs incurred by the different possible replacement strategies under consideration. 2008 Elsevier Ltd. All rights reserved.

Clay, S., "Material Risk Index (MRI) and Methods for Calculating an MRI for Electronic Components."

No abstract available.

Clay, W.S., Sykora, R.A., and Morrison, J.R., "Systems and Methods for Automatically Determining and/or Inferring Component End of Life (EOL)," Rockwell Automation Technologies, Inc., Mayfield Heights, Ohio, 2010.

The invention relates to a system and methodology for facilitating managing product life cycle. A component that determines relevance of components to a product; an analyzing component that determines, infers or predicts obsolescence, level of risk to EOL of a subset of the components. A substitution component that identifies replacement components and suppliers for the subset of components. A cost analysis component that determines material/components cost savings, and redesign cost implementation and/or redesign cost avoidance. A viability component that measures reliability of a component. A transition component that identifies components that require updating or replacement. A profitability component that determines the expected revenue derived from a component over its projected remaining life.

Cobbaert, K. and Van Oudheusden, D., "Inventory Models for Fast Moving Spare Parts Subject to 'Sudden Death' Obsolescence," *International Journal of Production Economics,* Vol. 44, No. 3, 1996, pp. 239–248.

Simple inventory models are developed for fast moving spare parts subject to the risk of unexpected, immediate obsolescence. The approach does not require a precise knowledge of the probability distribution of the moment of obsolescence, as is the case for models discussed in the literature. A rough estimate of the obsolescence risk for the next order cycle is sufficient. The models can be seen as extensions of the EOQ-formula. Following cases are studied: 1. Constant obsolescence risk; no shortages allowed 2. Varying obsolescence risk; no shortages allowed 3. Varying obsolescence risk; shortages allowed. It appears that the models are practicable and, in the proper circumstances, lead to a substantial reduction of cost.

Cole, I.D., "The Replacement of Nuclear Monitoring Equipment," *International Conference on Refurbishment of Power Station Electrical Plant,* London, England, November 7–8, 1988, pp. 54–58.

> The safe and efficient operation of the reactor within nuclear power stations is determined largely by the measurement and control of neutron flux and core temperature. These parameters are measured using complex sophisticated electronics, located throughout the station, which has to be replaced due to component obsolescence and more onerous operating requirements. The author discusses the problems associated with the replacement of these equipments against a background of the dual requirements of satisfying the Nuclear Installations Inspectorate (NII) on safety matters while achieving successful installation during the very limited reactor shut down periods.

Comella-Dorda, S., Wallnau, K., Seacord, R.C., and Robert, J., "A Survey of Black-Box Modernization Approaches for Information Systems, *International Conference on Software Maintenance*, San Jose, California, October 11–14, 2000, pp. 173–183.

> Information systems are critical assets for modern enterprises and incorporate key knowledge acquired over the life of an organization. These systems must be updated continuously to reflect evolving business practices. Unfortunately, repeated modification has a cumulative effect on system complexity, and the rapid evolution of technology quickly renders existing technologies obsolete. Eventually, the existing information systems become too fragile to modify and too important to discard. For this reason, organizations must consider modernizing these legacy systems to remain viable. The commercial market provides a variety of solutions to this increasingly common problem of legacy system modernization. Understanding the strengths and weaknesses of each modernization technique is paramount to select the correct solution and the overall success of a modernization effort. This paper provides a survey of modernization techniques, including screen scraping, database gateways, XML integration, CGI integration, object-oriented wrapping and componentization of legacy systems. This general overview enables engineers performing legacy system modernization to pre-select a subset of applicable modernization techniques for further evaluation.

Component Obsolescence Group (UK), "Obsolescence - (993) Companies Must Face up to a Growing Problem, States COG," *Jane's Defence Industry,* 2005.

> The Component Obsolescence Group (COG) reports that the UK industry could avoid likely costs through effective obsolescence management. This ranges from more than 300,000 for a major component redesign to 13,500 to find a substitute component and 100 for a solution involving the use of existing stockpiled parts. The early identification of an obsolescence problem can lead to avoid more expensive solutions. COG advises organizations to take pro-active steps to predict where potential problems might arise and to monitor the availability of components that have a high risk of becoming obsolete.

Compson, K., "Control and Instrumentation Systems in Power Station Refurbishment Schemes," *International Conference on Refurbishment of Power Station Electrical Plant,* London, England, November 7–8, 1988, pp. 95–99.

> To sustain the operation of major plant items in a power station during its proposed lifetime requires a planned programme of overhaul and maintenance. This is likely to include the replacement or refurbishment of components due to general `wear and tear', obsolescence, unavailability of spare parts or as a result of modifications elsewhere on the plant. Control and instrumentation (C and I) systems are particularly prominent in these respects usually having a life expectancy less than that expected for major items of mechanical and electrical plant. To offset this however, it is shown that some of the greatest returns on investment can result from the replacement, upgrading or refurbishment of power station C and I systems.

Condra, L., "Combating Electronic Component Obsolescence by Using Common Processes for Defense and Commercial Aerospace Electronics, *NDIA*," 1999.

> No abstract available.

Condra, L., Anissipour, A., Mayfield, D.D., Pecht, M.G., "Electronic Components Obsolescence," *IEEE Transactions on Components, Packaging, and Manufacturing Technology - Part A,* Vol. 20, No. 3, 1997, pp. 368–371.

> Until recently, permanence was an underlying assumption of aerospace electronic equipment. The intent was to design electronic equipment once, and the design was assumed to be static, producible and maintainable for the lifetime of the airframe, which was, and still is, often several decades. Furthermore, the aerospace-oriented culture that pervaded the avionics equipment industry, allowed each equipment design to be optimized independently, with little regard for commonality, modularity, reuse, scalability, or extendibility to other applications. Provisions for design and production changes were minimal or nonexistent and suppliers focused on producing spares, rather than developing more competitive products. This situation was abetted by the lack of any significant competition and the long-term availability of military grade electronic components. In recent years, several major electronic component manufacturers have ceased production of military-grade components which were once considered immune to obsolescence [1]. The reasons are associated mostly with global competitiveness and the financial benefits of manufacturing components for the high volume electronics industries (e.g., computers, consumer products, and telecommunications), rather than for the low volume complex systems industries (see Fig. 1). The pullout of many of the leading component manufacturers from the military market has had mixed effects on the aerospace industry. The use of commercial electronic components has already provided such advantages as availability of more and advanced functions, availability of state-of-the art technology, extremely reliable components, and significantly lower costs than traditional military (and QML) components [1]. On the other hand, the decline of the military components industry and the fast pace of the commercial components industry have both led to shortened component availability and thus concerns about component

obsolescence. Some aspects of the current challenges and "costs" associated with the phenomenon of component obsolescence are described below to illustrate the problems and the demand for urgent attention

Condra, L., D. Followell, Houchens, G., et al., "Minimizing the Effects of Electronic Component Obsolescence," *Boeing Aero Magazine,* 2000, pp. 10.

The ongoing revolution in the electronics industry has created a significant challenge for the aerospace industry. Manufacturers of aerospace electronic components such as integrated circuits, diodes, resistors, and transistors are leaving the aerospace market to pursue the rapidly expanding computer, consumer electronics, and telecommunications markets. Boeing continues to lead the aerospace industry in developing new approaches for adapting to the changing electronics market and ensuring access to a supply of suitable components.

Condra, L., D. Followell, Houchens, G., et al., "Electronic Component Obsolescence," *SAMPE Journal,* 2002, Vol. 38, pp. 46–50.

The ongoing revolution in the electronics industry has created a significant challenge for the aerospace industry. Manufacturers of aerospace electronic components are pursuing the rapidly expanding computer, consumer electronics, and telecommunications markets. To successfully adapt to this changing environment, both designers and users of aerospace systems must understand and address several issues which are as follows: a). scope of the component obsolescence problem, b), selection and management of electronic components, c). design of electronic systems and equipment, d). operation, maintenance, and support of electronic equipment, e). qualification and certification of electronic equipment.

Cordero, R.,"Managing for Speed to Avoid Product Obsolescence: A Survey of Techniques," *Journal of Product Innovation Management,* Vol. 8, No. 4, 1991, pp. 283–294.

Competition among product manufacturers is intensifying in many industries. The nature of this competition forces firms to manage the product supply process for speed to avoid product obsolescence and decreased competitiveness. Rene Cordero describes a number of time-saving techniques and develops a framework for managing the product supply process for speed: making speed a central objective of the firm, selecting faster product strategies, managing for the speedy implementation of these product strategies, and managing human resources for speed. Although speeding the product supply process requires significant changes in the traditional management of product development, managing for speed can bring benefits such as faster response to market needs, reduced product cost, and increased product quality.

Cox, P.A., Hartley, A.J., Redling, T.J., et al., "Paradigm Shifting from Military to Commercial Business Practices, *Digital Avionics Systems Conference, 20th DASC,* Vol. 1, pp. 3E1/1–3E1/11.

Advances in commercial technologies have sparked an evolution in the military marketplace. Parts obsolescence driven by rapid advances in technology and acquisition reform are two key drivers that are causing military platforms to rapidly incorporate commercial technologies. Improvements to military platforms based on commercial technology are targeted at increased safety, asset availability, lower cost of ownership, and overall operating efficiency. Recognizing that they cannot build an infrastructure independent from the commercial sector and that they can benefit from recent technological strides, the military has embraced commercial technology in their upgrade programs. This paper explores the US government's desired migration to a more commercial-like procurement model and the challenges associated with that shift. It also attempts to provide some insight for government agencies and defense contractors as they shift to this new paradigm and make the appropriate strategic adjustments.

Craig, R.W., "A Methodology for Addressing Support Equipment Obsolescence," *IEEE Aerospace and Electronic Systems Magazine,* Vol. 17, 2002, pp. 20–25.

The rapid growth of technology over the last twenty years is providing vastly improved capabilities for both avionics and avionics test systems. Unfortunately, an environment of rapid technological growth breeds a corresponding environment of rapid technological obsolescence. Test systems developed fifteen years ago are becoming increasingly more difficult to support due to obsolescence issues and, additionally, such a test system does not reflect the current state-of-the-art for automatic test equipment. The ability of a test system to evolve is essential to providing cost-effective support systems for electronic systems. The F-15 Tactical Electronic Warfare System (TEWS) Intermediate Support System (TISS) was developed under the Modular Automatic Test Equipment (MATE) guidelines to support the suite of F-15 electronic warfare LRUs. MATE imposed hardware architecture constraints, which were factors that contributed to its abandonment. However, the modular aspect of MATE has provided a system that can easily evolve with technological advancements. Modularity is the cornerstone of modern software systems and this is the aspect that has been exploited in the evolution of the TISS.

Cruickshank, D., Daughtridge, S., Schmitt, M., and Aparicio, A., "Proven Method to Eliminate Ground System Obsolescence," *7th International Symposium Reducing the Costs of Spacecraft Ground Systems and Operations (RCSGSO),* Moscow, Russia, 2007.

Satellite operators select hardware and software for a ground control system that they will rely on to monitor and control their spacecraft effectively throughout a 15+-year lifetime. However, evolving technology can render equipment provided at the beginning of the mission obsolete. Using a true COTS (Commercial Off-the-Shelf) software approach, ISI (Integral Systems, Inc.), addresses this issue by implementing and supporting a long-term product maintenance program and by providing the same software system to all users. For the satellite industry, this proven approach eliminates ground system obsolescence

problems and enables operators to leverage the latest product improvements and enhancements. Therefore, operators are guaranteed a system that is fully supported and cost effective for the entire satellite lifetime. For this model to work, the ground system software must provide to a large customer base a comprehensive set of evolving COTS products, such as IST s EPOCH IPS (Integrated Product Suite). Then, a maintenance program and new license sales can economically make advanced capabilities and new features available to all operators and manufacturers using the product suite. In addition, new hardware with the latest operating system version can be added to replace aging equipment without adding capital costs beyond the relatively low cost of standard COTS hardware. Under this program, existing and prospective customers benefit from the same enhancements and updates. Each release is tested and guaranteed to be compatible with each customer's satellite fleet. Thus, operators are never abandoned to rely on obsolete, unsupported systems. As an independent systems integrator, ISI has successfully supported satellite operators worldwide for over 10 years using this model. One such customer, Loral Skynet, currently operates a mixed fleet of ten GEO (Geostationary Earth Orbiting) spacecraft. In 1996, Loral Skynet decided to replace multiple, manufacturer-proprietary ground systems with a common ISI ground system. This was an important decision for Loral Skynet; because it provided a common operator interface, provided scalability for future expansion, and reduced long-term operating costs by simplifying ground system maintenance, administration, and training. Loral Skynet has participated in the ISI maintenance program since its inception and has benefited from the various updates and improvements over the years.

Darling, D.R., Cirillo, T., Fuller, D., Herald, T., and Green, J., "Parts Obsolescence Management Technology Transition (POMTT)", 2004.

Obsolescence impacts everything, especially in the Defense industry. The reduction of sources and availability affects component parts, assemblies, software, and even complete systems. Changes in the commercial and military marketplace have also resulted in military-grade parts becoming less available. These obsolete high-reliability components are now too expensive to reproduce, and often less reliable than new commercial parts that perform the same function. As a result, manufacturers of high reliability weapon systems must now use commercial parts for their military applications. The Air Force established the Electronic Parts Obsolescence Initiative (EPOI) in 1998 to help address these problems, and specifically support the mitigation of obsolescence. Tools, technologies, and methodologies were established and funded; and follow-on pilot demonstration programs were also established to evaluate the performance and commercial viability of these tools.

David, I. and Greenshtein, E., "Brownian Analysis of a Buffered-Flow System in the Face of Sudden Obsolescence," *Operations Research Letters,* Vol. 19, No. 1, 1996, pp. 43–49.

We consider a stochastic flow system with an intermediate storage buffer. When the buffer is depleted of stock, orders from outside are placed. It is assumed that there is a risk of failure (which is referred to as obsolescence) that wipes out existing inventory, and that the time to obsolescence is exponentially distributed. The problem is to

determine order quantities so as to minimize expected inventory costs when faced with obsolescence. The underlying input-output (production-demand) process is not controllable and the resulting inventory level is modeled by a Brownian motion. We develop an exact expression for the expected total cost until obsolescence, dependent on the order-quantity decision-variable. Numerical results which center around one specific application are examined to gain insight into the problem. The work is a generalization of recent research on the EOQ in the face of obsolescence in that it studies the influence of randomness in the inventory level process.

David, I., Greenshtein, E., and Mehrez, A., "Dynamic-Programming Approach to Continuous-Review Obsolescent Inventory Problems", *Naval Research Logistics,* Vol. 44, 1997, pp. 757–774.

Inventory models of modern production and service operations should take into consideration possible exogenous failures or the abrupt decline of demand resulting from obsolescence. This article analyzes continuous-review versions of the classical obsolescence problem in inventory theory. We assume a deterministic demand model and general continuous random times to obsolescence ('failure'). Using continuous dynamic programming, we investigate structural properties of the problem and propose explicit and workable solution techniques. These techniques apply to two fairly wide (and sometimes overlapping) classes of failure distributions: those which are increasing in failure rate and those which have finite support. Consequently, several specific failure processes in continuous time are given exact solutions.

Dawson, C.R., "Processor Designs for Protecting The Software Investment," *Conference Proceedings, MILCOMP Europe 91. Military Computers - Systems + Software*, Microwave Exhibitions and Publishers, 1991, pp. 141–149.

The growing complexity of modern avionics systems, together with the relevant enabling hardware and software technologies, have conspired to produce avionics systems in which a significant proportion of the total life cycle costs are incurred in designing, writing and maintaining the operational flight programmes (OFPs). This paper presents processor design techniques for containing these software costs, using both post- and pre-planned product obsolescence, whilst simultaneously enabling advances in processor technology to be utilised with no impact on the software costs.

Dillard, A.E., "Real-Time Operational Evaluations Using Advanced Flight Simulators," *Proceedings of the AIAA/IEEE/SAE Digital Avionics Systems Conference, 17th DASC,* Vol. 1, Bellevue, Washington, 1998, pp. E16/11–E16/17.

The increased speed with which new technologies are being introduced into the modern aviation operating environment has made it necessary to find new ways of evaluating certification, human factors, operational and safety issues. We no longer have the luxury of an extended development program, followed by an evolutionary period of products maturing into more complex forms, with an extended useful life. Modern technology delivers fully formed products to the marketplace with rapid wide distribution and, in

many cases, a limited operating life due to forced obsolescence caused by new advances and technologies. Aviation has always been a technology leader, and this hasn't changed, so the introduction of new communication, navigation, surveillance and display technology is moving forward at a fast pace. Aviation is also a very competitive business, and maximum benefit comes from the early implementation of innovative new products and applications. While some time elements of the product life cycle have changed, critical requirements for validating safety, reliability and system integrity in civil aviation have not. The process of operationally integrating a new technology into an existing, highly complex, costly and potentially hazardous domain, such as airports and aircraft cockpits, demands an exhaustive evaluation of their effects on the existing system, while maintaining safety and performance standards, support logistics and affordability. To shorten the time required for equipment and procedural development, and operational implementation, the use of simulation has grown in importance. Simulation can consist of virtual modeling on a computer workstation, part task devices with actual system hardware and software, or full-mission man-in-the-loop simulators with visual systems and motion. All have their place in the process, and all play a role in shortening development time and cost. We will be looking at the use of full-mission simulators for piloted operational evaluations.

Dinesh Kumar, U. and Saranga, H., "Optimal Selection of Obsolescence Mitigation Strategies Using a Restless Bandit Model," *European Journal of Operational Research,* Vol. 200, pp. 170–180.

Obsolescence of embedded parts is a serious concern for managers of complex systems where the design life of the system typically exceeds 20 years. Capital asset management teams have been exploring several strategies to mitigate risks associated with Diminishing Manufacturing Sources (DMS) and repeated life extensions of complex systems. Asset management cost and the performance of a system depend heavily on the obsolescence mitigation strategy chosen by the decision maker. We have developed mathematical models that can be used to calculate the impact of various obsolescence mitigation strategies on the Total Cost of Ownership (TCO) of a system. We have used classical multi-arm bandit (MAB) and restless bandit models to identify the best strategy for managing obsolescence in such instances wherein organizations have to deal with continuous technological evolution under uncertainty. The results of dynamic programming and greedy heuristic are compared with Gittins index solution. 2008 Elsevier B.V. All rights reserved.

DiSandro, R. and Torok, R., "Managing IC Reliability and Obsolescence," *Nuclear News*, American Nuclear Society, Vol. 48, 2005, pp. 26–31.

A strategy for managing instrumentation and control (IC) obsolescence and phasing in new technology developed by Exelon Nuclear is discussed. This will balance the need for high reliability against budget constraints of a highly competitive business environment. This strategy meets the needs of the fleet and captures the benefits of applying proven solutions to multiple plants, with reduced incremental costs. It comprises two major segments, the IC systems implementation plan and the component management strategy,

and facilitates the identification of those components that have become a major support challenge and also helps prioritize solutions.

Drake, M., "Sharing Obsolescence Information at Raytheon With the Component Obsolescence and Reuse Tool," *The International Symposium on Product Quality and Integrity; Transforming Technologies for Reliability and Maintainbility Engineering,* Tampa, Florida, 2003, pp. 277–279.

Diminishing Manufacturing Sources (DMS) is an industry wide problem that still attains considerable attention [1]. Every company and contract that deals with the manufacturing of electronic equipment has to deal with the problem of component obsolescence, that is using parts that are or soon will be no longer available. This issue has obvious impact on new designs, repairs, and product upgrades. It is especially difficult to plan for obsolescence when so many legacy systems exist as well. It is predicted that 70-80% of the US Military systems will be classified as legacy by the year 2010 [2]. Therefore, the challenge is to try to make an estimated 5 year redesign cycle [3] last considerably longer than 5 years. Though many companies have developed policies and procedures to deal with obsolescence, software tools are needed to accompany processes and to gain maximum return on investment of those processes. The Component Obsolescence and Reuse Tool is a software tool that Raytheon Company has developed to enhance our obsolescence best practice process. Currently the tool contains over 100,000 parts each containing obsolescence colored "life" indicators. So far, the return on investment that the tool is generating is exceeding long term savings estimates. Not only has Raytheon Company Northeast sites been using the tool, but Raytheon sites in Fort Wayne, Indiana; Falls Church, Virginia; Towson, Maryland; and Huntsville, Alabama have completed obsolescence assessments for their programs. Collaboration continues across other Raytheon sites to share and leverage component obsolescence management information.

DuBois, T.A., Clevenger, J.J., and Hill, T.L., "Candidate Technologies and Design Concepts for Comanche Mission Computer Cluster (MCC) Production," *Digital Avionics Systems Conference, 20th DASC.*, Vol. 1, pp. 4A1/1–4A1/13.

Rapid advances in computer and electronics technologies has created the situation in which all aviation platforms need to contend with varying degrees of parts obsolescence. Having just entered an Engineering Manufacturing Development (EMD) phase with production in 2006, the Comanche program recognizes the challenges of parts obsolescence and is considering the introduction of selected emerging technologies to proactively address this issue. The presented approaches focus on solutions that reduce space, weight, cost, and power requirements while minimizing the need to deviate from established platform integration and supportability requirements. By introducing technologies during EMD, the cost impact of parts obsolescence in production can be drastically reduced

Dubos, G.F. and Saleh, J.H., "Risk of Spacecraft On-Orbit Obsolescence: Novel Framework, Stochastic Modeling, and Implications," *Acta Astronautica,* Vol. 67, 2010, pp. 155–172.

The Government Accountability Office (GAO) has repeatedly noted the difficulties encountered by the Department of Defense (DoD) in keeping its acquisition of space systems on schedule and within budget. Among the recommendations provided by GAO, a minimum Technology Readiness Level (TRL) for technologies to be included in the development of a space system is advised. The DoDconsiders this recommendation impractical arguing that if space systems were designed with only mature technologies (high TRL), they would likely become obsolete on-orbit fairly quickly. The risk of on-orbit obsolescence is a key argument in the DoDposition for dipping into low technology maturity for space acquisition programs, but this policy unfortunately often results in the cost growth and schedule slippage criticized by the GAO. The concept of risk of on-orbit obsolescence has remained qualitative to date. In this paper, we formulate a theory of risk of on-orbit obsolescence by building on the traditional notion of obsolescence and adapting it to the specificities of space systems. We develop a stochastic model for quantifying and analyzing the risk of on-orbit obsolescence, and we assess, in its light, the appropriateness of DoDrationale for maintaining low TRL technologies in its acquisition of space assets as a strategy for mitigating on-orbit obsolescence. Our model and results contribute one step towards the resolution of the conceptual stalemate on this matter between the DoDand the GAO, and we hope will inspire academics to further investigate the risk of on-orbit obsolescence. 2010 Elsevier Ltd. All rights reserved.

Easingwood, C.J., Mahajan, V., and Muller, E., "A Nonuniform Influence Innovation Diffusion Model of New Product Acceptance," *Marketing Science,* Vol. 2, No. 3, 1983, pp. 273.

A nonuniform influence (NUI) innovation diffusion model for forecasting first adoptions of a new product is proposed. An extension of the Bass model, the proposed model overcomes three limitations of the existing single-adoption diffusion models. First, the current models generally assume that the word-of-mouth effect remains constant over the entire diffusion span. However, for most innovations, the word-of-mouth effect is likely to increase, decrease or remain constant over time. Second, the existing models assume that an innovation must attain its maximum penetration rate before capturing a prespecified level of potential market, for example, 50%. That is, they restrict the location of the inflection point for the diffusion curves. Third, the current models assume that the adoption patterns after and before the location of maximum penetration rate are mirror images of each other. That is, the diffusion curve is symmetric. By allowing the word-of-mouth effect to systematically vary over time, the proposed model allows the diffusion curve to be symmetrical as well as nonsymmetrical, with the point of inflection responding to the diffusion process. Data from five consumer durables are analyzed to illustrate the generality of the model. [ABSTRACT FROM AUTHOR].

warranty is given about the accuracy of the copy. Users should refer to the original published version of the material for the full abstract. (Copyright applies to all Abstracts.)

Eckersley, J.E. and Adams, W., "Achieving Test Program Set Transportability Through Interface Design," *AUTOTESTCON,* 2009, 161–163.

For decades, the automatic test community has worked to develop hardware standardization and interface protocols that aid in mitigating the impact of equipment obsolescence on the repair and maintenance mission. The traditional view of Test Program Set (TPS) transportability in this environment has always been one of migrating a legacy TPS to a new hardware architecture design born out of a need to replace aging technology or provide new test capability. The Department of Defense (DoD) has recognized the benefit of standardizing automatic test systems (ATS) through policy guidance whose intent is to drive the services to a common configuration test environment, thereby reducing life cycle sustainment costs for all DoD systems. Today, hardware standardization has advanced to the point that many ATS look and function very similar to one another. However, there are two major hurdles that continuously thwart our efforts to develop a standard core test system, the lack of a standard UUT interface and the lack of an open architecture software design that facilitates operations in any environment and on any test system architecture. Automatic Test Markup Language (ATML) provides promise with regards to the development of standardized test software interfaces. Developing a standard hardware configuration for all test requirements is ultimately achievable with the technology currently available today except for one simple, but hugely significant hurdle, the cost involved in re-hosting the myriad of test program sets currently in existence. Therefore, any significant advance in common interface design has to take into account the need to minimize the impact to existing test program sets. This paper will seek to explore the various technological possibilities for overcoming the barriers to true TPS transportability that exist in today's automatic test community.

Egghe, L., Ravichandra Rao, I.K., Rousseau, R., "On the Influence of Production on Utilization Functions: Obsolescence or Increased Use?" *Scientometrics,* Vol. 34, No. 2, 1995, pp. 285–315.

We study the influence of production on utilization functions. A concrete example of this is the influence of the growth of literature on the obsolescence (aging) of this literature. Here, synchronous as well as diachronous obsolescence is studied. Assuming an increasing exponential function for production and a decreasing one for aging, we show that, in the synchronous case, the larger the increase in production, the larger the obsolescence. In the diachronous case the opposite relation holds: the larger the increase in production the smaller the obsolescence rate. This has also been shown previously by Egghe, but the present proof is shorter and yields more insight in the derived results. If a decreasing exponential function is used to model production the opposite results are obtained. It is typical for this study that there are two different time periods: the period of production (growth) and — per year appearing in the production period — the period of aging (measured synchronously and diachronously). The interaction of these periods is described via convolutions (discrete as well as continuous).

Electronic Industries Alliance, "Product Life Cycle Data Model," 1997.

No abstract available.

FAA, "Guidance for Assuring the Software Aspects of Certification When Replacing Obsolete Electronic Parts Used in Airborne Systems and Equipment." Washington, DC, , CAST-3,1999.

This paper proposes guidance and an approach for assessing and ensuring that the replacement of electrical and electronic parts used in aircraft electrical systems and equipment is addressed safely from the software perspective in the certification process while minimizing manufacturer and operator costs and schedule impacts. Many electronic components used in already certified aircraft systems and equipment are no longer being manufactured, that is, are obsolete, and this paper proposes an effective and efficient approach for ensuring the software aspects of certification for replacement of these parts in existing airborne systems and equipment.

FAA, "Design Assurance, Guidance For Airborne Electronic Hardware," Advisory Circular 20-152 RTCA DO-254, Washington, DC, 2005.

No abstract available.

FAA, "Frequently Asked Questions (FAQs) on the Use of RTCA Document DO-254 and EUROCAE Document ED-80, Design Assurance Guidance for Airborne Electronic Hardware," Washington, DC, CAST-30, 2006.

This CAST paper provides responses to some questions that are frequently asked by industry concerning the application of DO-254/ED-80 for certification projects.

FAA, "Final Policy Statement on Applying Advisory Circular 20-152, 'RTCA, Inc., Document RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware,' to Title 14 Code of Federal Regulations, Part 23 Aircraft; PS-ACE100-2005-50001," Washington, DC, 2007.

This final policy statement sets up Federal Aviation Administration (FAA) certification policy on applying Advisory Circular (AC) 20-152 to complex airborne electronic hardware (CEH) installed in part 23 aircraft or in airships. The specific issues addressed concern selecting and applying hardware design assurance levels (HDAL) to CEH.

FAA, "Job Aid: Conducting Airborne Electronic Hardware Reviews," Washington, DC, 2008.

No abstract available.

FAA, "Simple and Complex Electronic Hardware Approval Guidance (Change 1)," Order 8110.105, Washington, DC, 2008.

No abstract available.

FAA, "Simple And Complex Electronic Hardware Approval Guidance GAMA Briefing," Order 8110.105, Washington, DC, 2008.

No abstract available.

Feldman, K. and Sandborn, P., "Integrating Technology Obsolescence Considerations into Product Design Planning," *ASME International Design Engineering Conferences & Computers and Information in Engineering Conference*, Las Vegas, Nevada, 2007.

Technology life cycles affect a product manager's ability to sustain systems through their manufacturing and field lives. The lack of availability of critical parts and technologies poses a challenge not only to the acquisition community, but to customers of products that must be maintained for long periods of time. Technology obsolescence has an especially serious impact on systems that have significant electronics content because electronic parts are quickly obsoleted in favor of newer, higher performance components. In this study, market availability data was analyzed for operational amplifiers, a technology integral to most electronic products, and for flash memory devices. Procurement lifetimes are shown to have shrunk since operational amplifiers emerged on the market. Algorithms for forecasting electronic part obsolescence are proposed and the ramifications of electronic part obsolescence on product design planning are discussed. Copyright 2007 by ASME.

Feng, D., "Optimizing Lifetime Buy Quantities to Minimize Lifecycle Cost," *Mechanical Engineering*, University of Maryland, College Park, Maryland.

Mismatches between electronic part procurement lifecycles and the lifecycles of the products they are used in causes products with long manufacturing and/or support lives to suffer from significant obsolescence management costs. Lifetime buy is a prevalent mitigation approach employed for electronic part obsolescence management. Making lifetime purchases of parts upon obsolescence involves managing interacting influences and concurrent buys for multiple parts in a sequential manner. This thesis is focused on optimizing lifetime buy quantities by minimizing lifecycle cost. The Life of Type Evaluation (LOTE) tool was created to optimize lifetime buy quantities. LOTE requires component and system data and expected demand information. With the given data, LOTE uses stochastic analysis to determine the lifetime buy quantity per part that minimizes the lifecycle cost for the system. Results from a LOTE analysis of a Motorola communication system indicate that organizations may be systematically overbuying at lifetime buys giving inventory shortage penalties a greater emphasis than other hidden costs.

Feng, D., Singh, P., et al., "Optimizing Lifetime Buys to Minimize Life-cycle Cost," *Aging Aircraft Conference*, Palm Springs, California, 2007.

> Mismatches between electronic part procurement lifecycles and the lifecycles of the products that they are used in cause products with long manufacturing and/or support lives to incur significant obsolescence management costs. Lifetime buy is one of the most prevalent mitigation approaches employed for electronic part obsolescence management. Making lifetime purchases of parts when they go obsolete involves managing many interacting influences and multiple concurrent buys for multiple parts. The focus of this paper is optimizing lifetime buy quantities by minimizing life-cycle cost. There are multiple factors that contribute to the life-cycle cost associated with a lifetime buy: procurement cost, inventory cost, disposal cost, and penalty cost. The Life of Type Evaluation (LOTE) tool was created to optimize lifetime buy quantities and minimize life-cycle cost. LOTE requires component and system data. With the given data, LOTE uses stochastic analysis to determine the lifetime buy quantity per part that minimizes the life-cycle cost for the system. LOTE was used to determine the optimum lifetime buy quantities for a Motorola communications system.

Fink, R.T., Betlack, J.O., and Torok, R.C., "Application of Guidelines on Digital I&C Upgrades," *Nuclear Science Symposium and Medical Imaging Conference, 1994 IEEE Conference Record*, Norfolk, Virginia, Vol. 3, 1994, pp. 1063–1067.

> Nuclear utilities are upgrading their existing instrumentation and control (I&C) systems. The upgrades are being driven primarily by the growing problems of obsolescence, difficulty in obtaining parts, and increased maintenance costs of existing systems. There also is great incentive to take advantage of modern digital technologies which offer potential performance and reliability improvements. A guideline to assist utilities in these upgrades has been prepared by a committee of EPRI, NUMARC and industry representatives. The committee worked with NRC to reach a consensus approach for design, implementation, and licensing of digital upgrades, which is the basis for the EPRI guideline. This paper briefly recaps the background for development of the guideline, and it gives a brief overview of the approach and content of the document. An update on the status of its use by the industry and acceptance by the NRC is provided. Finally, some lessons learned from recent upgrades and applications of the EPRI guidance are discussed.

Fitzhugh, G.L., "Rapid Retargeting a Solution to Electronic Systems Obsolescence," *Proceedings of the 1998 IEEE National Aerospace and Electronics Conference, NAECON*. Dayton, Ohio, 1998, pp. 169–176.

> In 1993, the Office of Naval Research (ONR), in conjunction with the Undersecretary of the Navy for Research, Development, and Acquisition, established a program known as Technology for Affordability. That program is executed today in many of the Navy's weapon systems procurements and is specifically resident in two ONR programs: Manufacturing Technology and Small Business Innovation Research (SBIR). The technology discussed in this paper was developed under the auspices of the SBIR

program and is known as Rapid Retargeting. It is executed through VisiCom Laboratories, Inc., a California-based small business. Rapid Retargeting rehosts existing logic into new hardware technology. This rehosting process begins by extracting the functionality of the target hardware and capturing it in VHSIC Hardware Descriptive Language (VHDL). The resulting software models are simulated and compared with the original hardware for verification. Once verified, the models are ported to a new hardware design. Subsequently, parts obsolescence is no longer an issue: software models can be rehosted whenever new technology becomes available.

Flaherty, N., "New Parts for Old," *IEE Review,* Vol. 51, No. 1, 2005, pp. 34–37.

A better understanding of the costs associated with contracting component lifetimes is enabling engineers to create more obsolescence-friendly designs.

Flaherty, N., "Working out the True Cost of Managing Obsolescence in Electronic Designs," *European Electronics Engineer*, 2005, pp. 16–18.

Obsolescence is becoming much more of an issue as chip making technology speeds up. Devices made on 0.5um and 0.35um are reaching the end of their product lifetimes and going `end of life', and that raises questions for industrial designers on how to manage that. Having a strategy to tackle the obsolescence of parts in three to five years is vital, and the latest survey from the National Obsolescence Centre gives engineers, for the first time, the metrics they need to argue the cost savings to put such a strategy in place.

Francis, L., "Advancing Through Obsolescence Lines," *Electronic Product Design*, Vol. 27, pp. 29–30.

The solution of the problems of component obsolescence issues, for military, high-reliability and ling-lifetime applications, are discussed. The first necessity is to nip problems in the beginning by preventing obsolescence issues in the first place, this means ensuring that products and systems are specified with back-ups and alternatives for critical components. Many component manufacturers are beginning to offer contractual lifetime support (CLS) plans or non-obsolescence policies to eliminate the problem altogether. It is worth noting that valuable though these can be, they can not be accepted at face value, purchasing and engineering professionals need to work together to ensure that such guarantees are not only correctly framed to protect the customer, but also technically achievable. Another way of securing supply is to use an obsolescence and parts procurement specialist to provide contact logistics support services.

Francis, L., "Lifetime Procurement - Look Deep for Dependability," *Electronics Systems and Software,* Vol. 4, No. 6, pp. 22–25.

It is difficult to avoid using commercial off-the-shelf hardware in military systems. You need to have plans in place to make sure the components will suit long lifetimes and high-reliability environments. The military and aerospace communities now regard the use of commercial off-the-shelf (COTS) equipment as commonplace. The shift to use

ready-made hardware and software encompasses not just individual components, but, sometimes, entire sub-assemblies. The impact of this change is already evident, particularly in terms of obsolescence: projects with development phases that last up to 20 years and in-service lifetimes of 40 years are being built using components with lifecycles that are, in some cases, measured in months. The scale of the problem is illustrated by recent estimates suggesting that electronic components are now going obsolete at a rate of more than 13,000 per month. The effects in terms of reliability, although important, are less clear, simply because insufficient in-service data currently exists to assess real failure rates and lifetimes. Against this background, military and aerospace engineers need to ensure the reliability safety integrity and lifetime of their designs. In particular, whole-life component management planning is essential to ensure adequate supplies of fit-for-purpose components and subassemblies throughout the lifecycle, from concept, assessment, development, manufacture and in-service life through to disposal.

Frederick, K., "Rapid Retargeting to Mitigate Obsolescence in the AN/ALQ-126B - A Logistics Success Story," *Digital Avionics Systems Conference, 20th DASC*, Vol. 1, 2001, pp. 3E3/1–3E3/10.

> This paper tells a logistics success story. It describes the successful application of an obsolescence mitigation technique developed by Naval Supply Systems Command (NAVSUP), Rapid Retargeting, to the AN/ALQ-126B by Titan Systems Corporation VisiCom Products Division. Through Rapid Retargeting, Titan created a UniModule that can be used as a form, fit, and functional replacement for any of eight SRAs used in eleven different slots in the ALQ-126B.

Freschi, S., Barton, D., and Bukata, E., "Rehosting Test Program Sets for Legacy Electronics: A Test Requirements-Based Approach," *AUTOTESTCON Systems Readiness Technology Conference,* Salt Lake City, Utah, August 24–27, 1998, pp. 315–320.

> The service lives of weapon systems and their electronic subsystems are being extended well beyond the affordable lives of the test equipment used to support them. The increasing commercial item content of these testers is shortening their product life cycles by increasing the frequency of obsolescence issues and the need for configuration changes. In addition, as the Department of Defense searches for ways to reduce the cost of operating and sustaining its aging tester infrastructure, the replacement of peculiar, obsolete testers with common, more efficient and cost-effective testers becomes an effective tactic. These factors all increase the probability that test programs for legacy electronics will need to be rehosted at least once during their service lives. This paper presents a test requirements-based approach to the design and verification of rehosted TPSs as a method to address these challenges. The approach will be to express test requirements, extracted from legacy TPSs and available product data, in a consistent information-based model, the Test Requirements Model (TeRM). This will, in turn, provide the TPS engineer with an objective and consistent basis for validating the rehosted TPS as a natural byproduct of the reengineering process. It will be shown that this approach can address TPS rehost challenges as well as extend to the reengineering of

obsolete electronics. The service lives of weapon systems and their electronic subsystems are being extended well beyond the affordable lives of the test equipment used to support them. The increasing commercial item content in these testers is shortening their product life cycles and increasing the frequency of obsolescence issues and configuration changes. In addition, as the Department of Defense searches for ways to reduce the cost of operating and sustaining its aging infrastructure, replacing peculiar, obsolete testers with common, more cost effective and efficient testers becomes an effective tactic.

Fuentes-Fernández, R., Pavón, J., and Garijo, F., "A Model-Driven Process for the Modernization of Component-Based Systems," *Science of Computer Programming*, Vol. 77, No. 3, March 1, 2012, pp. 247–269.

Software modernization is critical for organizations that need cost-effective solutions to deal with the rapid obsolescence of software and the increasing demand for new functionality. This paper presents the XIRUP modernization methodology, which proposes a highly iterative process, structured into four phases: preliminary evaluation, understanding, building and migration. This modernization process is feature-driven, component-based, focused on the early elicitation of key information, and relies on a model-driven approach with extensive use of experience from the previous projects. XIRUP has been defined in the European IST project MOMOCS, which has also built a suite of support tools. This paper introduces the process using a case study that illustrates its activities, related tools and results. The discussion highlights the specific characteristics of modernization projects and how a customized methodology can take advantage of them.

Gaillat, G., "Generic Tools and Methods for Obsolescence Control," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, pp.14-11–14-13.

The increasing discrepancy between the life cycles of professional electronics equipment and the life cycles of the components (which are largely intended for volume markets) means that professional electronics manufacturers must implement methods processes and tools to give their customers long-term availability guarantees for their products despite obsolescence problems in the components. Although this effort must be made at the level of each unit and adapted to the type of product the customers needs and internal organization the existence of common methodological tools and principles can significantly help each unit set up the appropriate procedure for their particular case. This paper gives an overview of the methods and tools set up within the Thomson-CSF group to support the units in this procedure.

Gao, C., Liu, X., and Wang, X., "A Model for Predicting the Obsolescence Trend of FPGA," *9th International Conference on Reliability, Maintainability and Safety (ICRMS)*, Guiyang, China, June 12–15, 2011, pp. 1354–1358.

Obsolescence makes equipments supporting and maintaining hard and costly. It hurts the equipments reliability seriously. In the past decades, electronic technology has developed very rapidly causing components (and particularly the FPGAs) to have a shortened life

span. So the problem of electronic component obsolescence in complex electronic or long life systems such as aircraft submarines and ships is getting more and more severe, therefore has heighten the interest of researchers. This paper analyses the FPGA obsolescence drivers, on based of which it introduces some traditional methods to deal with obsolescence, and proposes a model to predict the obsolescence trend of FPGA. It can be a reference for system designers selecting FPGAs. For the purpose of verifying the model, XC4085 is used to be an example.

Gassmann, H.I. and Ireland, A.M., "Scenario Formulation in an Algebraic Modeling Language," *Annals of Operational Research,* Vol. 59, pp. 45–75.

> Algebraic modelling languages have simplified management of many types of large linear programs, but have not specifically supported stochastic modelling. This paper considers modelling language support for multistage stochastic linear recourse problems with finite distributions. We describe basic language requirements for formulation of finite event trees in algebraic modelling languages and show representative problems in AMPL using three commonly used scenario types.

Gittins, J., Glazebrook, K., and Weber, R., *Multi-Armed Bandit Allocation Indices*, John Wiley, 2011.

> No abstract available.

Gort, M. and Wall, R.A., "Obsolescence, Input Augmentation, and Growth Accounting," *European Economic Review,* Vol. 42, No. 9, 1998, pp. 1653–1665.

> The paper points to a serious conceptual inconsistency in conventional measures of capital used in most empirical work on economic growth. When appropriate corrections are made, it is found that plausible alternative values for the relative magnitude of obsolescence and physical decay imply very different rates of growth in capital. This, in turn, leads to large differences in the fraction of growth in output attributed to input augmenting technical change as compared with the 'Solow residual.'

Goswami, A., "Impact of Hardware Obsolescence on System Software for Sustainment-Dominated Electronic Systems," Department of Mechanical Engineering, University of Maryland, College Park, Maryland, 2004.

> The last two decades have witnessed manufacturers of sustainment-dominated long field life electronic systems incorporate Commercial Off the Shelf (COTS) technology products into their systems on a large scale. Many of these products, however, have lifetimes of significantly shorter duration than the systems they are incorporated into and as a result become obsolete long before the system's intended duration of useful life is over. This problem is especially prevalent in avionics and military systems, where systems may encounter obsolescence problems even before they are fielded and always during their support life. Manufacturing that takes place over long periods of time exacerbates this problem. Many part obsolescence mitigation strategies exist including:

lifetime buy, last-time buy, part replacement, aftermarket source, uprating, emulation, re-engineering, salvage, and ultimately redesign of the system. Design refresh (or redesign) has the advantage of treating multiple existing and anticipated obsolescence problems concurrently and additionally allows for functional upgrades. Hitherto, there have been studies concentrated on determining the optimum combination of different obsolescence strategies by using life cycle cost as the deciding criterion. However, these studies take into account only hardware life cycle costs. In many systems, such as avionics systems, software life cycle costs (redesign, rehosting and requalification) have a significant bearing on total life cycle cost. Thus software redesign due to part obsolescence triggered hardware redesign should also be addressed during life cycle management planning. This thesis describes a methodology and it's implementation for determining the hardware part obsolescence impact on life cycle sustainment costs for system software based on future production projections, maintenance requirements and part obsolescence forecasts. The methodology extends the MOCA (Mitigation of Obsolescence Cost Analysis) methodology/tool that determines the optimum design refresh plan during the field-support-life of the product in order to minimize life cycle cost. The design refresh plan consists of a set of design refresh activities and their respective calendar dates. The methodology incorporates the use of two software commercial cost analysis models: PRICE S and COCOMO. The methodology developed in this thesis has been validated using a Navy test case (VH-60N Digital Cockpit Upgrade Program). It has also been applied to Honeywell International, Inc.'s AS900 engine controller. The results obtained demonstrate the necessity of taking software redesign analysis into account during life cycle management planning.

Grabowski, G., Balser, B., and Forster, M., "Integrated Modular Avionics With COTS Directed to Open Systems and Obsolescence Management," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, 2000, pp. 18-11–18-19.

This paper describes bow to design open computer systems for mission critical applications within the avionics of military aircraft using Commercial Off The Shelf (COTS) computer components. Design aspects of 'Integrated Modula Avionics' (IMA) are incorporated. How these aspects contribute to an effective obsolescence management is also described. The content of this paper is presented within the context of projects currently running at the European Aeronautic Defence and Space (EADS) Deutschland GmbH, Military Aircraft Business Unit (MABU), which are dealing with the subjects COTS and obsolescence.

Grant, R.T., "The Effect of Diminishing Manufacturing Sources on Legacy Systems Using System Dynamics," Graduate School, Vanderbilt University, Nashville, Tennessee, 2006.

No abstract available.

Gravier, M.J. and Swartz, S.M., "The Dark Side of Innovation: Exploring Obsolescence and Supply Chain Evolution for Sustainment-Dominated Systems," *Journal of High Technology Management Research,* Vol. 20, No. 2, 2009, pp. 87–102.

> The problem of technological obsolescence in vendor supplied parts in the new product development process has increased in importance in recent years. This is compounded by both the rapid pace of technological advance and increasingly disintegrated supply chains. This issue has become particularly problematic for products with both a high degree of technology and long life cycles. This exploratory study relates empirical obsolescence findings to theoretically predicted models of innovation diffusion for different product-market conditions. Implications are analyzed for supply chain evolution and obsolescence management. 2009 Elsevier Inc. All rights reserved.

Greenway, T., "CI Aging Obsolescence Strategy for Nuclear Power Plants," *IET Seminar on Power Generation Control*, Birmingham, United Kingdom, 2007, pp. 13–28.

> British Energy has a fleet of 8 nuclear power stations in the UK. Much of the control and instrumentation (CI) equipment is over 30 years old. British Energy and its predecessors have a long history of effectively managing ageing and obsolescence of CI equipment. There are new internal and external expectations and challenges. These arise from aspirations to extend the life of plant, the need to manage risk and investment, newly published standards and not least the continuing march of time and its effects on equipment. This presentation will describe the development of British Energy's response to these challenges. The strategy and some implementation details will be presented. While what will be presented will represent work in progress, it has progressed to a point where there are some useful lessons for other organisations involved in similar asset lifetime management programmes. British Energy Generation Ltd.

Guzman-Miranda, H., Sterpone, L., Violante, M., Aguirre, M.A., and Gutierrez-Rizo, M., "Coping With the Obsolescence of Safety - or Mission-Critical Embedded Systems Using FPGAs," *IEEE Transactions on Industrial Electronics,* Vol. 58, No. 3, June 1, 2010, pp. 814–821.

> Today many companies are facing the problem of component obsolescence in embedded systems. The incredibly fast growth-rate of semiconductor companies is reducing dramatically the time components are available on the market. Twenty years ago, components remained on the market for 5 to 10 years, while nowadays they disappear from the market in less than 2 years. Developers of safety- or mission-critical systems are particularly sensitive to the obsolescence problem as their systems are expected to remain operative for very long periods of time (e.g., 30 years or more), and maintaining them fully operative is becoming difficult as the needed components may be no longer available. A possible solution for this problem may be the implementation of the needed components using FPGAs. The purpose of this paper is to provide an overview of the different possibilities designers have to face when developing such dependability-oriented solution. Also a design flow is presented, describing its applicability to the implementation of processor cores, to be employed as replacement of obsolete parts in

safety- or mission-critical applications. Results show that there is a strong dependence of the reliability of the design with the specific application. The scrubbing process can also be optimized using the related technique.

Hamilton, M.H. and Hackler, W.R., "001: A Rapid Development Approach for Rapid Prototyping Based on a System That Supports Its Own Life Cycle," *First International Workshop on Rapid System Prototyping, 1990. Shortening the Path from Specification to Prototype,* 1990, pp. 46–62.

A Development Before the Fact system is an intelligent system in that it contains built-in properties to provide itself the best opportunities that are available for its own development. It provides the opportunity to begin its own development tasks as soon as possible and to check as you go throughout its own development process. It is an independent system in that it is not locked into obsolescence. The 001 technology directly addresses the issues of Development Before the Fact systems. With 001, integration happens early with the use of TMaps and FMaps; errors are eliminated early when, for example, the primitive structures are ultimately used to eliminate interface errors. Flexibility and the ability to handle the unpredictable are issues that are dealt with early since system definitions based on the three primitive structures have properties of single-reference and single assignment, ensuring traceability and safe reconfiguration, preparing for distributed environments happens early, with explicit delineation of independencies, dependencies and decision making. Reusability happens early with the use of mechanisms such as defined structures and parameterized types. Automation happens early, since TMaps, FMaps and their associated instantiations support automated tools with sufficient and necessary information to understand formally both a system and its definition.

Harkness, L.L. and Sjoberg, E.S., "Generalized Approach for Identification and Evaluation of Technology-Insertion Options for Military Avionics Systems," *Proceedings of SPIE, Radar Sensor Technology*, Orlando, Florida.

The Georgia Tech Research Institute, sponsored by the Warner Robins Air Logistics Center, has developed an approach for efficiently postulating and evaluating methods for extending the life of radars and other avionics systems. The technique identifies specific assemblies for potential replacement and evaluates the system level impact, including performance, reliability and life-cycle cost of each action. The initial impetus for this research was the increasing obsolescence of integrated circuits contained in the AN/APG-63 system. The operational life of military electronics is typically in excess of twenty years, which encompasses several generations of IC technology. GTRI has developed a systems approach to inserting modem technology components into older systems based upon identification of those functions which limit the system's performance or reliability and which are cost drivers. The presentation will discuss the above methodology and a technique for evaluating and ranking the different potential system upgrade options.

Hegland, D.E., "Technology and Obsolescence," *Assembly*, Bensenville, Illinois, Vol. 48, 2005, pp. 6.

No abstract available.

Helsen, K. and Schmittlein, D.C., "Analyzing Duration Times in Marketing: Evidence for the Effectiveness of Hazard Rate Models," *Marketing Science,* Vol. 12, No. 4, pp. 395–414.

Some statistical methods developed recently in the biometrics and econometrics literature show great promise for improving the analysis of duration times in marketing. They incorporate the right censoring that is prevalent in duration times data, and can be used to make a wide variety of useful predictions. Both of these features make these methods preferable to the regression, logit, and discriminant analyses that marketers have typically used in analyzing durations.This paper is intended to fulfill three objectives. First, we demonstrate how decision situations that involve durations differ from other marketing phenomena. Second, we show how standard modeling approaches to handle duration times can break down because of the peculiarities inherent in durations. It has been suggested in recent marketing articles that an alternative to these conventional procedures, i.e., hazard rate models and proportional hazard regression, can more effectively handle duration type data. Third, to investigate whether these proposed benefits are in fact delivered for marketing durations data, we estimate and validate both conventional and hazard rate models for household interpurchase times of saltine crackers. Our findings indicate the superiority of proportional hazard regression methods vis-à-vis common procedures in terms of stability and face validity of the estimates and in predictive accuracy.

Henke, A.L. and Maher, T.P., "Artificial Intelligence Techniques for Parts Obsolescence Prediction. Phase 1," Stottler Henke Associates, Inc., 1995.

The primary objective of our Phase I effort was to explore the feasibility of a Navy-wide DMSMS prediction system and develop improved methods of obsolescence prediction. In pursuit of this goal we investigated the DMSMS process at various Navy sites and identified and evaluated tools or processes currently in use. We decided to focus our efforts on micro circuit obsolescence prediction, because our study revealed that other types of parts are not nearly as significant a DMSMS problem. Furthermore, we concentrated on automating the largely manual obsolescence prediction currently performed by the MOM program. We used the artificial intelligence techniques of knowledge engineering, case-based reasoning, knowledge base development and object oriented programming to devise a solution to the obsolescence prediction problem. We also developed a preliminary design and functional description for a pro active Navy-wide DMSMS intelligent system which will be developed in a Phase II effort. We implemented both these solutions in a prototype improve their feasibility beyond a doubt. There is great potential for use of the Phase II system throughout the Navy, other branches of the military and in the commercial sector.

Herald, T., Verma, D., Lubert, C., and Cloutier, R., "An Obsolescence Management Framework for System Baseline Evolution-Perspectives Through the System Life Cycle," *Systems Engineering,* Vol. 12, pp. 1–20.

> In military, civil, and commercial systems there exists a need to affordably manage the operational effectiveness of the system of interest through the acquisition and operational stages of its life cycle. Once a system design is baselined and instantiated, then the challenge during development, production, and utilization life cycle stages is to maintain the currency of the physical system baseline to facilitate affordable system support. In essence, the system must adapt to potentially frequent asynchronous obsolescence of its constituent elements, requirements growth (driven by the operational environmental and external constraints such as funding, schedule or risk), and external environment changes. This paper specifically addresses the impact that system element obsolescence has on a system baseline during the various system life cycle phases and provides a framework for affordable system evolution. 2008 Wiley Periodicals, Inc.

Herald, T.E., "An Obsolescence Forecasting Methodology for Strategic System Sustainment Decision Making," Stevens Institute of Technology, Hoboken, NJ, 2007.

> The effectiveness of commercial, civil, and military systems must be affordably managed through their life cycles. Once the design baseline of such systems is defined and instantiated, the challenge during the development, production, and utilization life cycle phases is to affordably sustain the physical system baseline. This baseline is continuously evolving in response to external influences such as; frequent and asynchronous obsolescence of system elements, changing requirements (mission, schedule and funding related), and changing policy and regulations (i.e., security, export laws and safety standards).
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> This research specifically addresses the impact of asynchronous obsolescence of system elements on system effectiveness and cost during its operational and support life cycle phases. An overview of a system obsolescence forecasting model, se-Fly Fisher, is provided. This model uses technology curves of individual system elements (parts) for an understanding of obsolescence at the lowest level. The model analyzes this system element data and formulates three key strategic system outputs. Output 1 forecasts how often a system baseline should synchronously change to minimize system ownership costs through support (i.e., the change strategy). Output 2 uses the forecast strategy to plan system element changes (i.e., the system change plan). The output strategy and system element plans provide program management and engineering with planning insight for technical change management, resource identification, and assessment of scope impacts of the recommended changes. Output 3 addresses the performance potential that is gained from each proposed system element baseline change. This performance potential becomes part of the systems engineering trade space for potential system operational gains.
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> The current literature provides a range of obsolescence forecasting approaches for electronic components (i.e., chips, resistors, capacitors), and optimization of change

recommendations for the next expected obsolete part. This research model extends existing obsolescence forecasting in three dimensions. Dimension 1 extends the time span from the next-forecasted part obsolescence date to a complete support life cycle timeline perspective. Dimension 2 extends the forecast scope from electronic components to all electronics, electrical, mechanical and software system elements. Dimension 3 extends obsolescence change analysis from a single product-view to a system-view.

Hitt, E.F., "Avionics Cost of Ownership," *Digital Avionics Systems Conference, 15th DASC, AIAA/IEEE*, 1996, pp. 27–31.

The cost of ownership of avionics includes not only the development and acquisition cost, but also the yearly operating and support (O&S) (maintenance) cost of hardware, software, and support equipment. This paper presents the avionics cost of ownership methodology developed for USAF, its data sources, and business metrics computed for USAF decision makers as we move toward operating avionics as a business. The business model is used to determine which existing avionics are candidates for replacement with new technology and to prioritize the replacements. These avionics are often used on multiple aircraft types which necessitates analysis of the causes of the high cost of ownership on each type. Databases are used to document the functions, and constraints of the item being analyzed. These constraints include physical, environmental, electrical, and data interfaces. Databases containing alternatives are evaluated against standard mission scenarios for aircraft utilizing these high cost avionics to determine their impact on performance, O&S costs, and mission effectiveness. The results of the foregoing analyses steps are then used in life cycle cost analyses which consider different retrofit scenarios for each alternative for each aircraft type against the avionics being analyzed for replacement. The alternatives are prioritized based on the foregoing and a risk analysis performed considering technical, schedule, and cost growth risks.

Hitt, E.F. and Schmidt, J., "Technology Obsolescence (TO) Impact on Future Costs," *Proceedings of the AIAA/IEEE/SAE Digital Avionics Systems Conference, 17th DASC,* Bellevue, Washington, Vol. 1, October 31–November 7, 1998, pp. A33-31–A33-37.

A method of assessing technology obsolescence and the tools to determine the impact of technology obsolescence and new technology on business management are addressed. Many complex systems, particularly major aircraft and military weapon systems, often have life spans of many of the supporting components. As customers use of technology accelerates, new products are introduced at ever increasing frequencies. Understanding and dealing with these market forces will separate the very successful program managers from those who constantly work only today's problem.

Hoener, S.J. and Wilkins, D.F., "AMLCD Obsolescence and the Impact on Military Aircraft Programs," *Cockpit Displays VII: Displays for Defense Applications*, Orlando, Florida, Society of Photo-Optical Instrumentation Engineers, Vol. 4022, 2000, pp. 2–7.

When current domestic Active Matrix Liquid Crystal Display (AMLCD) sources became unavailable, prime contractors for military aircraft faced a severe problem with the

sudden obsolescence of these assemblies. AMLCDs had become central to crew station design, but the only qualified North American source had failed. The problem was further complicated as several programs were beginning production, and supplies of existing, useable AMLCDs were rapidly being depleted. Solutions to the availability of AMLCDs had to be found quickly. The F/A-18E/F program faced a unique situation in that three different displays, manufactured by two different suppliers, were affected by the loss of the AMLCD source. Both of the suppliers, for various technical and programmatic reasons, chose different approaches to the crisis. The advantages and disadvantages of each approach are examined in this paper. In addition, Boeing has formed a Displays Process Action Team (DPAT) to examine whether or not it is possible to use common displays across the Company's diverse product lines.

Honeywell, "Aerospace Obsolescence Management Procedure," 2007.

No abstract available.

Hong, J.S., H.-Y. Koo, Lee, C.-S., and Ahn, J., "Forecasting Service Parts Demand for a Discontinued Product," *IIE Transactions (Institute of Industrial Engineers,* Vol. 40, No. 7, 2008, pp. 640–649.

Stochastic demand forecasting methods for service parts of a discontinued product are proposed. The identified four major factors are the number of product sales, the discard rate of the product, the failure rate of the service part, and the replacement probability of the failed part. During a given period, typically a year, the number of failed service parts is estimated using the first three factors, and then the demand for those service parts is obtained with the use of the last factor. A stochastic model is derived to estimate the demand in a certain prediction interval, and the closed-form solutions in the case of a constant failure rate are provided. An approximate model is proposed to render actual computation possible when the part failure time is not distributed exponentially. Numerical data from the automotive industry are used to validate the model.

Howard, M.A., "Component Obsolescence, It's Not Just for Electronics Anymore," *DMSMS 2002 Conference*, 2002, pp. 1–10.

Fueled by constant and rapid technology changes, component obsolescence has long been a fact of life for users and managers of electronic components. Organizations like the Government and Industry Data Exchange Program (GIDEP) and the Defense Microelectronics Activity (DMEA) have developed over the years to help pull together and apply Government and commercial resources to solve obsolescence problems for electronic components. Although obsolescence is not a thing of the past for electronics, GIDEP, DMEA, and others have made significant strides toward creating viable, cost effective solutions for program managers with electronic obsolescence problems. For nonelectronic components, drastic shifts in technology are not as common. As a result, nonelectronic obsolescence problems have generally been slower to develop. While an electronic component may become obsolete in a matter of a few years or even months, nonelectronic components typically remain supportable for a few decades. Today,

however, large and complex aging systems in the military (such as aircraft, ships, and tanks) with tens of thousands of nonelectronic components have been in operational service for over 40 years. Many of these systems are projected to remain in service for another 40 years or more. Given these facts, system operators and managers are beginning to face significant obsolescence problems with nonelectronic components and will continue to face them in the future. This paper describes common signs and symptoms of nonelectronic obsolescence problems in military aviation and proposes an approach based on the author's experience that integrates both short term and long term solutions. Short term solutions recognize that there are immediate requirements for components that must be met to keep critical resources operational. Long term solutions are focused on eliminating the root cause of the obsolescence problem and solving the obsolescence problem for the life of the system. In addition to describing specific approaches to solving existing obsolescence problems, this paper describes two obsolescence management strategies that could be used by system managers to help predict and respond to obsolescence of nonelectronic components.

Hsieh, C.-T., "Endogenous Growth and Obsolescence," *Journal of Development Economics,* Vol. 66, No. 1, 2001, pp. 153–171.

This paper presents a model of intentional industrial innovation that features the endogenous obsolescence of existing capital goods as a result of the introduction of new capital goods of higher quality. In contrast to existing models of endogenous obsolescence, the introduction of new capital goods in this model does not immediately result in the displacement of older capital goods. Instead, many old capital goods remain in use, albeit less intensively than the newer machines. In addition, since the rate at which new capital goods become obsolete depends on expectations of the rate at which new higher quality capital goods are expected to be introduced in the future, this creates the possibility of multiple equilibria, one with high growth rates, in which capital goods quickly become obsolete and another with low growth rates, in which capital goods are used for a long time.

Huang, Z., Sandborn, P., Pecht, M., "Life Cycle Forecasting of ASICs," *Future Circuit International,* Vol. 7, 2001, pp. 101–107.

This paper presents an approach to forecast the life cycle stage and the years to obsolescence of ASICs. Forecasting is based on curve fitting past sales data of each ASIC type. We then show how attributes such as package style and voltage can modify the forecasts. In addition, the trends in the ASIC industry, by ASIC category, are discussed, and a roadmap is presented.

Hummel, J.W. and Jesse, R.R., "Spreadsheet Heuristic Approach for the Stocking and Retention of Slow-Moving, Obsolescent Items," *Computers and Industrial Engineering,* Vol. 18, 1990, pp. 163–173.

This paper describes a practical approach for the stock control of slow-moving items subject to obsolescence. A heuristic procedure is developed for determining stocking

quantities and inventory retention times. A spreadsheet is presented for implementation of the heuristic, with an example demonstrating its use. The advantage of the proposed approach is its simplicity in comparison with dynamic programming optimization. As illustrated by a set of examples, the proposed approach can provide near-optimal cost performance.

Hunt, K. and Haug, S., "Challenges of Component Obsolescence," *Royal Aeronautical Society (RAeS) Conference,* London, England, 2001.

Although component obsolescence has always been a fact of life, it previously occurred so infrequently that it didn't have to be planned as a specific activity and was probably handled on an ad hoc basis by most equipment suppliers. Unfortunately, the present situation is quite different with many semiconductor components having a life cycle of less than 5 years. This is now causing significant challenges for commercial aircraft equipment which first entered service more than 10 years ago, as many key parts are now being threatened with obsolescence due to a shift in emphasis within the electronics sector towards very high volume, highly integrated low cost components. Equipment currently being procured for use within the aerospace sector must therefore be designed in a manner which minimises the cost and impact of changes due to obsolescence whilst complying with the various international guidance being generated on these issues. Meeting the stringent requirements for a fully documented, supportable, modular design which can be cost effectively manufactured to meet the reliability and performance requirements with commercial components may favour the higher volume avionic equipment suppliers.

IEC, "Obsolescence Management - Application Guide," 2006.

No abstract available.

IEC, "Obsolescence Management - Application Guide - Edition 1.0," 2007.

This International Standard gives guidance for establishing a framework for obsolescence management and for planning a cost-effective obsolescence management process that is applicable through all phases of the product life cycle, the term 'product' includes: capital equipment; infrastructure; consumer durables; consumables; software products. Obsolescence management covers the following areas: a) design of new products; b) new technology insertion into existing products; c) support and maintenance of legacy products.

IEC, "Process Management for Avionics – Management Plan – Part 1: Preparation and Maintenance of an Electronic Components Management Plan (draft)," Geneva, Switzerland, 2011.

No abstract available.

IHS, "Electronics Database Life Cycle Information," 2006.

> This paper presents an overview of the IHS Life Cycle Content, its relationship with ED and an insight into the factors that are considered for generating Life Cycle Prediction data and the processes.

International Atomic Energy Agency, "Management of Life Cycle and Ageing at Nuclear Power Plants: Improved I&C Maintenance," *IAEA Technical Working Group on Nuclear Power Plant Control and Instrumentation,* Vienna, Austria, 2004.

> No abstract available.

International Atomic Energy Agency, "Ageing Management for Nuclear Power Plants: Safety Guide," *IAEA,* Vienna, Austria, 2009, pp. 65.

> No abstract available.

Jackson, M., Sandborn, P., Pecht, M., Hemens-Davis, C., and Audette, P., "A Risk-Informed Methodology for Parts Selection and Management," *Quality and Reliability Engineering International,* Vol. 15, No. 4, 1999, pp. 261–271.

> This paper presents an overview of a risk-informed methodology for electronic parts selection and management, which addresses both application-independent processes (part availability, part cost, part manufacturer quality, distributor quality and part family quality and integrity) and application-specific processes (determination of the local environment, part performance, part reliability, assembly and life cycle obsolescence). Risk management activities, which follow the parts selection activities, are also addressed.

Jain, K. and Silver, E.A., "Lot Sizing for a Product Subject to Obsolescence or Perishability," *European Journal of Operational Research,* Vol. 75, pp. 287–295.

> This paper presents a stochastic dynamic programming model for determining the optimal ordering policy for a perishable or potentially obsolete product so as to satisfy known time-varying demand over a specified planning horizon. We have considered random life time perishability where, at the end of each discrete period, the total remaining inventory either becomes worthless or remains usable for at least the next period. Two approximate solution methods are shown. The optimal and heuristic methods are compared on a large set of test problems and their performance as a function of various problem parameters is analyzed.

Jakovljevic, M., "Obsolescence Management Outlook With Time-Triggered Architecture (TTA)," *Digital Avionics Systems Conference, 26th DASC, IEEE/AIAA,* 2007, pp. 2.B.4-1.

> No abstract available.

Jakovljevic, M., Fulcher, L., and Benson, D., "Expectations and Vision for True Modular Distributed Engine Control - Beyond 1st Project," *44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit*, Hartford, Connecticut, 2008.

> Distribution of functions in engine control systems is closely related to the control strategy and control platform capabilities based on open and COTS technologies. Particularly in a distributed environment, control system platforms can play the role of key differentiator in terms of system and software architecture development approach, system integration, engine maintenance, obsolescence management, upgradeability, system reuse and other lifecycle costs. This means that the distributed control platform helps reduce the time to develop, integrate, modify and change a control system and thus engine capabilities. This paper analyzes how time-triggered systems and architectures enable the design of modular and distributed engine controls.

JEDEC, "Management of Component Obsolescence by Government Contractors," 1996 (Rescinded October 2002).

> This standard outlines the practices to be used by government contractors and government buying activity regarding component obsolescence issues. Due to the dynamics of the commercial electronic component industry, it is essential that government contractors manage the electronic content of their designs to ensure they maintain the supportability and affordability of these systems. By managing obsolescence issues, an overall decrease in system lifecycle cost should be realized by the contractor and its customers. The purpose of this standard is to provide fundamental guidelines for component selection for managing this issue.

JEDEC, "Product Discontinuance," 2005.

> This standard was developed by suppliers and users of electronic components to provide a standard set of requirements for timely customer notification of planned product discontinuance, which will assist customers in managing end-of-life supply, or to transition on-going requirements to substitute products.

JEDEC, "Guidelines for User Notification of Product/Process Changes by Semiconductor Suppliers," 2006.

> This standard establishes procedures to notify customers of semiconductor product and process changes. Requirements include: documentation; procedures for classification, notification and customer response; content; and records. Documentation of a suppliers change notification system should set clear and understandable expectations for both the originators of the change and their end customers.

Jibb, D.J. and Walker, J.B., "Avionics Architecture Standards as an Approach to Obsolescence Management," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, 2000.

> Obsolescence management techniques can be categorized as either production engineering based techniques that attempt to control an existing situation or design based approaches that attempt to minimize the initial problem. This paper addresses system architecture design as an approach to obsolescence management. The work of the ASAAC program in developing open architecture standards designed to exhibit a high level of obsolescence robustness is described. Other issues that relate to the financing and organization of obsolescence management are also discussed.

Ji-wen, S., Li-feng, X., Shi-chang, D., and Er-shun, P., "Tool Maintenance Optimization for Multi-Station Machining Systems With Economic Consideration of Quality Loss and Obsolescence," *Robotics and Computer-Integrated Manufacturing,* Vol. 26, 2010, pp. 145–155.

> Tools used in a machining process are vulnerable to frequent wear-outs and failures during their useful life. Maintenance is thus considered essential under such conditions. Additionally, it is widely recognized that the maintenance of manufacturing equipments and the quality of manufactured product are highly interrelated. However, few detailed study has been found in the literature dealing with the effects of maintenance policies on the operational performance of such a system, especially the long-term average cost. The need for a method to determine the optimal tool maintenance policy has become increasingly important. Since the multiple tools in a multi-station machining system generally have significant interactive impacts on the product quality loss, the optimal multi-component maintenance models for several policies are investigated to address the interdependence among these tools. Three distinctive multi-component maintenance policies, i.e., age replacement, block replacement, and block replacement with minimal repair, are identified and analyzed. The proposed approach focuses on these maintenance policies with consideration of both component catastrophic failures, and the interdependence of component degradations on the product quality loss as well as the obsolescence cost. The effects of various maintenance policies on the system performance are simulated, and they are used to determine the best policy for a given system. An illustrative example is used to demonstrate effectiveness and applicability of the proposed approach. The results presented a comparative analysis of specified maintenance policies with respect to the total maintenance cost with consideration of the product quality loss and the obsolescence cost. 2009 Elsevier Ltd. All rights reserved.

Joglekar, P. and Lee, P., "An Exact Formulation of Inventory Costs and Optimal Lot Size in Face of Sudden Obsolescence," *Operations Research Letters,* Vol. 14, No. 5, 1993, pp. 283–290.

> Recently, approximate formulas for determining the relevant total costs and the optimal lot size in face of sudden obsolescence were proposed. In this paper, we provide an exact formulation of the relevant costs which, when minimized, give the true optimal lot size.

The estimation errors of the approximate model are significant in some situations, and the use of our exact model is recommended.

Johnson, D.L., "Rotorcraft Open Systems Avionics (ROSA)," *Digital Avionics Systems Conference, 19th DASC*, Vol. 1, 2000, pp. 4E2/1–4E2/7.

Commercial standards adopted from the volume driven electronics markets provide improved processing capacities over those widely used military standards and at reduced cost. Desired future capabilities and advanced functions. such as RPA, require the throughput, bandwidth, and memory provided by commercial processors and data buses. The primary issues needing resolution prior to implementation are related to operations in military rotorcraft environment, reliability, redundancy management, and fault and battle damage tolerance. In addition, some required network components presently do not exist in the preferred form factors. The ROSA project is providing effective laboratory demonstrations of COTS products and open systems specifications and standards to rotorcraft avionics. Preliminary cost estimates forecast large potential savings and create a compelling business case for follow on research and transition to production systems. In addition, the project is developing a rotorcraft technical architecture with the participation of many industry partners and will promote the resulting documentation as background materials for the JTA-A

Josias, C., Terpenny, J.P., and McLean, K.J., "Component Obsolescence Risk Assessment," *IIE Annual Conference and Exhibition 2004*, Houston, Texas, 2004,pp. 2373–2378.

Custom low volume products and systems, such as those utilized by military and avionics applications; often make use of commercial high-tech components. In the past decade, technology has advanced very rapidly causing such components to have a shortened life span. Newer and better technologies are being introduced frequently, rendering components obsolete. Yet, custom low volume products and systems such as ships, submarines and aircraft can be in use for decades. Being proactive about obsolescence is critical to maintaining fully capable products and systems and satisfied customers. This paper presents an obsolescence risk measurement tool that is being developed to better predict and manage component obsolescence. Critical variables in this assessment that are precursors to a component becoming obsolete are described. A multiple regression model developed for forecasting obsolescence is presented. An industrial case study with Kollmorgen, an international manufacturer of motion control systems, is also presented.

Jung, K.M., Park, M., and Park, D.H., "System Maintenance Cost Dependent on Life Cycle Under Renewing Warranty Policy." *Reliability Engineering & System Safety,* Vol. 95, No. 7, 2010, pp. 816–821.

A number of optimal maintenance policies have been proposed and studied based on several types of warranty policies. As the criteria for optimality, the expected cost rate per unit time during the life cycle of the system is quite often used by many authors. However, the expected cost rate may depend on the length of life cycle and so the definition of life cycle plays a significant role in optimizing the maintenance policy. This

paper considers a system maintenance policy during the post-warranty period under the renewing warranty policy and the life cycle is defined from the user's perspective. The life cycle starts with the installment of a new system and ends when the system is replaced by a new one at the expense of the user. In many renewing warranty models, the life cycle is defined as the lifelength of the new system installed initially, which is quite different from our definition. The expected cost rate per unit time is evaluated based on the life cycle newly defined and is compared with the existing results.

Kaminker, A., Lavi, Y., et al., "NS16000: Non-Obsolescence by Architectural Features and High Level Language Support," *Electro/80 Conference Record*, pp. 19–12.

The NS16000 microprocessor family, presented by National Semiconductor Co. (Santa Clara, CA), is a totally new generation of devices, using the advanced XMOS technology. It consists of a selection of CPU chips and a set of peripherals and slave processors. The NS16000 architectural features allow easy future growth path, so that the introduction of next generation processors will not make present-day designs obsolete.

Karsai, G., Massacci, F., Osterweil, L., and Schieferdecker, I., "Evolving Embedded Systems," *Computer,* Vol. 43, No. 5, 2010, 34–40.

Embedded systems pose special challenges to system evolution: they're embedded in a changing environment, often interacting with evolving processes of human organizations, and thus must be verified because of their critical nature. Complicating the situation, the analyses and testing regimens used to verify them must evolve as well. Both software engineering research and industrial practice need to improve to address these problems. While admittedly underemphasized in software engineering education, system evolution is crucial, and the challenges discussed here will be addressed by improving on the initial results presented.

Karyagina, M., Wong, W., and Vlacic, Ljubica, "Life Cycle Cost Modelling Using Marked Point Processes," *Reliability Engineering & System Safety,* Vol. 59, No. 3, 1998, pp. 291–298.

This article presents a life cycle cost (LCC) model of a repairable system. The model is based on a marked point process and allows for non-constant failure intensity as well as stochastic nature of costs associated with system's failures. The model is applied to failure data from computer numerically controlled (CNC) machines.

Kennedy, C.R., "Software Replacement of Test Module Adapters for Depot Instrumentation Due to Obsolescence," *IEEE Aerospace and Electronic Systems Magazine*, Vol. 19, 2004, pp. 25–30.

Depot-level automatic test equipment has been used over the years by various facets of both the government and commercial industry. Over time, the instrumentation used in the depot will need to be repaired or replaced and, oftentimes, the older instruments are no longer serviceable or manufactured. This paper discusses how to replace the obsolete instrument and its associated hardware. Test module adapter with a software module and driver that allows compatibility between the original test executive and the modern

instrument without re-hosting existing test program sets. Systems & Electronics, Inc. has implemented this procedure for a digitizer and precision DC power supply on a depot that utilizes the IEEE-488 general purpose interface bus (GPIB) for communication between the control computer and instrumentation.

Kennedy, F. and Kulvinskas, A., "Coping with Component Obsolescence in the Manufacture of a Legacy Military Product," *49th Annual Fuze Conference: Safety and Reliability Through Technology*, Seattle, Washington, 2005.

No abstract available.

Khalil, S.E.D.A. and Wahba, A.M., "Usage of Run-Time Re-Configuration for System Porting in Automotive Applications," *4th International Design and Test Workshop (IDT),* 2009 pp. 1–6.

The automotive industry is now facing many problems and challenges that put many restrictions on car design, towards the minimization of the car cost. Most of the problems arise from the continuously increasing need to provide more advanced features in the modern cars. This lead to a dramatically increase in the percentage electronics inside the car, which lead to increasing the number of Electronic Control Unit in the Cars. This will lead to power consumption problems, wiring problems, code complexity problems, and the most important, the obsolescence problems. In this paper, we will use the runtime partial reconfiguration feature of the FPGA to minimize the costs associated with migration and porting of the software due to microcontroller obsolescence.

Kidd, M. and Sullivan, M., "Reactive Obsolescence Management Measurements, a Better Approach," *Naval Engineers Journal,* Vol. 122, 2010, pp. 75–80.

Current programmatic metrics for obsolescence reporting do not provide actionable information to logistics, engineering, or program managers. At best, they provide feedback on the volume of cases being worked, and provide a rough order of magnitude on cost avoidance, but with no indication of the criticality of cases, or the time frame in which avoidances will be realized. This paper introduces the Reactive Obsolescence Health Indicator, a new way to analyze reactive programs, ensuring that resources are being spent wisely. 2010, American Society of Naval Engineers.

Kiley, G.T., "The Effects of Aging on the Costs of Operating and Maintaining Military Equipment," Congressional Budget Office, 2001.

No abstract available.

Komoto, H., Tomiyama, T., Silvester, S., and Brezet, H., "Analyzing Supply Chain Robustness for OEMS From a Life-Cycle Perspective Using Life-Cycle Simulation," *International Journal of Production Economics*, Vol. 134, No. 2, 2009, pp. 447–457.

Long-term relationships between original equipment manufacturers (OEMs) and stakeholders in their supply chain and end-of-life process can be designed, while

considering uncertainty in future environmental legislation changes. This study proposes a method to analyze the capability of OEMs to reconfigure their supply chain and end-of-life operations to achieve performance targets, which are defined in terms of environmental impacts and life-cycle costs. Using life-cycle simulation (LCS), the physical deterioration and the functional obsolescence of individual products are considered as stochastic elements in the analysis. The analyzed reconfiguration capability provides the OEM with robustness against uncertainty from a life-cycle perspective.

Krum, A., "Chip Obsolescence Strategies for MCMs," *2000 HD International Conference on High-Density Interconnect and Systems Packaging,* Reston, Virginia, April 25–28, 2000, pp. 563–568.

The military, in conjunction with their contractors, are facing a major problem: their hardware life cycle is increasing while component life cycle is decreasing. In the face of declining budgets, the military must maintain their hardware for up to 30 years. This is becoming increasingly difficult to accomplish when the average component life cycle has gone from over 20 years to less than five. In the past, the military electronics market used to drive semiconductor device development. Now the military accounts for only 1% of the entire semiconductor market and has very little influence in product direction, pricing and life cycle. The military and industry have come up with tools to counteract this diminishing resources problem. Most available tools in industry and military for combating obsolescence deal with individually packaged chips. MCM manufacturers face the same problems as circuit card manufacturers plus additional ones of die size and pad locations. This paper addresses strategies for dealing with obsolete chip components in military applications. The MCM manufacturer can be proactive or reactive in fighting chip obsolescence. The proactive techniques start with the initial electrical and physical design of the MCM and continue until the system is removed from service. The reactive techniques come into play when the MCM manufacturer is notified that chips are becoming, or have become, unavailable. Some of the reactive techniques include lifetime buys, part substitution, physical redesign, use of interposers with alternate parts, electrical redesign and emulation.

Krum, A., "Chip Obsolescence Strategies for MCMs." *HD International Conference on High-Density Interconnect and Systems Packaging*," Denver, Colorado, Vol. 4217, 2002, pp. 563–568.

Minimizing the effects of obsolescence in MCMs requires the MCM manufacturer develop a strategy starting in the design stage to maximize the life cycle of each of the components while controlling costs. This strategy includes selecting components in their early stages of life, identifying alternate sources and providing flexibility in the substrate layout. While in production, the MCM manufacturer needs to stay abreast of the semiconductor market to learn of possible obsolescence while viable, low risk options are available.

Kurawarwala, A.A. and Matsuo, H., "Forecasting and Inventory Management of Short Life-Cycle Products," *Operations Research,* Vol. 44, No. 1, 1996, pp. 131–150.

> In this paper, we provide an integrated framework for forecasting and inventory management of short life-cycle products. The literature on forecasting and inventory management does not adequately address issues relating to short life-cycle products. We first propose a growth model that can be used to obtain accurate monthly forecasts for the entire life-cycle of the product. The model avoids limiting data requirements of traditional methods. Instead, it extracts relevant information from past product histories and utilizes the information on total life-cycle sales and the peak sales timing. Using disguised demand data from a personal computer (PC) manufacturer, we validate the model. Next, we model the inventory management problem for the short life-cycle environment. The uncertainty in demand is modeled through the uncertainty in the realized values of the parameters of the forecasting model. The high cost of terminal inventory, shortages, and rapidly changing procurement costs are all included in the model. Extensions to the basic model are also developed. Using optimal control theory, we derive a solution that provides valuable information on procurement cutoff time and terminal service levels. A detailed example explains the characteristics of the policy and its relevance in decision making. Many of the issues covered in the models were brought to our attention while implementing a forecasting model at a PC manufacturer. The benchmark monthly forecasts and the associated inventory levels provide information that can be very helpful in planning and controlling marketing, sales, and production.

Kurawarwala, A.A. and Matsuo, H., "Product Growth Models for Medium-Term Forecasting of Short Life-Cycle Products," *Technological Forecasting and Social Change,* Vol. 57, No. 3, 1998, pp. 169–196.

> Short product life cycles are becoming increasingly common in many industries. Traditional approaches to medium-term forecasting are not designed for the type of information available (or the lack thereof) in the short life-cycle environment. A typical demand curve for these products consists of rapid growth, maturity, and decline phases coupled with seasonal variation. With reference to product demand curves of a personal computer (PC) manufacturer, we suggest the use of information on total life-cycle sales and the peak sales timing to obtain initial monthly forecast in the absence of a sales history. Three growth models are presented in which such information can be utilized to estimate the parameters. We also outline procedures that use demand history of prior products to estimate the seasonal variation in demand. Using data on PC products, we empirically validate the models and compare their fit and forecast performance with ARIMA models. We show that the accuracy of the forecast made multiple periods ahead using two of the three models investigated is comparable to that made one period ahead using ARIMA models. Empirical observations and issues relating to the implementation of the models at a PC manufacturer are also discussed.

Kwiat, K.A. and Manno, P.F., "Avoiding Microelectronics Obsolescence: Forewarned is Forearmed," *Southcon/87 Conf Rec.,* Atlanta, Georgia, Vol. 7, 1986, pp. 1. 5p.

> Problems are discussed that arise when equipment/systems reach the upper end of and even beyond their intended useful lifetime and replacement parts are no longer available. Rapid advances in the state-of-the-art (SOTA), as well as economic considerations, result in parts obsolescence. Various approaches to the problems are presented and some solutions are suggested for the military equipment parts.

Land, J.E., "HUMS-the Benefits-Past, Present and Future," *Aerospace Conference 2001*, Vol. 6, 2001, pp. 6.3083–3086.3094.

> This paper presents a comprehensive model of how military and commercial operators achieve benefits in Health and Usage Monitoring Systems (HUMS) equipped helicopters. The model uncovers the substantial set of the potential benefits and presents a framework that each operator can use as a tool to analyze particular benefits that are tuned to the operating environment for which HUMS is being used or being considered. The model presents real-life cases to show the benefits that can be achieved from operational HUMS systems and actual operational data and analysis. The paper examines HUMS as it affects potential roles and missions of helicopters, including commercial and military. Consideration is given to such issues as fleet readiness, management of spares assets, cost of M&O staff, and effects of aircraft downtime. The model includes all sources of costs for the HUMS, including the costs of equipment, installation costs, downtimes for installation, cost of support of the HUMS, etc. The model also looks into the perceived future operational environment, where the operator and the aircraft manufacturer are integrated into a real-time team to get the best performance from the deployed fleet. A major emphasis of the paper is the use of practical, real-life experience as a feedback into the HUMS system. The system includes equipment, operating procedures and personnel, integrated into a cohesive force.

Lareau, N.W., "New Procurement Strategy for Technology Insertion," *Proceedings of the IEEE 1996 National Aerospace and Electronics Conference, NAECON 1996*, Vol. 2, 1996, pp. 788–791.

> Even in times of increased defense spending, defense systems have been required to operate beyond their originally estimated lifetimes. Periodic technology insertion helps to remedy parts and performance obsolescence by keeping a fielded system more in tune with commercial designs. The benefits of keeping a design close to the commercial marketplace are many, but the primary results are reduced parts costs and reduced design labor costs. Unfortunately, a recurring problem with technology insertion efforts is that the government does not own the data rights to the original design, which makes form, fit, and functional compatibility requirements difficult to fulfill by any, but the original supplier of the system. If government ownership is maintained by using an independent design agent, lower costs are possible, since the resultant system is not tied to a single manufacturing source. With governmental ownership of the design, the government can shop for low cost production. A downside to governmental ownership of the design exists

if selecting a production source and first-article qualification lengthens the procurement cycle. These delays build obsolescence into the system. This problem can be eliminated by selecting a preferred manufacturing source early in the technology insertion design phase. Having the preferred source manufacture the first articles allows the reprocurement data package, the design, and the production line to be qualified simultaneously. This paper details the use of technology insertion, government ownership of independent design agent produced designs, and preferred manufacturing sources as the basis for a cohesive business plan to economically reduce parts and performance obsolescence problems in aging military systems. Actual results for the use of this plan in several recent technology insertion projects are discussed.

Lee, I.H. and Lee, J., "A Theory of Economic Obsolescence," *The Journal of Industrial Economics,* Vol. 46, No. 3, 1998, pp. 383–401.

A new generation of durable goods makes an old generation economically, even if not physically, obsolete. Economic obsolescence due to technological innovation requires the durable goods monopolist to implement price discrimination in two dimensions, both between consumers with different valuations and between consumers with different purchase histories. Equilibrium in the game between the durable goods monopolist and consumers depends on the extent of economic obsolescence and the relative sizes of the consumer groups. Underinvestment in innovation may take place. This contrasts with the standard literature on planned obsolescence where the durable goods monopolist overinvests in durability reducing technology.

Leonard, J.V., Wolf, J., and Stolinski, R., "Microcircuit Parts Obsolescence," *IEEE Region 5 Conference, 1988: 'Spanning the Peaks of Electrotechnology'*, Colorado Springs, Colorado, March 21–23, 1988, pp. 229-231.

Electronic microcircuit technology has evolved so rapidly that parts designed may become obsolete when production starts or during the production cycle. The authors explore methods to combat the parts obsolescence problem. They argue that the earlier in a program that obsolescence is treated, the greater the possibility that obsolescence will not become a problem.

Lillie, C.F. and Thompson, B.E., "Parametric Cost Estimation for Space Science Missions," *Advanced Optical and Mechanical Technologies in Telescopes and Instrumentation*, Marseille, France, Vol. 7018, 2008.

Cost estimation for space science missions is critically important in budgeting for successful missions. The process requires consideration of a number of parameters, where many of the values are only known to a limited accuracy. The results of cost estimation are not perfect, but must be calculated and compared with the estimates that the government uses for budgeting purposes. Uncertainties in the input parameters result from evolving requirements for missions that are typically the "first of a kind" with "state-of-the-art" instruments and new spacecraft and payload technologies that make it difficult to base estimates on the cost histories of previous missions. Even the cost of

heritage avionics is uncertain due to parts obsolescence and the resulting redesign work. Through experience and use of industry best practices developed in participation with the Aerospace Industries Association (AIA), Northrop Grumman has developed a parametric modeling approach that can provide a reasonably accurate cost range and most probable cost for future space missions. During the initial mission phases, the approach uses mass- and powerbased cost estimating relationships (CER)'s developed with historical data from previous missions. In later mission phases, when the mission requirements are better defined, these estimates are updated with vendor's bids and "bottoms- up", "grass-roots" material and labor cost estimates based on detailed schedules and assigned tasks. In this paper we describe how we develop our CER's for parametric cost estimation and how they can be applied to estimate the costs for future space science missions like those presented to the Astronomy Astrophysics Decadal Survey Study Committees.

Livingston, H., "GEB1: Diminishing Manufacturing Sources and Material Shortages (DMSMS) Management Practices," EIA Government Electronics and Information Technology Association, 2000.

No abstract available.

Liwen, L., Yunfei, S., and Yao, J., "An Extended Analysis of Consignment Stock Policy in the Presence of Product Obsolescence," *IEEE International Conference on Automation and Logistics*, Jinan, China, August 18–21, 2007, pp. 2193–2198.

Consignment stock (CS) is a special case of vendor managed inventory (VMI). The present literature on CS model has focused on the one-vendor, one-buyer system with or without the presence of product obsolescence. This paper extends the present works from two aspects. One is to change the system to one-vendor and two-buyer. The overlapped effects of the CS mechanism and different transportation policies are analyzed. Results demonstrate that system costs with different transportation policies depend on the demand, cost parameters and production policies. A numerical method to compare system costs is given. Another is to change the product lifetime from determinate to indeterminate. The several production and transportation policies under this setting are analyzed. Results show that high production flexibility and keeping outdated products in the vendor's site could lead to lower system costs.

Luecke, K.R., Ellis, B.J., Baxter, I., Akers, R.L., and Mehlich, M., "Software Code Base Conversions," *IEEE/AIAA Digital Avionics Systems Conference, 26th DASC,* Dallas, Texas, October 21–25, 2007, pp. 6.C.4-1–6.C.4-11.

Current and future military avionic systems require real-time embedded software based on the latest technological advances in software tools, capabilities, and languages. However, the development time and lifecycle of avionic systems is so long, that the tools, processes, methodologies, and languages used by the system developers are often obsolete by the time the systems need significant upgrades or replacement. Hence, software obsolescence is a major issue faced by many avionic systems. Previously, avionics programs have tackled software obsolescence using different approaches. These

approaches have included code conversions by hand, which are costly and time consuming, scripting tools/languages which have scalability problems, emulators which involve re-engineering of the peripheral code base and retention of the obsolete code engineering environment, and software wrappers which are not costly, but hinder future modifications to the legacy software that is accessed by the software wrappers. Each of these approaches has its own liabilities. For our research and development effort we chose to upgrade our legacy code base with a specially developed code refactoring transformer, the Boeing migration tool (BMT). Specially developed code transformers based on new technologies and more powerful computers are scalable, capable of converting almost the entire code base, allow for future development on the updated code base with the latest tools, processes, methodologies, and languages, and are less costly than updating code by hand. This paper details the inputs, the code transformer itself, the outputs, and how well the code transformer performed its task for updating a software code base. This work was performed for the Defense Advanced Research Projects Agency (DARPA) program composition for embedded systems (PCES) program. The resulting code base generated by the code transformer could be updated with the most recent tools, processes, and languages. DARPA's objective - was to find faster and easier software code base conversion processes that lead to new software code bases that were closer to the final product than previous mechanizations.

Luke, J., Bittorie, J.W., Cannon, W.J., and Haldeman, D.G., "A Commercial off-the-Shelf Based Replacement Strategy for Aging Avionics Computers," *Proceedings of the IEEE 1998 National Aerospace and Electronics Conference. NAECON 1998,* Dayton, Ohio, July 13–17, 1998, pp. 177–181.

With decreasing defense dollars available to purchase new military aircraft, the inventory of existing aircraft will have to last many more years than originally anticipated. As the avionics computers on these aging aircraft get older, they become more expensive to maintain due to parts obsolescence. In addition, expanding missions and changing requirements lead to growth in the embedded software which, in turn, requires additional processing and memory capacity. Both factors, parts obsolescence and new processing capacity, result in the need to replace the old computer hardware with newer, more capable microprocessor technology. New microprocessors, however, are not compatible with the older computer instruction set architectures. This generally requires the embedded software in these computers to be rewritten. A significant savings-estimated in the billions of dollars-could be achieved in these upgrades if the new computers could execute the old embedded code along with any new code to be added. This paper describes a commercial-off-the-shelf (COTS) based form, fit, function, and interface (F^3I) replacement strategy for legacy avionics computers that can reuse existing avionics code as is while providing a flexible framework for incremental upgrades and managed change. It is based on a real-time embedded software technology that executes legacy binary code on the latest generation COTS microprocessors. This technology, developed by TRW and being applied under the sponsorship of the Air Force Research Lab (AFRL), promises performance improvements of 5-10 times that of the legacy avionics computer that it replaces. It also promises a 4X decrease in cost and schedule over rewriting the code and provides a known good starting point for incremental upgrades of the embedded

flight software. Code revalidation cost and risk are minimized since the structure of the embedded code is not changed, allowing the replacement computer to be retested at the blackbox level using existing qualification tests.

Luke, J., Bittorie, J.W., Cannon, W.J., Haldeman, D.G., "Replacement strategy for aging avionics computers," *IEEE Aerospace and Electronic Systems Magazine,* Vol. 14, No. 3, March 1999, pp. 7–11.

> With decreasing defense dollars available to purchase new military aircraft, the inventory of existing aircraft will have to last many more years than originally anticipated. As the avionics computers on these aging aircraft get older, they become more expensive to maintain due to parts obsolescence. In addition, expanding missions and changing requirements lead to growth in the embedded software which, in turn, requires additional processing and memory capacity. Both factors, parts obsolescence and new processing capacity, result in the need to replace the old computer hardware with newer, more capable microprocessor technology. New microprocessors, however, are not compatible with the older computer instruction set architectures. This generally requires the embedded software in these computers to be rewritten. A significant savings-estimated in the billions of dollars-could be achieved in these upgrades if the new computers could execute the old embedded code along with any new code to be added. This paper describes a commercial-off-the-shelf (COTS)-based form, fit, function, and interface (F3I) replacement strategy for legacy avionics computers that can reuse existing avionics code "as is" while providing a flexible framework for incremental upgrades and managed change. It is based on a real-time embedded software technology that executes legacy binary code on the latest generation COTS microprocessors. This technology promises performance improvements of 5-10 times that of the legacy avionics computer that it replaces. It also promises a 4x decrease in cost and schedule over rewriting the code and provides a "known good" starting point for incremental upgrades of the embedded flight software. Code revalidation cost and risk are minimized since the structure of the embedded code is not changed, allowing the replacement computer to be retested at the "blackbox" level using existing qualification tests.

MacCormac, P., "Getting proactive in the fight against obsolescence," *Engineering Technology,* Vol. 6, 2003, pp. 28.

> Obsolescence is a critical factor that need to be addressed by all businesses and manufacturers. Two strategies can be implemented to tackle this problem. One is to be reactive, that is, solving the problem when it arises and implies that no specific provision has been made for obsolescence. Another approach is to become proactive, meaning, identify critical components and stringently monitor their inclusion in equipment for any event of obsolescence.

Madisetti, V., Jung, Y.K., Khan, M., Kim, J., and Finnessy, T., "On Upgrading Legacy Electronics Systems: Methodology, Enabling Technologies and Tools," *Proceedings of the VHDL International Users Forum Fall Workshop,* 2000, pp. 7–14.

> Defense and commercial electronics systems need upgrading for a number of reasons; obsolete parts, diminishing manufacturing sources (DMS), availability of newer technologies that are superior to older ones, requirements for newer functionality and form-fit-function replacements, in addition to the drive towards using commercial-off-the-shelf (COTS) technology. We propose a comprehensive methodology and a set of enabling technologies that facilitate the efficient recovery of legacy component and system functionality, tradeoff-based redesign and functional replacement, followed by synthesis and test of the upgraded system (consisting of hardware and software). Our VHDL-based methodology is currently being evaluated on several avionics programs under the auspices of the Air Force Electronics Parts Obsolescence Initiative (EPOI), and some recent results are presented.

Mahajan, V. and Muller, E., "Innovation Diffusion and New Product Growth Models in Marketing," *Journal of Marketing,* Vol. 43, No. 4, pp. 55–68.

> This paper assesses the state-of-the-ad of the diffusion models of new product acceptance. A number of issues related to the further development and validation of these models are discussed.

Mahajan, V., Muller, E., and Bass, F.M., "New Product Diffusion Models in Marketing: A Review and Directions for Research," *Journal of Marketing,* Vol. 54, No. 1, January 1990, pp. 1–26.

> Since the publication of the Bass model in 1969, research on the modeling of the diffusion of innovations has resulted in a body of literature consisting of several dozen articles, books, and assorted other publications. Attempts have been made to reexamine the structural and conceptual assumptions and estimation issues underlying the diffusion models of new product acceptance. The authors evaluate these developments for the past two decades. They conclude with a research agenda to make diffusion models theoretically more sound and practically more effective and realistic. [ABSTRACT FROM PUBLISHER]

Mahajan, V., Muller, E., and Bass, F.M., "Diffusion of New Products: Empirical Generalizations and Managerial Uses," *Marketing Science,* Vol. 14, No. 3, 1995, pp. G79–G88.

> This article discusses the empirical generalizations that stem from the diffusion model and it also discusses some of the managerial applications of the model. The model was developed by F.M. Bass, which represents a pattern or regularity that has been shown to repeat over many new products and services in many countries and over a variety circumstances. As a theory of communications, diffusion theory's main focus is on communications channels, which are the means by which information about an innovation is transmitted to or within the social system. These means consist of both the mass media and interpersonal communications. Members of a social system have different propensities for relying on mass media or interpersonal channels when seeking information about an innovation. Interpersonal communications, including nonverbal observations, are important influences in determining the speed and shape of the S-shaped pattern of the diffusion process in a social system. The model is designed to apply to initial purchase of the product and not to apply to replacement demand. Over time the replacement component of total demand will increase relative to the initial purchase component and if sales data, as opposed to adoption data, are used in fitting the model, care must be taken to restrict time periods to those in which the replacement demand is negligible.

Mahajan, V., E. Muller, and Srivastava, R.K., "Determination of Adopter Categories by Using Innovation Diffusion Models," *Journal of Marketing Research (JMR),* Vol 27, No. 1, February 1990, pp. 37–50.

> Using the analytical logic underlying the classical adopter categorization approach proposed by Rogers, the authors suggest that adopter categories for a product innovation can also be developed by using other well-established diffusion models such us the Bass model. With data on 11 consumer durable products, they compare adopter categories generated by the classical approach and the Bass diffusion model, respectively. An application examining the diffusion of personal computers is documented to illustrate the usefulness of the adopter categorization based on the Bass diffusion model in studying differences among adopter categories. [ABSTRACT FROM AUTHOR]

Mahajan, V. and Sharma, S., "Simple Algebraic Estimation Procedure for Innovation Diffusion Models of New Product Acceptance," *Technological Forecasting and Social Change,* Vol. 30, No. 4, 1986, 331–345.

A simple algebraic estimation procedure is developed to estimate the parameters of diffusion models of new product acceptance. The procedure required knowledge of the occurrence of the point of inflection (based on actual data, analogous products, or management judgments). It is conceptually easy to use and can be implemented by using a hand calculator. Since the procedure does not employ period-by-period time-series diffusion data, it is not expected to provide the best fit to the data as compared to the maximum likelihood and nonlinear least squares estimation procedures. However, the procedure can provide very reasonable estimates about the relative magnitudes of the parameter estimates. In that respect, the procedure can be used to generate good starting values for the maximum likelihood and nonlinear least squares estimation procedures. In the absence of data, using management judgments about the point of inflection, the procedure can be implemented in a decision-support system to develop conditional diffusion curves for a new product. Data from four diverse innovations are used to illustrate the procedure.

Mani, D.R., Drew, J. ,Betz, A., and Datta, P., "Statistics and Data Mining Techniques for Lifetime Value Modeling," *KDD '99; Proceedings of the Fifth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, 1999, pp. 94–103.

Customer lifetime value (LTV)-which is a measure of the profit generating potential, or value, of a customer-is increasingly being considered a touchstone for customer relationship management. The central challenge in predicting LTV is the production of estimated customer tenures with a given service supplier, based on information contained in company databases. Classical survival analysis techniques like proportional hazards regression focus on covariate effects frequently presumed to be linear, and examination of age-wise effects can be difficult. Further, segments of customers, whose lifetimes and covariate effects can vary widely, are not necessarily easy to detect. A new neural network model for hazard prediction is used to free proportional hazards-like models from their linearity and proportionality constraints, and clustering tools are applied to identify segments of customer hazard patterns. Using the proportional hazards and neural network models in tandem, we demonstrate how data mining tools can be apt complements of the classical statistical models, and show that their combined usage overcomes many of the shortcomings of each separate tool setresulting in a LTV tenure prediction model that is both accurate and understandable

Marijan, S. and Petrovic, I., "Platform Based Development of Embedded Systems for Traction and Power Engineering Applications - Experiences and Challenges," *5th IEEE International Conference on Industrial Informatics*, Vol. 1, 2007, pp. 371–376.

The paper deals with development of platform based, embedded, hard real-time systems for traction and power engineering applications. Such systems are intended to have lifecyle of more than 20 years. Several cases of successful projects based on two typical

platform architectures are presented. Both hardware and software platforms and components are described along with some topics that can help to identify advantages and disadvantages of such an attitude. Particular attention is given to the problem usually not taken into account, component obsolescence.

Marshall, M.M. and Lambert, K.R., "Insights Into Supporting Complex Systems Under Conditions of Obsolescence," *Portland International Conference on Management of Engineering & Technology, PICMET 2008,* 2008, pp. 1918–1923.

Maintaining and supporting complex systems within a developing world context has many challenges including dealing with systems that are being operated beyond their designed life or where obsolescence is a major concern. Current methodologies to develop an integrated logistics support system (ILSS) are based on assumptions that are not valid in all cases, and a more robust framework with grounded design rules is required. The approach followed in developing the grounded technological rules was by deconstructing the available ILSS and related literature six case studies into the a framework. After analysis of this qualitative work, a third phase was added on where a questionnaire was used to explore the key areas of concern. Some of the insights regarding obsolete and beyond life complex systems were found to be: the effect of obsolescence is significantly wider than the obsolescence and retirement element of the existing frameworks; obsolescence planning must be done on reliability data for the specific operating environment, it is essential to understand technological changes and scan continuously for the impact on system or component obsolescence and that a risk based approach is essential to develop a obsolescence plan as part of the ILSS.

Martin, G.E. and Wang, M.-C., "Estimation Technique for Non-Stationary Parameters With Application to Disposal of Inventories Subject to Obsolescence," *International Journal of Systems Science*, Vol. 21, 1990, 1855–1868.

In this paper we develop a parameter estimation procedure for a stochastic process when that process is non-stationary. Although the estimation procedure itself is very general, we derive the model for the particular case of a Poisson process with parameter (t) subject to exponential decay. We then illustrate the application of this particular model to a fundamental problem in the management of inventories subject to obsolescence, i.e., how to identify excess inventories in sufficient time to ensure that stocks are cleared before the end of the season.

Matthews, J. and Condra, L., "Dealing With Electronic Component Obsolescence in the Aerospace Industry," *Airlines International Electronics Meeting*, Paris, France, 1997.

No abstract available.

Matthews, J. and Condra, L., "Impact of Component Obsolescence on Commercial Aerospace," *Airlines International Electronics Meeting*, St. Petersburg, Russia, 1998.

No abstract available.

McComb, D., Robe, S., Hoare, S., and Crawford-Hines, S., "Dependency Analysis and Visualization as Tools to Prolong System Life," *26th Annual International Computer Software and Applications Conference, COMPSAC 2002*, 2002, pp. 463–465.

   This paper describes our experience using dependency analysis and visualization as a tool to identify intervention points for migrating applications to environments where they can live out their natural lives, less dependent of the vagaries of platform obsolescence. The first part of the paper describes our methodology and deliverables. The second part presents case studies on applying this approach to commercially installed applications.

McWilliams, A., "Electronic Chemicals and Materials: The Global Market," Wellesley, Massachusetts, 2013.

   No abstract available.

Meade, N. and Islam, T., "Technological Forecasting - Model Selection, Model Stability, And Combining Models," *Management Science,* Vol. 44, No. 8, 1998, 1115–1130.

   The paper identifies 29 models that the literature suggests are appropriate for technological forecasting. These models are divided into three classes according to the timing of the point of inflexion in the innovation or substitution process. Faced with a given data set and such a choice, the issue of model selection needs to be addressed. Evidence used to aid model selection is drawn from measures of model fit and model stability. An analysis of the forecasting performance of these models using simulated data sets shows that it is easier to identify a class of possible models rather than the `best' model. This leads to the combining of model forecasts. The performance of the combined forecasts appears promising with a tendency to outperform the individual component models.

Meixell, M.J. and Wu, S.D., "Scenario Analysis of Demand in a Technology Market Using Leading Indicators," *IEEE Transactions on Semiconductor Manufacturing,* Vol. 14, No. 1, 2001, pp. 65–75.

   This paper proposes an approach to analyzing demand scenarios in technology-driven markets where product demands are volatile, but follow a few identifiable lifecycle patterns. After examining a large amount of semiconductor data, we found that not only can products be clustered by lifecycle patterns, but in each cluster there exists a leading indicator product that provides advanced indication of changes in demand trends. Motivated by this finding, we propose a scenario analysis structure in the context of stochastic programming. Specifically, the demand model that results from this approach provides a mechanism for building a scenario tree for semiconductor demand. Using the Bass growth model and a Bayesian update structure, the approach streamlines scenario analysis by focusing on parametric changes of the demand growth model over time. The Bayesian structure allows expert judgment to be incorporated into scenario generation while the Bass growth model allows an efficient representation of time varying demands. Further, by adjusting a likelihood threshold, the method generates scenario trees of

different sizes and accuracy. This structure provides a practical scenario analysis method for manufacturing demand in a technology market. We demonstrate the applicability of this method using real semiconductor data

Mercier, S., "Optimal Replacement Policy for Obsolete Components With General Failure Rates," *Applied Stochastic Models in Business and Industry,* Vol. 24, 2008, pp. 221–235.

Identical components are considered, which become obsolete once new-type ones are available, more reliable and less energy consuming. We envision different possible replacement strategies for the old-type components by the new-type ones: either purely preventive, where all old-type components are replaced as soon as the new-type ones are available; either purely corrective, where the old-type ones are replaced by new-type ones only at failure; or a mixture of both strategies, where the old-type ones are first replaced at failure by new-type ones and next simultaneously preventively replaced after a fixed number of failed old-type components. To evaluate the respective value of each possible strategy, a cost function is considered, which represents the mean total cost on some finite time interval [0, t]. This function takes into account replacement costs, with economical dependence between simultaneous replacements, and also some energy consumption (and/or production) cost, with a constant rate per unit time. A full analytical expression is provided for the cost function induced by each possible replacement strategy. The optimal strategy is derived in long-time run. Numerical experiments conclude the paper. Copyright 2008 John Wiley Sons, Ltd.

Mercier, S., "Optimal Replacement Policy for Components With General Failure Rates Submitted to Obsolescence," *Joint ESREL (European Safety and Reliability) and SRA-Europe (Society for Risk Analysis Europe) Conference*, Valencia, Spain, Vol. 1, 2009, pp. 603–609.

Identical components are considered, which become obsolete once new-type ones are available, more reliable and less energy consuming. We envision different possible replacement strategies for the old-type components by the new-type ones: purely preventive, purely corrective and different mixtures of both types of strategies. To evaluate the respective value of each possible strategy, a cost function is considered, which takes into account replacement costs, with economical dependence between simultaneous replacements, and energy consumption (and/or production) cost, with a constant rate per unit time. A full analytical expression is provided for the cost function induced by each possible replacement strategy. The optimal strategy is derived in long-time run. Numerical experiments close the paper. Taylor Francis Group, London. 2009 Taylor Francis Group.

Mercier, S. and Labeau, P.E., "Optimal Replacement Policy for a Series System With Obsolescence," *Applied Stochastic Models in Business and Industry*, Vol 20, 2004, pp. 73–91.

Most maintenance policies assume that failed or used components are replaced with identical units. Actually, such a hypothesis neglects the possible obsolescence of the components. When a new, more reliable and less consuming technology becomes available, a decision has to be made as for the replacement strategy to be used: old-type

components can all be immediately replaced, or new-type units can be introduced progressively, each time a corrective action is undertaken. Partly corrective, partly preventive policies can also be envisioned. This work tackles this issue in the case of a series system made of n identical and independent components with a constant failure rate. It provides, under given modelling assumptions, the fully analytical expression of the mean total cost induced by each possible strategy, as well as the optimal replacement policy, as a function of the problem parameters. This is performed by accounting for different costs for preventive or corrective replacements, with some economical dependence between replacements, different energy consumption rates for old-type and new-type components as well as a discount rate. Copyright 2004 John Wiley Sons, Ltd.

Merola, L., "The COTS Software Obsolescence Threat," *Fifth International Conference on Commercial-off-the-Shelf (COTS)-Based Software Systems*, Orlando, Florida, 2006, pp. 127–133.

Software is the primary focus of integration efforts for development of Open Architected, scalable, adaptable solutions in today's Defense Systems of Systems. Unfortunately, successful software vendors obsolete their own product versions to maintain the pace with the market, without regard for the military need for continued support or expandability. Recognized by many professionals as being of equal gravity as the hardware obsolescence issue, software obsolescence has to-date not enjoyed the same level of visibility. This paper reveals the obsolescence problem in development, integration, test, production, and program management environments; a different perspective compared to the typical focus on obsolescence risk management and mitigation in the end-user, operational environment. Despite the portfolio of methods implemented for the effective management of COTS hardware obsolescence on a growing number of military programs, the software obsolescence problem is not being managed or mitigated. Could software obsolescence become more overwhelming than the hardware obsolescence dilemma? 2006 IEEE.

Meyer, A., Pretorias, L., and Pretorius, J.H.C., "A Model to Manage Electronic Component Obsolescence for Complex or Long Life Systems," *IEEE International Engineering Management Conference: Innovation and Entrepreneurship for Sustainable Development, IEMC 2004*, Singapore, October 18–21, 2004, Vol. 3, pp. 1303–1309.

This paper provides an overview on the problem of component obsolescence. It discusses typical influences and drivers of obsolescence during the through life support of complex electronic or long life systems. Obsolescence management planning requirements in support of the identified influences and drivers is presented. Simplified life cycle costing models are presented together with proposed supply and design related mitigation options. 2004 IEEE.

Meyer, A., Pretorius, L., and Pretorius, J.H.C., "A Model Using an Obsolescence Mitigation Timeline for Managing Component Obsolescence of Complex or Long Life Systems," *IEEE International Engineering Management Conference: Innovation and Entrepreneurship for Sustainable Development, IEMC 2004*, Singapore, October 18–21, 2004, Vol. 3 pp. 1310–1313.

> This paper provides an overview on the problem of component obsolescence. It proposes a model to develop an obsolescence mitigation timeline for the through life support of complex electronic or long life systems. Obsolescence mitigation actions are presented as a function of mitigation options during the life cycle until end of life. 2004 IEEE.

Miao, C.-H., "Planned Obsolescence and Monopoly Undersupply," *Information Economics and Policy*, Vol. 23, No. 1, 2011, pp. 51–58.

> This paper examines the welfare implications of planned obsolescence in situations where the traditional monopoly undersupply exists. We find that the monopolist's introduction of incompatibility between successive generations of products alleviates the monopoly undersupply problem and may therefore generate higher social welfare than compatibility. Paradoxically, the stronger the network effects, the more likely welfare will increase as a result of incompatibility. Our result also extends to two-sided markets characterized by indirect network effects. 2010 Elsevier B.V.

Minghui, W., Honglun, H., Liu, C., Ying, J., "COTS-Based System's Obsolescence Risk Evaluation," *10th International Conference on Computer Supported Cooperative Work in Design*, Nanjing, China, May 3–5, 2006, pp. 1–5.

> COTS (commercial off the shelf) component products undergo a technology refresh and renewal cycle. New versions or releases of COTS component products are brought to the market frequently. And rapid evolution of the COTS component product means the obsolescence of the COTS-based systems, especially during COTS-based systems' maintenance (in a long run). This is the fundamental problem to application developer. So the evaluation of the system's COTS component part is primary issue. This paper provides an open evaluation model to complete the task. The model bases on AHP and WSM, considering of COTS components lifecycle.

Misra, K.B., "Handbook of Performability Engineering", Springer, 2008.

> No abstract available.

Morgan, M.J., "Integrated Modular Avionics for Next-Generation Commercial Airplanes," *Proceedings of the IEEE 1991 National Aerospace and Electronics Conference - NAECON 1991*, Piscataway, New Jersey, Vol.1, 1991, pp. 43–49.

> Compilation and indexing terms, Copyright 2003 Elsevier Engineering Information, Inc. The authors describe the goals and objectives of integrated modular avionics (IMA) and present one candidate architecture for IMA as applied to the Boeing 777 airplane. It is pointed out that the integration concepts being developed for the 777 Boeing represent an

important first step in real world application of the IMA technologies being developed in the ARINC subcommittees. It is concluded that it is the realization of these concepts that will allow the necessary step improvement in system quality, reliability, safety, and maintainability demanded for all next-generation avionic equipment.

Morris, A.T., "COTS Score: An Acceptance Methodology for COTS Software," *Digital Avionics Systems Conference, 19th DASC*, Vol. 1, 2000, pp. 4B2/1–4B2/8.

> Over the last decade the United States Government has significantly increased its use of commercial-off-the-shelf (COTS) software as stand-alone solutions and as components in safety-critical systems. This increased use stems from the realization that pre-existing software products can be a means of lowering development costs, shortening development time, and keeping pace with the changing software market. The Federal government, particularly with regards to safety-critical systems, has found that COTS software is currently not plug-and-play, has significant tradeoffs, and usually contains a 'cradle-to-grave' dependence on the software manufacturer. Unfortunately, there is currently no standard 'best commercial practice' with regard to the acceptance of COTS software. Ad hoc attempts to apply standards for commercial software acceptance have been based upon subjective criteria and have proven to be imprecise and prone to error. Moreover, acceptability in safety-critical systems generally demands analysis of source code. Many software vendors, however, have chosen to keep all such source code proprietary due to liability and intellectual property concerns. When the source code is not available, there is very little that can be done to ensure the safety, reliability, and integrity of the software. This paper discusses the COTS Score, an approach that aids in determining the acceptability of COTS software. The process involves the application of predictive techniques used for financial credit scoring to the COTS domain. The methodology addresses the issue of acceptability by incorporating both functional and environmental software measures related to reliability, compatibility, certifiability, obsolescence, and life cycle including trade-off analyses. This approach satisfies NASA and ISO 9001 requirements to define an acceptance procedure for COTS software.

Morse, P.M. and Elston, C., "Probabilistic Model for Obsolescence," *Operations Research,* Vol. 17, No. 1, 1969, pp. 36–47.

> Markovian model is presented of class of items with use-rate that is randomly distributed and with mean use or popularity that dimishes exponentially with time; tables are given of functions involved; as example, it is shown that yearly circulation of books in library corresponds to model, thus enabling circulation characteristics of various book classes to be predicted probabilistically. (15708)

Murthy, D.N.P. and Blischke, W.R., "Strategic Warranty Management: A Life-Cycle Approach," *IEEE Transactions on Engineering Management,* Vol. 47, No. 1, 2000, pp. 40–54.

> The role of warranty has become increasingly important, both as a promotional (particularly where competing products are nearly indistinguishable) and as a protectional device (for complex and expensive products where customers need some assurance).

Offering warranty implies additional cost to the manufacturer over the period from product launch to obsolescence. This cost is influenced by technical decisions made prior to the launch. This paper develops a strategic approach to warranty management where warranty-related decisions are made in a framework encompassing the product life cycle and from a business perspective which links technical and commercial issues.

Nair, S.K. and Hopp, W.J., "A Model for Equipment Replacement Due to Technological Obsolescence," *European Journal of Operational Research,* Vol. 63, No. 2, 1992, pp. 207–221.

We consider the problem of deciding whether to keep a piece of equipment or to replace it with a more advanced technology. This decision must take into account both the nature of the available replacement technology and the possibility of future technological advances. Existing models are restrictive in the way they model the appearance of future technologies and the costs and revenues associated with those technologies. In an earlier paper we allowed the probability of appearance of new technologies to be non-stationary in time, but required the costs and technologies to be different, but constant over time. In this paper, we allow the technology forecasts and revenue functions associated with technologies to be non-stationary in time and consider salvage values for technologies. We develop a simple and efficient algorithm for finding the optimal decision using a forecast horizon approach. This approach finds the optimal decision in any period with minimal reliance on forecast data.

NATO, "Proceedings: Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, 2000.

The meeting proceedings from this symposium on Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components was organized and sponsored by the Systems Concepts and Integration (SCI) Panel of the Research and Technology Organization of NATO in Budapest, Hungary from 23 to 25 October 2000. The symposium's goal was to propose new strategies for obsolescence management including open architecture, functional partitioning and technology insertion that have to be addressed during system engineering, detailed design, production and product support. The symposium outlined actual problems and solutions to the issue of obsolescence by the entire defense system community. It also addressed burning questions related to the problem of parts obsolescence and diminishing manufacturing sources and material shortages. Management tools and methodologies to cope with the risk of obsolescence were discussed. This included new design concepts and system architectures to allow advanced technology insertion during the system life cycle. Session topics were organized under the four topics of: status and experience with COTS technology in defense electronic systems, obsolescence management tools, new design concepts and architectures to combat obsolescence, strategies and initiatives for life cycle management.

NATO, "Obsolescence Management," 2010.

No abstract available.

Nelson III, R. and Sandborn, P., "Strategic Management of Component Obsolescence Using Constraint-Driven Design Refresh Planning," *ASME International Design Engineering Conferences & Computers and Information in Engineering Conference*, Washington, DC, 2011.

> When an original equipment manufacturer no longer supplies and/or supports a product then the product is considered to be obsolete. Obsolescence is a significant problem for systems whose operational and support life is much longer than the procurement lifetimes of their constituent components. Unlike high-volume, commercial products, which are quickly evolved, long field life, low-volume systems, such as aircraft may require updates of their components and technology called design refreshes to simply remain manufacturable and supportable. However these systems can't perform design refreshes all the time due to the high nonrecurring and re-qualification costs. One approach to optimally managing this problem is to use DRP (Design Refresh Planning), which is a strategic method for scheduling design refreshes such that the life cycle cost impact of obsolescence is minimized. The planning of these design refreshes is restricted by various constraints, which need to be implemented into the DRP process. These constraints can reflect technology roadmap requirements, obsolescence management realities, logistical restrictions, budget ceilings and management policy. In this paper, constraints imposed on the DRP process are explored, classified within a taxonomy, and implemented in the planning process. A communications system design example is included

O'Dowd, R.J., "A Survey of Electronics Obsolescence and Reliability," Australian Government, Department of Defence, Air Operations Division, Defence Science and Technology Organisation, Victoria, Australia, 2010.

> The service life of military assets significantly exceeds design life of commercial electronic systems used within them. Electronic obsolescence is increasingly associated with physical characteristics that reduce component and system reliability, both in usage and storage, with few design margins outside commercial warranty periods. Software content, however, remains a dominant limiting factor for reliability of electronic systems, and emerging commercial trends compound this. Traditional approaches to manage and sustain electronic systems are therefore increasingly ineffective and costly. This report surveys the interrelated concerns of obsolescence and reliability of electronic systems, and describes emerging responses to these concerns.

Ornellas, R.P. and Gross, R.S., "Strategies for Instrumentation and Control Upgrades," *Nuclear Science Symposium and Medical Imaging Conference*, Vol. 3, 1994, pp. 1047–1050.

> The original system instrumentation in many nuclear power plants is aging, and as a result, system reliability is decreasing while maintenance and testing costs are increasing. Replacement components and spare parts are difficult, if not impossible, to obtain, therefore decreasing the feasibility repairing these devices. In addition, compared to today's technology, system operation functions are limited by the original analog technology. In response to this situation, GE Nuclear Energy (GE-NE) has developed replacements for both safety and non-safety BWR instrumentation and control systems which resolve the equipment obsolescence problem while improving reliability and

reducing maintenance costs. Digital technology offers BWR owners the opportunity to install a high degree of intelligence, various levels of redundancy, and elaborate operator displays into instrumentation and control systems. The use of digital technology also allows for easy implementation of strategies not previously considered practical in older analog equipment systems. This paper discusses the strategies for instrumentation and control upgrades to replace existing analog systems in operating Boiling Water Reactors (BWR) together with the use of productivity tools developed by Black & Veatch to improve design efficiency, increase design quality, minimize the total implementation cost, and enhance configuration management of the design basis.

Pagel, E., "Tactical Aircraft Moving Map Capability (TAMMAC): Using Commercial-off-the-Shelf (COTS) Technology to Solve Common Military Aircraft Avionics Obsolescence Problems," AIAA/IEEE/SAE *Digital Avionics Systems Conference, 17th DASC,* Vol. 1, 1998, pp. B21/21–B21/28.

> Many military aircraft have on-board computers that generate moving map video for display in the cockpit. Many of these same aircraft have computers that record aircraft data in flight. The F/A-18 Hornet and the AV-8B Harrier, manufactured by Boeing (formerly McDonnell Douglas Aerospace (MDA)), have both computers. However, the computers that perform these tasks on the Hornet and Harrier have become obsolete. They were designed in the late 1970's, built in the early 1980's, and contain several electronic components within them that can no longer be procured. In 1995, MDA teamed with the Naval Air System Command's Air Combat Electronics or ACE group, to design and develop the TAMMAC system to replace these computers on the F/A-18 and AV-8B as well as be the common digital map/data recording system for all Navy aircraft. This paper describes the system engineering process used to develop the TAMMAC system and how this process helped maximize the application of COTS technology within TAMMAC while maintaining performance in military aircraft environmental conditions

Pangburn, M.S. and Sundaresan, S., "Capacity Decisions for High-Tech Products With Obsolescence," *European Journal of Operational Research,* Vol. 197, 2009, pp. 102–111.

> Modern high-tech products experience rapid obsolescence. Capacity investments must be recouped during the brief product life-cycle, during which prices fall continuously. We employ a multiplicative demand model that incorporates price declines due to both market heterogeneity and product obsolescence, and study a monopolistic firm's capacity decision. We investigate profit concavity, and characterize the structure of the optimal capacity solution. Moreover, for products with negligible variable costs, we identify two distinct strategies for capacity choice demarcated by an obsolescence rate threshold that relates both to market factors and capacity costs. Finally, we empirically test the demand model by analyzing shipping and pricing data from the PC microprocessor market. 2008 Elsevier B.V. All rights reserved.

Parnell, K., "Goodbye Device Obsolescence?," *Electronic Product Design*, Vol. 23, pp. 44–46.

> A report on the obsolescence which is a major concern of automotive telematics equipment engineers is presented. The legacy software is preserved and the process is relatively cheap and fast. The creation of unusual processor configurations which can be changed at any time to suit changes in the specifications is reduced to a simple task. It was shown that emulation requires about twenty clock cycles of the latest processor for every legacy instruction it executes.

Parnell, K., "Could Microprocessor Obsolescence Be History?," *Xcell Journal,* 2003.

> No abstract available.

Paska, M., Dvorak, P., Racek, S., and Janecek, E., "Model Based Support for Life Cycle Management of I&C Systems," *EUROCON, 2007. The International Conference on "Computer As a Tool&#34* Warsaw, Poland, September 9–12, 2007, pp. 2217–2220.

> This article describes a method, which helps to cope with aging and obsolescence of long running computerized systems Instrumentation and Control systems (I&C). In this method, a model of the observed system is created. The model is based on the Fault Tree method. The Fault Tree is extended to work with lifetimes of the system components. The aim of the model is to recommend which part of the system should be considered for modernization or replacement.

Pecht, M. and Das, D., "The Electronic Part Life Cycle," *IEEE Transactions on Components and Packaging Technologies,* Vol. 23, No. 1, 2000, pp. 190–192.

> No abstract available.

Pecht, M. and Humphrey, D., "Uprating of Electronic Parts to Address Obsolescence," *Microelectronics International,* Vol. 23, 2006, pp. 32–36.

> Purpose: The paper presents an alternative solution to address part obsolescence. This paper discusses approaches to solve part obsolescence including an uprating approach. This paper also describes the methods to uprate parts, and demonstrates the practical application of the uprating approach in the form of a case study. Design/methodology/approach: This paper has been written to provide an understanding of the uprating approach to mitigate the problems caused by part obsolescence. The paper discusses the challenge faced due to part obsolescence, the temperature ratings for electronic parts, the uprating methods and finally explains the use of uprating to mitigate part obsolescence in the form of a case study. The part being uprated is a microcontroller unit used in many avionics applications. The case study describes a particular use of uprating and the return on investment. Findings: Based on the uprating approach, it was discovered that for the particular application, the commercially available plastic quad flat pack microcontroller could be used as a substitute for the "military" ceramic BGA version, which was discontinued by the manufacturer. It was discovered that there would

be no problem with the commercial part's quality or reliability for the particular application. Parametric tests showed no evidence of instability of electrical characteristics over the uprated temperature range. There was substantial return on investment due to the use of uprated parts. Practical implications: This paper can help electronics manufactures deal with part obsolescence. This paper demonstrates the practicality of uprating parts. Uprating can save companies money by reducing the need for life-time buys, substitution of parts and even redesign. Originality/value: The paper provides an alternative approach to address the problem of part obsolescence. This paper shows that proper uprating leads to cost saving while continuing to provide reliable service. Emerald Group Publishing Limited.

Pecht, M., Solomon, R., Sandborn, P., Das, D., and Wilkinson, C., *Life-Cycle Forecasting, Mitigation Assessment and Obsolescence Strategies*, CALCE EPSC Press, College Park, Maryland, 2002.

No abstract available.

Pecht, M., Solomon, R., Sandborn, P., Wilkinson, C., and Das, D., *Parts Selection and Management,* John Wiley, Hoboken, NJ, "Obsolescence Prediction and Management," pp. 321.

No abstract available.

Pecht, M. and Tiku, S., "Spectral Lines: Counterfeiting and You," *IEEE Spectrum,* Vol. 43, No. 5, 2006, pp. 10.

No abstract available.

Pecht, M.G. and Humphrey, D., "Addressing Obsolescence—The Uprating Option," *IEEE Transactions on Components and Packaging Technologies,* Vol. 31, No. 3, pp. 741–745.

Uprating is a process that assesses the capability of a part to meet the functional and performance requirements for an application in which the part is used outside the specified temperature range provided in the manufacturer's datasheet. This article discusses the use of uprating as a means to address obsolescence. The article begins by explaining the rationale and opportunities for using parts outside the specification range. The technical issues for using uprating to address obsolescence [obsolescence is known in the military community as diminishing manufacturing sources and material shortages (DMSMS)] are then presented. Finally, a case study is presented.

Pence, M.J., "F-16 Parts Obsolescence Report," Lockheed Martin, 1995.

No abstract available.

Persona, A., Grassi, A., and Catena, M., "Consignment Stock of Inventories in the Presence of Obsolescence," *International Journal of Production Research,* Vol. 43, May 2005, pp. 4969–4988.

The Consignment Stock (CS) inventory policy is becoming an important strategy that companies adopt to face new manufacturing and supply chain management challenges. A CS policy implies great collaboration between the buyer and supplier, pushing them towards a complete exchange of information and a consistent sharing of management risks. In such a context, the effects of the obsolescence of products have to be carefully evaluated since they fall onto both actors, causing an increase in total supply chain costs. This paper proposes an analytical model able to take into account the effects of obsolescence in a supply chain managed with a CS policy. The deterministic single-vendor, single-buyer CS model is used as a base to develop the proposed model. A comparison with a non-obsolescence optimal solution available in the literature is presented. Moreover, the stochastic behaviour of the product lifetime estimation is also taken into consideration. Results demonstrate that the effects of obsolescence can consistently influence the global optimum condition.

Pertowski, T. and Denham, C., "Approaches to Reduce Impact of Electronic Component Obsolescence. Component Information Management System," *Proceedings of the 1998 IEEE International Frequency Control Symposium,* pp. 430–438.

The shortage of sources for qualified electronic devices used in defense systems has continued to grow at an accelerating pace and creates a serious dilemma for contractors and military centers producing and supporting DoD systems. Major suppliers of MIL devices have chosen to discontinue the manufacture of these devices and suggest they be replaced by similar commercial devices manufactured by their commercial facilities. Having studied this situation and related problems with the quality and availability of good component information, the Electronic Industries Alliance (EIA) recognized the need to establish a data warehouse. This warehouse, entitled the Component Information Management System; (CIMS), promises to alleviate the dilemma of diminishing manufacturing sources. With the CIMS data warehouse, access to accurate component and supplier information for both commercial and military applications will be readily available for a variety of individuals as well as small, medium, or large sized firms. Smaller organizations can access the data directly through the Internet Home page, while larger firms may choose to access the data through value added data product suppliers using various bulk data access methods.

Peters, L.S., "GEM: Technology for Improved Logistics Support," *Proceedings of the IEEE 1993 National Aerospace and Electronics Conference, NAECON,* 1993, pp. 939–943.

Generalized Emulation of Microcircuits (GEM) technology is currently being validated by producing emulated microcircuits for logistics support of military systems. The perspective provided by the GEM development is the basis of a strategy that can break the microcircuit obsolescence cycle. With the 1992 National Military Strategy directing Service Life Extension for major DoD weapon systems, emulation is increasingly

recognized as an important technology. The constrained defense budget further increases the importance of logistics (supportability, reliability, and maintainability) during the design, upgrade, or redesign phases of weapon systems. The lack of long-term supply for microcircuit components places a major supportability burden on military organizations. The absence of microcircuits for logistics support places undue pressure on program managers to authorize costly upgrades or redesigns to compensate for nonavailable replacement microcircuit components. GEM was developed to address this problem by providing a source for needed, but nonavailable integrated circuits (ICs). Emulation was identified as an approach that has significant promise to provide a cost-effective and reliable source for needed ICs. The GEM system provides a generic approach to emulation and is producing FFF microcircuits of military quality at minimum cost, when needed, and in the quantities required for logistics support.

Petersen, L, "Use of Commercial Components in Defense Equipment to Mitigate Obsolescence. A Contradiction in Itself," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, 2000.

> The paper identifies and discusses the presently unresolved contradictions between the requirements of the national customers (MODs or Purchasing Agencies) and the viable options the industry can offer to mitigate the adverse effects of obsolescence for defense material with emphasis on the extended use of COTS.

Peterson, G.D., "Language-Based Electronics Systems Design Automation," *Proceedings of the IEEE Computer Society Workshop on System Level Design, VLSI '98*, 1998, pp. 130–135.

> The ever-increasing complexity of electronic systems makes it imperative to develop effective systems level design automation languages, methodologies, and tools. Commercial systems face increasing complexity and performance requirements, while achieving decreasing times to market and maximizing profits despite shrinking product life-cycles. Defense systems face similar issues, but must also support life cycles which span years or decades, thus requiring redesign, support or prevention of parts obsolescence challenges. For cost-effective development of systems in this context, design teams need to exploit the best commercial and defense design practices and adapt them as needed to also support concurrent engineering considerations. This paper explores requirements for the emerging system level design language and the methodological needs for it to support multi-disciplinary design, including hardware software co-design, mechanical and packaging support, concurrent engineering, test, and related issues.

Peterson, G.D. and Mills, M., "Mission Success: Meeting the Systems Acquisition Challenge With Electronic Systems Design Automation," *Proceedings of the IEEE 1998 National Aerospace and Electronics Conference, NAECON,* 1998, pp. 613–619.

> The ever-increasing complexity of electronic systems and interdependency of hardware and software throughout the system life cycle makes it imperative to develop effective electronic design automation languages, methodologies, and tools. Commercial systems

face increasing complexity and performance requirements, while achieving decreasing times to market and maximizing profits despite shrinking product life-cycles. Defense systems face similar issues, but must also support life cycles spanning years or decades, thus requiring redesign support or prevention of parts obsolescence challenges. For cost-effective development of systems in this context, design teams need to exploit the best commercial and defense design practices and adapt them as needed to also support concurrent engineering considerations. This paper explores requirements for the emerging system level design language and the methodological needs for it to support multi-disciplinary design, including hardware software co-design, mechanical and packaging support, concurrent engineering, test, and related issues. By employing these techniques and representations, weapons systems acquisition programs will reduce technical, cost, and schedule risk to help ensure mission success

Philbin, T., "Insulating DSP From ASIC Obsolescence," *Electronic Product Design*, Vol. 22, 2001, pp. 17–20.

> The progress in the digital signal processing (DSP) applications in specific integrated circuits (ASIC) technology was analyzed. While progressing towards modern and smaller geometries, the ASIC suppliers must consider maintaining the older fabrication processes. In a design flow, an application goes through an up-front design and simulation to ensure the operation and performance of the ASIC. In order to reduce the effects of truncation errors within the design, an ASIC can be over-designed to guarantee a level performance in all the operation modes. Programmable logic allows for improvements and enhancements to the design of a product after shipment to the customer.

Pierskalla, W.P., "An Inventory Problem With Obsolescence," *Naval Research Logistics Quarterly,* Vol. 16, No. 2, 1969, pp. 217–228.

> A stochastic single product convex cost inventory problem is considered in which there is a probability, p sub j, that the product will become obsolete in the future period j. In an interesting paper, Barankin and Denny essentially formulate the model, but do not describe some of its interesting and relevant ramifications. The present paper is written not only to bring out some of these ramifications, but also to describe some computational results using this model. The computational results show that if obsolescence is a distinct possibility in the near future, it is quite important that the probilities of obsolescence be incorporated into the model before computing the optimal policies. (Author)

Pince, C. and Dekker, R., "An Inventory Model for Slow Moving Items Subject to Obsolescence," *European Journal of Operational Research,* Vol. 213, 2011, pp. 83–95.

> In this paper, we consider a continuous review inventory system of a slow moving item for which the demand rate drops to a lower level at a known future time instance. The inventory system is controlled according to a one-for-one replenishment policy with a fixed lead time. Adapting to lower demand is achieved by changing the control policy in

advance and letting the demand take away the excess stocks. We show that the timing of the control policy change primarily determines the tradeoff between backordering penalties and obsolescence costs. We propose an approximate solution for the optimal time to shift to the new control policy minimizing the expected total cost during the transient period. We find that the advance policy change results in significant cost savings and the approximation yields near optimal expected total costs. 2011 Elsevier B.V. All rights reserved.

Plesovs, A. and Herndon, H., "Commercial Sounder Solves Navy's Part Obsolescence Issues," *Sea Technology,* Vol. 47, 2006, pp. 25–28.

> The consortium of Professional Employer Organization (PEO), Crane Division of Naval Surface Warfare Center (NSWC), and Naval Undersea Warfare Center (NUWC) Division has been working closely with Knudsen Engineering to develop the Commercial off-the-shelf (COTS) depth sounder solution. The solution will replace the AN/UQN-4,4A sonar sounding set and harnesses the power of technology for the warfighter. Knudsen has developed 320N navigation echo-sounder to better serve the Navy's needs for navigational depth sounding. The echo-sounder is configured with a touch screen for set-up, operation, and echogram display, and a hard drive that records and stores depth data and supports all AN/UQN-4,4A unique interfaces essential in replacing the AN/UQN-4,4A. The 320N design incorporates state-of-the-art digital signal processing technology and operates with the legacy system's standard 12-kilohertz transducer. Installation of the 320N on Navy ships can be accomplished utilizing simple adapter brackets mounted to the existing AN/UQN-4,4A foundation.

Pope, S.M., Elliott, J.R., and Turbini, L.J., "Designing for Technological Obsolescence and Discontinuous Change: An Evaluation of Three Successional Electronic Products," *Proceedings of the 1998 IEEE International Symposium on Electronics and the Environment, ISEE,* Oak Brook, Illinois, May 4–6, 1998, pp. 280–286.

> Product displacement has been occurring for many years and will continue to challenge the market as technological advances result in product obsolescence. While opportunities do exist to incorporate environmentally conscious design and engineering criteria into the product development process, much of the ultimate environmental success is dependent upon closing the product life cycle, through reuse (upgrade and/or repair), re-manufacture and recycling. This paper reports on the analysis and evaluation of three successional audio video home electronic products: the VHS Video Cassette Recorder (VCR), the Laser Disc Player (LD) and the Digital Video/Versatile Disc Player (DVD). The newly released DVD player has rendered the LD player obsolete and will soon render the VCR obsolete. This paper investigates potential environmental improvements to the DVD player through design strategies for upgrading a successional product and for reducing its end-of-life impact.

Porter, Z.G., "An Economic Method for Evaluating Electronic Component Obsolescence Solutions," Boeing, 1998.

No abstract available.

Pourakbar, M., Frenkz, J.B.G., and Dekker, R., "End-of-Life Inventory Decisions for Consumer Electronics Service Parts," Econometric Institute, 2010.

We consider a consumer electronics (CE) manufacturer's problem of controlling the inventory of spare parts in the final phase of the service life cycle. The final phase starts when the part production is terminated and continues until the last service contract or warranty period expires. Placing final orders for service parts is considered to be a popular tactic to satisfy demand during this period and to mitigate the effect of part obsolescence at the end of the service life cycle. To satisfy demand for service in the final phase, previous research focuses on repairing defective products by replacing the defective parts with properly functioning spare ones.

However, for consumer electronic products there is a remarkable price erosion while repair costs may stay steady over time. As a consequence, this introduces the idea that there might be a point in time at which the unit price of the product is lower than repair associated costs. Therefore, it would be more cost effective to adopt an alternative policy to meet demands for service such as offering customers a replacement of the defective product with a new one or giving a discount on the next generation of the product. This paper examines the cost trade-offs of implementing alternative policies for the repair policy and develops an exact formulation for the expected total cost function. Based on this developed cost function we propose policies to simultaneously find the optimal final order quantity and the time to switch from the repair to an alternative replacement policy. Numerical analysis of a real world case study sheds light over the effectiveness and advantage of these policies in terms of cost reduction and also yields insights into the quantitative importance of the various cost parameters.

Powell, D., Arlat, J., Beus-Dukic, L., et al., "GUARDS: A Generic Upgradable Architecture for Real-Time Dependable Systems," *IEEE Transactions on Parallel and Distributed Systems,* Vol. 10, Issue 6, August 6, 2002, 580–599.

The development and validation of fault-tolerant computers for critical real-time applications are currently both costly and time consuming. Often, the underlying technology is out-of-date by the time the computers are ready for deployment. Obsolescence can become a chronic problem when the systems in which they are embedded have lifetimes of several decades. This paper gives an overview of the work carried out in a project that is tackling the issues of cost and rapid obsolescence by defining a generic fault-tolerant computer architecture based essentially on commercial off-the-shelf (COTS) components (both processor hardware boards and real-time operating systems). The architecture uses a limited number of specific, but generic, hardware and software components to implement an architecture that can be configured along three dimensions: redundant channels, redundant lanes, and integrity levels. The

two dimensions of physical redundancy allow the definition of a wide variety of instances with different fault tolerance strategies. The integrity level dimension allows application components of different levels of criticality to coexist in the same instance. The paper describes the main concepts of the architecture, the supporting environments for development and validation, and the prototypes currently being implemented.

Powers-Garmon, J., Gary, M.J., Laughlin, L.L., et al., "Just-in-Time Sustainment," *Digital Avionics Systems Conference, 20th DASC*, Vol. 1: 3E2/1–3E2/7.

Sustainment engineers, responsible for insuring that military avionics systems are supportable, are facing increasing challenges to assure that the systems for which they are accountable are mission ready. Deciding what sustainment actions are necessary and when they need to be performed is the key to the "just-in-time" sustainment concept being pursued by the F-15 Hardware Avionics Section at the Warner Robins Air Logistics Center (WR-ALC/LFEFA). This concept requires that the sustainer have visibility into all aspects of a system. The sustainer must consider system configurations, indentured parts lists and their interchangeability, component obsolescence, assembly repair information, repair history down to the component level, spares at all assembly levels, Defense Logistics Agency (DLA) and depot component inventory and usage rates, and anticipated force structure. The sustainer needs an analysis tool to correlate all these data to determine what needs to be done and when it needs to be accomplished before mission readiness is impacted. The SUSTAIN^{TM} (sustainment strategy for avionics information needs) tool, developed by the Georgia Tech Research Institute (GTRI), allows implementation of a true just-in-time sustainment approach by consolidating all the required information into a single automated tool that displays data in a concise and informative manner. This paper describes SUSTAIN^{TM}, its data sources, and analysis capabilities.

Prabhakar, V. and Sandborn, P., "A Model For Making Part Sourcing Decisions for Long Life-Cycle Products," *ASME International Design Engineering Conferences & Computers and Information in Engineering Conference, DFMLC 11*, Washington, DC, 2011, to be published.

Long life-cycle products, commonly found in aviation, medical and critical infrastructure applications, are often fielded and supported for long periods of time (20 years or more). The manufacture and support of long life-cycle products rely on the availability of suitable parts, which over long periods of time, leaves the parts susceptible to a number of possible supply chain disruptions such as suppliers exiting the market, counterfeit part risks, and part obsolescence. One solution to mitigating the supply chain risk is the strategic formulation of suitable part sourcing strategies (optimally selecting one or more suppliers from which to purchase parts over the life of the part's use within a product or within an organization). Strategic sourcing offers one way of avoiding the risk of part unavailability (and its associated penalties), but at the possible expense of qualification and support costs for multiple suppliers. Existing methods used to study part sourcing decisions are procurement-centric where cost tradeoffs focus on part pricing, negotiation practices and purchase volumes. These studies are commonplace in strategic parts management for short life-cycle products; however, conventional procurement-centric

approaches offer only a limited view when assessing parts used in long life-cycle products. Procurement-driven decision-making provides little to no insight into the accumulation of life-cycle cost (attributed to the adoption and use of the part), which can be significantly larger than procurement costs in long life-cycle products. This paper presents a new life-cycle modeling approach to quantify risk that enables cost effective part sourcing strategies. The method quantifies obsolescence risk as "annual expected total cost of ownership (TCO) per part site" modeled by estimating the likelihood of obsolescence and using that likelihood to determine the TCO allowing sourcing strategies to be compared on a life-cycle cost basis. The method is demonstrated for electronic parts in an example case study of linear regulators and shows that when procurement and inventory costs are small contributions to the part's TCO, the cost of qualifying and supporting a second source outweighs the benefits of extending the part's effective procurement life.

Prabhakar, V. and Sandborn, P., "A Part Total Cost of Ownership Model for Long Life-Cycle Electronic Systems," *International Journal of Computer Integrated Manufacturing,* Vol. 25, No. 4-5, 2012, pp. 384–397.

Dedicated part selection and management groups within large original equipment manufacturers are responsible for various tasks involved with managing parts or components used in electronic systems. The tasks range from part adoption to obsolescence management and include numerous assembly and support activities that are performed on a regular basis. Long life-cycle electronic systems typically utilise commercial 'off-the shelf' parts, which subject them to the same supply chain constraints imposed by a market that is oriented towards short-term, high-volume products. Relevant issues involve a high frequency of part procurement obsolescence, reliability concerns, and the risk of long-term supply-chain disruptions. Unfortunately, initial part selection decisions are often driven by procurement management processes with little or no insight into the total cost of ownership (TCO) of the part's adoption and use within the organisation. The part TCO model proposed in this article enables better informed part selection and management decisions. The article discusses and demonstrates the model's use in Lifetime Buy and Design Reuse case studies for an example surface-mount electronic part. Additionally, the model proposed in this article is well suited for addressing the impacts of part number reduction, retirement of parts from databases, organisational adoption of new parts, sourcing strategies and part-specific long-term supply chain disruptions by influencing initial component selection and providing guidance on what actions taken at the component management level provide the maximum payback (or maximum future cost avoidance).

Prophet, G., "Guarding Against Component Obsolescence," *EDN (US Edition)*, Vol. 47, 2002, pp. 63–73.

The problem of component obsolescence has been around for as long as the industry, but it has become a more serious concern in the last decade. In a technology sector in which rapid progress is the norm, new generations of components succeed the previous ones in only months, and manufacturers cannot keep every variant of every generation in

production indefinitely. As the demand for each variant drops below economic viability the component disappears from production in a more or less orderly fashion. The electronics industry's problem has always been that it designs products whose life cycles regularly far exceed the life spans of the components inside them. Also military/high-reliability systems that evolved to handle component obsolescence are now coming under strain as the influence of COTS purchasing grows. However, the long-established procedures for establishing reserves of deleted semiconductors still work well and software tools are in development to help optimize life cycles with programmed design revisions and redesigns.

QinetiQ, "QinetiQ New Web-Base Cuts Obsolescence Cost." *III-Vs Review*, Vol. 16, 2003, pp. 12.

No abstract available.

QinetiQ and Arinc, "Ministry of Defence Component Obsolescence Resolution Cost Metrics Study," 2004.

No abstract available.

Queenan, R.M., "IC Obsolescence Solutions for Operating Plants," *5th International Topical Meeting on Nuclear Plant Instrumentation Controls, and Human Machine Interface Technology (NPIC and HMIT 2006)*, Albuquerque, New Mexico, 2006, pp. 430–434.

Operating plants have a large investment in their existing instrumentation and control systems. Engineers are trained on and have implemented monitoring programs for the existing hardware; maintenance technicians have been trained and have years of experience with the existing systems; operations personnel have had extensive training in how the existing systems operate, as well as hands-on experience with the human-machine interface and the response of the systems. The training department typically has lesson plans for both engineering, maintenance, and operations on the various systems. And finally, the other NSSS plants that use common equipment have contributed a wealth of operating experience, improving overall reliability and reducing down time. So an operating plant is reluctant to replace any instrumentation and control system. However, the systems are or are becoming obsolete. Parts and repairs and service are getting harder and harder to find, and in general operating plants want to focus on power generation, not equipment maintenance. This paper will discuss the four main options available for operating plants: buy a new one, repair it, buy a replacement, or replace it. 'Repair' includes (1) only replacing the failed components, and (2) replacing all aging capacitors, worn switches and adjustments, and generally resetting the qualified life of the module. Buy a replacement includes (1) duplicate the existing design, and (2) redesign a form/fit/function replacement for the module with new parts and current technology. Finally, 'replace' means removing the old equipment - usually at the system level - and replacing it with a new digital system. The advantages and disadvantages of each will be presented, with input from the recent EPRI/NRC meeting on digital upgrade licensing. A

balanced view will be presented, resulting in some guidance to plants on which option to chose.

Raab, C. and Parham, J., "Removing Obsolescence in the 3A GPS Legacy Receiver Through the Application of Current Technologies: A Case Study," *Institute of Navigation National Technical Meeting, NTM 2007*, San Diego, California, Vol. 2, pp. 1034–1040.

>The GPS Receiver R-2332J/AR (RCVR3A) is a five-channel airborne Precise Positioning Service (PPS) GPS Receiver that currently supports the navigation and timing requirements of nearly 70 military platforms. This 25-year old technology receiver is at a life-cycle phase in which its supportability is severely impacted by parts obsolescence. The Avionics Component Obsolescence Management (AVCOM), reports that currently 18% of the integrated circuits, hybrids, discretes and radio frequency devices are obsolete. Additionally, AVCOM projects that by the year 2015 obsolescence issues will be over 50%. Rockwell Collins, Cedar Rapids was tasked by Warner Robins Air Logistics Command (WRALC) to develop a design that mitigates the obsolescence issues of the RCVR3A while maintaining backward compatibility to Host Vehicles (HV) with respect to form, fit, and function. In order to keep this new receiver functionally viable for the next decade, the receiver is to incorporate current Selective Availability Anti Spoofing Module (SAASM) technologies and provide a platform to expand to future capabilities such as the Joint Precision Approach and Landing System (JPALS) and Global Air Traffic Management (GATM). Additionally, a clear roadmap to M-Code technology is required. A key issue in developing this new receiver is to maintain full backwards compatibility with the RCVR3A with respect to its interfaces of the HV. This interface compatibility will enable existing RCVR3A platforms to an upgraded R-2332M/AR (RCVR3A-S) replacement with minimal integration effort. This paper describes the key activities for Phase 1 of a three phase effort, which paid significant dividends for the engineering team's efforts. A description of how Rockwell Collins has achieved the goal of maintaining backward compatibility to the RCVR3A while integrating Rockwell Collins' GPS Embedded Module with All-In-View SAASM functionality is provided. The future phases of the modernized RCVR3A development will also be addressed. Finally, we address the RCVR3A relative to the future phases of the initial development and describe the plans going forward to develop the full suite of HV interfaces and the challenges that we will encounter going forward into the platform integration phase of the 3A Upgrade program.

Rai, R. and Terpenny, J., "Principles for Managing Technological Product Obsolescence," *IEEE Transactions on Components and Packaging Technologies,* Vol. 31, No. 4, 2008, pp. 880-889.

>Products evolve to accommodate competitive market pressures, rapid rates of technology change, and constant improvements in performance and functionality. While adding functionality and value, the fast moving technologies also make products obsolete quickly. One of the primary reasons for product obsolescence is technological obsolescence which results when consumers are attracted to functions in newer models of products that are more technologically advanced. One way to deal with problem is piggybacking a strategy that enables renewed functionality of a technologically obsolete

product through the integration or add-on of a secondary device or component. Not to be confused with upgrading strategies, piggybacking requires a device that fits adjacent to, upon, or within the existing product architecture. Piggybacking is an attractive strategy for consumer electronic products that are particularly prone to technological obsolescence as it offers a means to accommodate fast and slower changing technologies within a single product. Currently, piggyback products are realized with ad-hoc methods that rely on the experience and intuition of the designer, often applied inconsistently and not well known by less experienced designers. In this paper, a set of formal principles is presented for guiding the design of piggyback products. These principles are derived from the results of an empirical study of 72 different products. As part of the study, various products are analyzed with a dissection tool with representative principles derived from the data. The utility of these principles is demonstrated via the conceptual design of a novel piggyback products.

Redling, T.J., "Considerations for Upgrading Aging Military Avionics Systems With State-of-the-Art Technology," *Digital Avionics Systems Conference, 23rd DASC*, Vol. 2, pp. 7.D.1–7.1-7.

Due to ever tightening budgets in the defense arena, the armed services are making conscious efforts to extend the service life of existing aircraft beyond what was intended at the time of their original design. These aircraft types include extremely old airframes such as B-52H and variants of the C-130, which continues to play a part in 21st century military actions. Relatively new weapons systems are also included, such as the F-117A and B-2A, which are already beginning to experience component obsolescence problems. A major aspect of these upgrade programs involves replacing existing aging avionics with modern digital systems that are more reliable and more capable. In many cases, however, these retrofits are not simply "plug-and-play." Careful analysis is required to ensure that no existing capabilities are lost and that the new system can function properly in the legacy aircraft. These considerations can vary depending upon aircraft type and mission. Factors are to consider include interoperability with legacy systems, aircraft mass properties, A-kit wiring, human factors, training, and growth capability for future upgrades. The paper provides guidance on the evaluation of a potential retrofit, thus assisting the readers in developing their own decision support system.

Regan, T., "Parts Obsolescence Management Tools (POMT)," TRW Electronics Systems Group, Dayton, Ohio, 2001.

The main focus of the Parts Obsolescence Management Tools (POMT) program was the definition of a reengineering methodology that supports both the initial design and the reengineering of modern products. This methodology begins with the product specification using the concept of the simulatable specification as defined by the Continuous Electronic Enhancements using Simulatable Specifications (CEENSS) program and continues with the reengineering process whereby an implementation is developed and culminates with the interface to the manufacturing process. This effort also focused on the development of two key computer-aided design (CAD) tools needed to support the application of this methodology in real-world product challenges. These

tools include a behavioral product reengineering (BRP) tool and design verification test generator (DVTG) tool.

Rennenkampf, E. and Rhyne, R., "Application of Commercial Parts Obsolescence Management (CPOM) - Final Technical Rept," *Northrop Grumman Systems Corp,* June 15, 1999–December 31, 2003.

Northrop Grumman Electronic Systems (Baltimore, Maryland) in cooperation with the AFRL Material and Manufacturing Directorate (WPAFB, Ohio) developed a 58-month ManTech obsolescence program to pursue a diverse group of tasks in various areas of parts obsolescence. The objective of the program was to reliably use COTS parts in military systems, implement ManTech funded tools and processes, integrate tools and processes in the Northrop Grumman design environment, and document the resulting cost avoidance. The program has completed its work with notable success. This succinct report highlights the results and benefits.

Rierson, L. and Lingberg, B., "Reverse Engineering of Software Life Cycle Data in Certification Projects," *Digital Avionics Systems Conference, 22nd DASC,* Vol. 1, 2003, pp. 3.B.2–3.1-7.

Some applicants, developers, and commercial-off-the-shelf (COTS) software vendors have proposed reverse engineering as an approach for satisfying RTCS/DO-178B objectives for airborne software. RTCA/DO-178B, Software Considerations in Airborne Systems and Equipment Certification, serves as the means of compliance for most airborne software in civil aircraft. DO-178B defines reverse engineering as "the method of extracting software design information from the source code" and provides guidance particular to reverse engineering, when it is used to upgrade a development baseline. For purposes of this paper, reverse engineering is an approach for creating software life cycle data that did not originally exist, cannot be found, is not adequate, or is not available to a developer in order to meet applicable DO-178B objectives. Reverse engineering is not just the generation of data - rather it is a process to assure that the data is correct, the software functionality is understood and well documented and the software functions as intended and required by the system. Reverse engineering is not, as some software developers propose, just an effort to generate the software life cycle data without intent to build in quality and the resulting design assurance. This paper explores reverse engineering in airborne software projects, by explaining a definition for the certification domain, describing the motivation for its use, and documenting the certification concerns. Two actual cases of reverse engineering are also described to illustrate the certification concerns in real projects.

Ritschard, M.R., "Technology Replacement Avoiding Obsolescence; Is It Possible?," *Proceedings ACM SIGUCCS User Services Conference,* 1998, pp. 199–207.

Replacing computing equipment before it is obsolete is a daunting challenge. Hardware vendors offer the latest technology at a rapid pace and new versions of software quickly take advantage of the new hardware. The variables involved in technology replacement with constrained resources are discussed, along with the planned technology replacement

on faculty desktops. As an example, the Desktop Computing Replacement Plan of Bucknell University is described.

Robbins, R.M., "Proactive Component Obsolescence Management," *A-B Journal,* Vol. 10, No. 4, 2003, pp. 49–54.

No abstract available.

Roddy, P.D., "Is an Open Architecture Tester Really Achievable?," *International Test Conference,* 2002, pp. 1209.

Summary form only given. Management of tester technology has been a real challenge with Motorola's diverse product portfolio. Global support for multiple tester hardware architectures and operating systems is very expensive, difficult, and time consuming. Migration to new proprietary tester platforms requires massive efforts from design, test engineering, production, maintenance, and other areas. The semiconductor industry is ready for a common OA (open architecture) tester. The OA tester will provide many benefits to semiconductor manufacturers such as: lower costs, faster access to new technology, wider supplier base, and protection from obsolescence. Also, the OA tester will provide benefits to the ATE suppliers such as: substantially reduced support costs, reduced training, and larger market potential. Development and acceptance of the OA tester concept will not be easy, but should be achievable.

Romero Rojo, F.J., "Development of a Framework for Obsolescence Resolution Cost Estimation," Cranfield University, 2011.

Currently, manufacturing organisations worldwide are shifting their business models towards Product-Service Systems (PSS), which implies the development of new support agreements such as availability-based contracts. This transition is shifting the responsibilities for managing and resolving obsolescence issues from the customer to the prime contractor and industry work share partners. This new scenario has triggered a new need to estimate the non-recurring engineering (NRE) cost of resolving obsolescence issues at the bidding stage, so it can be included in the support contract. Hence, the aim of this research is to develop an understanding about all types of obsolescence and develop methodologies for the estimation of NRE costs of hardware (electronic, electrical and electromechanical (EEE) components and materials) obsolescence that can be used at the bidding stage for support contracts in the defence and aerospace sectors. For the accomplishment of this aim, an extensive literature review of the related themes to the research area was carried out. It was found that there is a lack of methodologies for the cost estimation of obsolescence, and also a lack of understanding on the different types of obsolescence such as materials and software obsolescence. A systematic industrial investigation corroborated these findings and revealed the current practice in the UK defence sector for cost estimation at the bidding stage, obsolescence management and obsolescence cost estimation. It facilitated the development of an understanding about obsolescence in hardware and software. Further collaboration with experts from more than 14 organisations enabled the iterative development of the EEEFORCE and M-

FORCE frameworks, which can be used at the bidding stage of support contracts to estimate the NRE costs incurred during the contracted period in resolving obsolescence issues in EEE components and materials, respectively. These frameworks were implemented within a prototype software platform that was applied to 13 case studies for expert validation.

Romero Rojo, F.J., Baguley, P., Shaikh, N., Roy, R., and Kelly, S., "TOMCAT: An Obsolescence Management Capability Assessment Framework," *25th International Congress on Condition Monitoring and Diagnostic Engineering, COMADEM 2012*, Huddersfield, United Kingdom, June 18–20, 2012. .

As the UK Ministry of Defence (MoD) moves away from the traditional support contracts to contracting for availability/capability, it is essential that the MoD has confidence in Industry's capability to manage the risk of obsolescence. For this purpose, it was necessary to develop a set of metrics to demonstrate it. The eight key elements identified are as follows: obsolescence management governance; supplier; design for obsolescence; risk assessment; obsolescence monitoring; communication; and obsolescence resolution process. Each one was assessed, ranked, and was further broken down into major constituents. They formed the basis of the final 25 metrics, which were then ranked and weighted accordingly. These metrics are embedded into the Total Obsolescence Management Capability Assessment Tool (TOMCAT), which provides a mean for contractors to perform self-assessment and for the MoD to set obsolescence management capability improvement targets. This tool was subjected to rigorous industry scrutiny through different means, including workshops and piloting sessions, which led to refining the TOMCAT tool and the way in which the metrics are formulated. This tool has been developed as a web based application. The MoD is planning to standardise its usage by incorporating it to the obsolescence management policy for defence contracting.

Romero Rojo, F.J., Roy, R., Kelly, S., "Obsolescence Risk Assessment Process Best Practice," *25th International Congress on Condition Monitoring and Diagnostic Engineering, COMADEM 2012*, Huddersfield, United Kingdom, June 18–20, 2012.

A component becomes obsolete when it is no longer available from the original manufacturer to the original specification. In long-lifecycle projects, obsolescence has become a major problem as it prevents the maintenance of the system. This is the reason why obsolescence management is now an essential part of the product support activities in sectors such as defence, aerospace, nuclear and railway; where systems need to be supported for several decades. The obsolescence risk assessment for the bill of materials (BoM) is a paramount activity in order to manage obsolescence proactively and cost-effectively. This is the reason why it was necessary to undertake a benchmarking study to develop best practice in this process. A total of 22 obsolescence experts from 13 different organisations/projects from across UK and USA have participated in this study. Their current processes and experience have been taken into account in the development of the best practice process for obsolescence risk assessment. The key factors that have to be analysed in the risk assessment process for each component in the BoM are: number of manufacturers, years to end of life, stock available, consumption rate and operational

impact criticality. For the very high risk components, a more detailed analysis is required to inform the decisions regarding the most suitable mitigation strategies. On the contrary, for the low risk components, a fully proactive approach is neither appropriate nor cost effective. Therefore, it is advised for these components that obsolescence issues are dealt with reactively. This process has been validated using case studies with several experts from industry and is currently being implemented by the UK Ministry of Defence as technical guidance within the JSP 886 Volume 7 Part 8.13 standards.

Romero Rojo, F.J., Roy, R., and Shehab, E., "Obsolescence Management for Long-Life Contracts: State of the Art and Future Trends," *International Journal of Advanced Manufacturing Technology,* Vol. 49, 2010, pp. 1235–1250.

This paper provides a comprehensive literature review on the problem of obsolescence in "sustainment-dominated systems" that require support for many decades. Research on this topic continues to grow as a result of the high impact of obsolescence on the in-service phase of long-term projects. Research on obsolescence also seeks to understand how it can be managed, mitigated and resolved. The paper aims to clarify and classify the different activities that may be included in an obsolescence management planning, taking into account not only electronic components, but also other aspects of the system such as mechanical components, software, materials, skills and tooling. The literature review shows that although there are many commercial tools available that support the obsolescence management during the in-service phase of the life cycle of a system, little research has been done to forecast the costs incurred. 2009 Springer-Verlag London Limited.

Romero Rojo, F.J., Roy, R., Shehab, E., and Cheruvu, K., "A Study on Obsolescence Resolution Profiles," SAGE Publications Ltd., London, United Kingdom, 2012.

This paper presents a study assessing the probability of selecting a resolution approach to tackle an obsolescence issue. First, the Delphi method was applied across an industry expert panel to derive a set of 15 obsolescence resolution profiles (ORPs). The ORPs represent the probability of using each obsolescence resolution approach to tackle an obsolescence issue. Each ORP is characterized by the complexity level of the obsolete component and the level of proactiveness for obsolescence management, which have been identified as the two major factors that influence the probability of using each resolution approach. Second, the results were enhanced by means of a definitions refinement workshop. Finally, the ORPs were refined and validated by means of a workshop with experts based on the theoretical trends expected for each resolution probability. More than 40 experts in obsolescence from across the UK from the defence, aerospace, railway and nuclear sectors have participated in the study. 2011 Authors.

Romero Rojo, F.J., Roy, R., Shehab, E., Cheruvu, K., and Mason, P., "A Cost Estimating Framework for Electronic, Electrical and Electromechanical (EEE) Components Obsolescence Within the Use-Oriented Product-Service Systems Contracts," SAGE Publications Ltd., London United Kingdom, 2012.

> This paper provides a cost estimating framework for electrical, electronic and electromechanical (EEE) components obsolescence, which represents the main source of obsolescence issues, owing to the increasingly short life cycle of these types of component. The framework comprises several areas: component complexity levels, obsolescence management levels, obsolescence resolution profiles and obsolescence cost metrics. Several studies, based on the literature and on interaction with numerous obsolescence management experts from industry, have been employed in this research, following a systematic approach. The framework is able to estimate the non-recurring cost of obsolescence during the contracted period within the inservice phase. This is based on the information available at the bidding stage concerning the product breakdown structure (PBS) and the obsolescence management strategy deployed. This framework has been validated at four different UK organizations in the defence and aerospace sectors using seven case studies, one of which is presented in this paper in detail. 2011 Authors.

Romero Rojo, F.J., Roy, R., Shehab, E., and Wardle, P.J, "Obsolescence Challenges for Product-Service Systems in Aerospace and Defence Industry," *1st CIRP Industrial Product-Service Systems (IPS2) Conference*, Cranfield University, United Kingdom, pp. 255.

> The aerospace and defence industries are moving towards new types of agreement such as availability contracts based on Product-Service System (PSS) business models. Obsolescence has become one of the main problems that will impact on many areas of the system during its life cycle. This paper presents the major challenges to managing obsolescence for availability contracts, identified by means of a comprehensive literature review and several interviews and forums with experts in obsolescence management. It is observed that there is a lack of understanding of the impact of obsolescence on whole life cost. Experts agree that the development of a framework to support estimation, management, and mitigation of these costs is desirable, but the difficulty in forecasting future obsolescence issues constrains industry to a reactive approach rather than proactive.

Rothmaier, M., "Modular Signal Processing Architecture to Mitigate Obsolescence in Airborne Systems," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, 2000, Vol. 21, pp. 21-21–21-26.

> After providing an introduction to the obsolescence problem, this paper explains bow the topic is handled to dated using an airborne radar system development as an example. In this the supplier primarily reacts on obsolete components with post design measures. In contrast to this a pro-active approach is suggested that starts with defining an architecture that eases the substitution of obsolete components and allows upgrades without involving major redesigns. This includes the need to safeguard the effort spend for developing and

qualifying application software. The article presents a modular structured signal processing architecture that employs COTS modules and standards. It discusses the ability of such an architecture to cope with the obsolescence problem by separating interfaces from processing units and applying COTS interface standards. Means of the designer are examined that allow to proactively design a processor that is likely to survive hardware and software component changes at minimum cost. Forming standard building blocks that encapsulate processing functions is presented as an approach that will considerably reduce the involved risk.

Saal, F. and Dube, J., "Minimizing the impact of parts obsolescence on PCB design," *Printed Circuit Design,* Vol. 18, No. 9, 2001, pp. 22.

Escalating time-to-market and cost pressures are no longer limited to new board designs. They play an equally important role in the replacement of obsolete parts and the constant renewal of established designs. Fortunately, the new comprehensive development environments with integrated obsolescence management capabilities can help designers cope with this ongoing problem. By focusing on team collaboration, and ensuring timely and accurate communication across the entire enterprise, board designers can minimize the impact of parts obsolescence and ensure that their boards are updated quickly and in the most cost-effective manner possible.

Sahyouni, K., Savaskan, R.C., and Daskin, M.S., "The Effect of Lifetime Buys on Warranty Repair Operations," *Journal of the Operational Research Society,* Vol. 61, 2010, pp. 790–803.

Lifetime buys are a common practice in the electronics and telecommunication industries. Under this practice, manufacturers procure their repair parts inventory in one order to support the spare part needs of a product for the duration of its warranty repair period. In this paper, we consider a repair operation in which defective items under warranty are returned to a manufacturer who either repairs these items using its spare parts inventory or replaces each defective unit with a new product. We show how fixed repair capability costs, variable repair costs, inventory holding costs, and replacement costs affect a firm's optimal repair and replacement decisions. The model is used to gain insights for products from a major mobile device manufacturer in the United States. 2010 Operational Research Society Ltd. All rights reserved.

Saleh, J.H., "Flawed Metrics: Satellite Cost per Transponder and Cost per Day," *IEEE Transactions on Aerospace and Electronic Systems,* Vol. 44, No. 1, 2008, pp. 147–156.

In engineering design, metrics play a critical role in guiding design choices. It is therefore of prime importance that the metrics used to guide decision-making be the "right" metrics. This paper makes the case that two metrics used to guide communications satellites design, namely cost per operational day, and cost per transponder, are flawed under certain conditions in the sense that they result in design choices-increasingly longer lived satellites and larger payloads-that do not necessarily maximize the system's value. This paper advocates a value-centric mindset in system design, and proposes shifting the emphasis from cost to value analyses to guide design choices that maximize a system's

value. Counter-examples are provided that challenge the traditional wisdom that longer lived or bigger satellites, being more cost effective on a per-day or per-transponder basis, are also more profitable or valuable. It is shown that while these metrics are useful guides for design choices in a supply-constrained market (in which a cost-centric mindset can prevail), they are flawed metrics on which to base decisions if the market is competitive, and in which the revenues from the system are not guaranteed to remain stable over time, through the impact of technology obsolescence, or overcapacity resulting in downward pressure on transponder lease prices. Finally, the case is made that the current market conditions require a value-centric mindset (as opposed to a cost-centric mindset) that views a spacecraft as a value-delivery artifact, and integrates considerations about the system's cost, its technical environment, and the market it is serving.

Sandborn, P., "Beyond Reactive Thinking – We Should Be Developing Pro-Active Approaches to Obsolescence Management Too!," *DMSMS Center of Excellence Newsletter,* Vol. 2, No. 4, 2004.

No abstract available.

Sandborn, P., "Designing for Technology Obsolescence Management," *IIE Annual Conference and Expo 2007 - Industrial Engineering's Critical Role in a Flat World*, Nashville, Tennessee, 2007, pp. 1684–1689.

Many types of products that have to be manufactured and supported for long periods of time lack control over critical parts of their supply chain, e.g., avionics, telecom infrastructure, and industrial controls. As a result, the components and technologies that these products depend on become obsolete long before the product's field life (and sometimes even manufacturing life) ends. Obsolescence management, which is an inevitability for these products, should be considered during product design and when planning for life cycle sustainment. This paper addresses forecasting obsolescence and other strategic planning methods to minimize future obsolescence impact.

Sandborn, P., "Strategic Management of DMSMS in Systems," *DSP Journal*, pp. 24–30.

No abstract available.

Sandborn, P., "Trapped on Technology's Edge," *IEEE Spectrum,* Vol. 45, No. 4, 2008, pp. 42–58.

No abstract available.

Sandborn, P. and Myers, J., "Designing Engineering Systems for Sustainability," *Handbook of Performability Engineering*, Springer, 2008, pp. 81–104.

Sustainability means keeping an existing system operational and maintaining the ability to manufacture and field versions of the system that satisfy the original requirements. Sustainability also includes manufacturing and fielding revised versions of the system

that satisfy evolving requirements, which often requires the replacement of technologies used in the original system with newer technologies. Technology sustainment analysis encompasses the ramifications of reliability on system management and costs via sparing, availability and warranty. Sustainability also requires the management of technology obsolescence (forecasting, mitigation and strategic planning) and addresses roadmapping, surveillance, and value metrics associated with technology insertion planning.

Sandborn, P., Prabhakar, V., and Ahmad, O., "Forecasting Technology Procurement Lifetimes for Use in Managing DMSMS Obsolescence," *Microelectronics Reliability,* Vol. 51, No. 2, 2011, pp. 392–399.

Many technologies have life cycles that are shorter than the life cycle of the product or system they are in. Life cycle mismatches caused by the obsolescence of technology can result in large life cycle costs for long field life systems, such as aircraft, ships, communications infrastructure, power plant and grid management, and military systems. This paper addresses DMSMS (Diminishing Manufacturing Sources and Materials Shortages) obsolescence, which is defined as the loss of the ability to procure a technology or part from its original manufacturer. Forecasting when technologies and specific parts will become unavailable (non-procurable) is a key enabler for pro-active DMSMS management and strategic life cycle planning for long field life systems. This paper presents a methodology for generating algorithms that can be used to predict the obsolescence dates for electronic parts that do not have clear evolutionary parametric drivers. The method is based on the calculation of procurement lifetime using databases of previous obsolescence events and introduced parts that have not gone obsolete. The methodology has been demonstrated on a range of different electronic parts and for the trending of specific part attributes.

Sandborn, P., Prabhakar, and Eriksson, B., "The Application of Product Platform Design to the Reuse of Electronic Components Subject to Long-Term Supply Chain Disruptions," *2008 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC 2008*, New York City, New York, Vol. 1, 2008, pp. 989–998.

Component reuse in multiple products has become a popular way to take advantage of the economies of scale across a family of products. Amongst electronic system developers there is a desire to use common electronic parts (chips, passive components, and other parts) in multiple products for all the economy of scale reasons generally attributed to platform design. However, the parts in electronic systems (especially those manufactured and supported over significant periods of time), are subject to an array of long-term life-cycle supply chain disruptions that can offset savings due to part commonality depending on the availability of finite resources to resolve problems on multiple products concurrently. In this paper we address the application of product platform design concepts to determine the best reuse of electronic components in products that are subject to long-term supply chain disruptions such as reliability and obsolescence issues. A detailed total cost of ownership model for electronic parts is coupled with a finite resource model to demonstrate that, from a life-cycle cost viewpoint, there is an optimum quantity of products that can use the same part beyond which costs increase. The analysis

indicates that the optimum part usage is not volume dependent, but is dependent on the timing of the supply chain disruptions. This work indicates that the risk and timing of supply chain disruptions should be considered in product platform design. Copyright 2008 by ASME.

Sandborn, P., Prabhakar, V., and Feng, D., "DMSMS Lifetime Buy Characterization via Data Mining of Historical Buys," *DMSMS Conference*, Orlando, Florida, 2007.

No abstract available.

Sandborn, P. and Singh, P., "Electronic Part Obsolescence Driven Design Refresh Optimization," *Proceedings of FAA/DoD/NASA Aging Aircraft Conference*, San Francisco, California, 2002.

Many electronic parts have life cycles that are shorter than the life-cycle of the product they are in. Life-cycle mismatches caused by the obsolescence of electronic parts result in higher sustainment costs for long life systems. In particular, avionics and military systems often encounter part obsolescence problems before being fielded and nearly always experience part obsolescence problems during their field life. This paper presents a methodology for determining the optimum design refresh (redesign) schedule for long field life electronic systems based on forecasted electronic part obsolescence and a mix of obsolescence mitigation approaches ranging from lifetime buys to part substitution.

Sandborn, P.A., "Editorial Software Obsolescence: Complicating the Part and Technology Obsolescence Management Problem," *IEEE Transactions on Components and Packaging Technologies,* Vol. 30, No. 4, 2007, pp. 886–888.

No abstract available.

Sandborn, P.A., Herald, Jr., T.E., houston, J., and Singh, P., "Optimum Technology Insertion Into Systems Based on the Assessment of Viability," *IEEE Transactions on Components and Packaging Technologies,* Vol. 26, No. 4, 2003, pp. 734–738.

Product sustainment means keeping an existing system operational and maintaining the ability to continue to manufacture and field versions of the system that satisfy the original requirements. Sustainment also includes manufacturing and fielding revised versions of the system that satisfy evolving requirements, which often requires the replacement of technologies used to construct the original system with newer technologies. Technology insertion involves determining which technologies to replace during a design refresh, i.e., deciding the design refresh content, and deciding when that design refresh should take place. Technology replacement decisions are driven by a broad range of issues including performance, reliability, environmental impact, cost, and logistics, and when, or if other design refreshes will take place. Traditional "value" metrics go part of the way toward providing a coupled view of performance, reliability and cost, but are generally ignorant of how product sustainment may be impacted. A metric that measures both the value of the technology refreshment and insertion, and its ability to support both the system's

current and future affordability and capability needs including hardware, software, information and intellectual property is required. This paper discusses a concept called viability. Viability is a measure of the producibility, supportability, and evolvability of a system and can serve as a metric for assessing technology insertion opportunities.

Sandborn, P.A., Mauro, F., and Knox, R., "A Data Mining Based Approach to Electronic Part Obsolescence Forecasting," *IEEE Transactions on Components and Packaging Technologies,* Vol. 30, No. 3, 2007, pp. 397–401.

Many technologies have life cycles that are shorter than the life cycle of the product they are in. Life cycle mismatches caused by the obsolescence of technology (and particularly the obsolescence of electronic parts) results in high sustainment costs for long field life systems, e.g., avionics and military systems. This paper demonstrates the use of data mining based algorithms to augment commercial obsolescence risk databases thus improving their predictive capabilities. The method is a combination of life cycle curve forecasting and the determination of electronic part vendor-specific windows of obsolescence using data mining of historical last-order or last-ship dates. The extended methodology not only enables more accurate obsolescence forecasts, but can also generate forecasts for user-specified confidence levels. The methodology has been demonstrated on both individual parts and modules.

Sandborn, P.A. and Wilkinson, C., "A Maintenance Planning and Business Case Development Model for the Application of Prognostics and Health Management (PHM) To Electronic Systems," *Microelectronics Reliability,* Vol. 47, No. 12, 2007, pp. 1889–1901.

This paper presents a model that enables the optimal interpretation of prognostics and health management (PHM) results for electronic systems. In this context, optimal interpretation of PHM results means translating PHM information into maintenance policies and decisions that minimize life-cycle costs, or maximize availability or some other utility function. The electronics PHM problem is characterized by imperfect and partial monitoring, and a random/overstress failure component must be considered in the decision process. Given that the forecasting ability of PHM is subject to uncertainties in the sensor data collected, the failure and damage accumulation models applied, the material dimensions and properties used in the models, the decision model in this paper addresses how PHM results can best be interpreted to provide value to the system maintainer. The result of this model is a methodology for determining an optimal safety margin and prognostic distance for various PHM approaches in single and multiple socket systems where the LRU's in the various sockets that make up a system can incorporate different PHM approaches (or have no PHM structures at all). The discrete event simulation model described in this paper provides the information needed to construct a business case showing the application-specific usefulness for various PHM approaches including health monitoring (HM) and life consumption monitoring (LCM) for electronic systems. An example business case analysis for a single socket system is provided. 2007 Elsevier Ltd. All rights reserved.

Sarthou, C., "Technical Progress and Obsolescence (Trans. from French)," *Cahier D'etudes of the Groupe D'etudes, Recherche et Developement de l'Association Francaise pour l'Accroissement de La Productivite (France),* Vol. 2, 1964, pp. 146.

> French tax structure with respect to write-off for scientific research and development, patent assignment and licensing, accelerated depreciation of equipment is described, with quotations from tax laws and sample questionnaires to be completed for exemption. Present and future impact of technical progress on national economy and world development is discussed and projected. Controversial opinions on allocation and tangible results of Govermment-sponsored and private R & D, between US and European economists are debated.

Sawyer, S.D., "Outdated Controls & Instrumentation in Nuclear Power Plants - Strategies for Extending Useful Life," *IEEE Nuclear Science Symposium Conference Record*, Vol. 5, 2003, pp. 3617–3621.

> Technological improvements in today's electronic systems continuously occur. For example, each and every year, computer platforms change significantly in functionality, reliability, and interface needs. In contrast, the Instrumentation and Controls (I&C) used in nuclear plant systems are generally very customized and demand a frozen design with long-term supplier participation in I&C support strategies. And for 20+ year-old plants, eventually such custom systems become more costly to maintain and out-of-sync with today's technology. As a result, today's nuclear I&C maintenance departments are faced with outdated electronics, increased failure rates, and tight plant operating budgets - it becomes a constant dilemma to identify solutions and strategies for sustained plant operation. This paper offers some strategies, techniques, and guidelines for obsolescence-proofing through I&C inventory service contracts, spare parts, repairs, and upgrades/mods. In addition, a Control Room Initiative program is discussed to create a framework for electronics life extension thereby improving the reliability, functionality, and human factors of the overall plant.

Scanlan, L. and Vahey, M., "Rapid prototyping of Application-Specific Signal Processors (RASSP)," AIAA/IEEE *Digital Avionics Systems Conference, 13th DASC, 1994,* pp. 432–437.

> RASSP will dramatically reduce the obsolescence of new electronic systems at their introduction and will maintain their technological currency over an extended life cycle. The four-year program will evolve and continually improve a design environment capable of yielding four times reduction in digital electronics design cycle time along with a similar improvement in quality. Success is demonstrated with the rapid development and easy model-year upgrade of an image signal processor for an infra-red search and track (IRST) application. Additional RASSP design environment (RDE) feedback and proof are obtained through a series of beta site evaluations and benchmarks assessments.

Schaller, R.R., "Technological Innovation in the Semiconductor Industry: a Case Study of the International Technology Roadmap for Semiconductors (ITRS)," George Mason University, 2004.

This dissertation is an historical and evaluative study of the Semiconductor Industry Association's (SIA) Technology Roadmap, now referred to as the *International Technology Roadmap for Semiconductors (ITRS)* or simply, the "Roadmap." Technology roadmaps and roadmapping practices comprise new and emerging tools in technology strategy, planning and management that have gained increasing attention by researchers. This study addresses how technology roadmaps affect technological innovation, corporate strategies, and public policies in the semiconductor industry.

This inquiry is accomplished through an examination of the technology roadmap 'landscape' more generally and a case-based analysis of the ITRS in particular. Several hypotheses were formulated to help seek greater and deeper understanding of not just the Roadmap, but the surrounding context within which it emerged and has since evolved. This unique approach will demonstrate the overall thesis that the Roadmap is part of a continuing tradition wedded to the goal of sustaining historical industrial productivity—also referred to as "Moore's Law."

In support of this, an important contribution of the study is substantial historical research of key developments within the semiconductor industry. The findings depart from more widely accepted interpretations of technological innovation advanced by much previous research. Specifically, this research is concerned with the industry's heritage of incremental or evolutionary technological change following a *normal* innovation pattern, particularly involving manufacturing *process* innovations in semiconductors.

The findings also suggest that the Roadmap continues the decades-long heritage of normal innovation, now conducted at an international level and reaching across a wide and complex supply chain network. Finally, the analysis supports a new structural approach to technological innovation, one that is more coordinated with the help of a global industry roadmap. Thus a theory of *organized innovation* is advanced that helps explain how the increasingly fragmented semiconductor innovation community is able to continue working in cadence to address the daunting technical and economic challenges facing the industry 'down the road'.

Schmied, D., Burtin, E., Guerin, P., Hahn, M., and Kersevan, R., "Upgrade of the ESRF Vacuum Control System," *Proceedings of the Particle Accelerator Conference, PAC 2005,* 2005, pp. 2857–2859.

The whole vacuum control system of the electron storage ring (SR) of the ESRF is in operation since more than ten years now. Apart from difficulties to have appropriate support for the old system, we start facing problems of aging and obsolescence. We have been reviewing our philosophy of data acquisition and remote control in order to upgrade our systems with state of the art technology, taking into account our operational experience. We have started installing shielded “intelligent” devices

inside the SR and taking advantage of the latest developments linked to new technologies, such as OPC Server (Openness, Productivity, Connectivity), Webpage instrument control and more. This paper outlines our actual work dedicated for Programmable Logical Controller (PLC) applications.

Schmittlein, D. and Mahajan, V., "Maximum Likelihood Estimation for an Innovation Diffusion Model of New Product Acceptance," *Marketing Science,* Vol. 1, No. 1, 1982, pp. 57–78.

A maximum likelihood approach is proposed for estimating an innovation diffusion model of new product acceptance originally considered by Bass (1969). The suggested approach allows: (1) computation of approximate standard errors for the diffusion model parameters, and (2) determination of the required sample size for forecasting the adoption level to any desired degree of accuracy. Using histograms from eight different product renovations, the maximum likelihood estimates are shown to outperform estimates front a model calibrated using ordinary least squares, m terms of both goodness of fit measures and one-step ahead forecasts. However, these advantages are not obtained without cost. The coefficients of innovation and imitation are easily interpreted in terms of the expected adoption pattern, but individual adoption times must be assumed to represent independent draws from this distribution In addition, instead of using standard linear regression, another (simple) program must be employed to estimate the model. Thus, tradeoffs between the maximum likelihood and least squares approaches are also discussed.

Schneiderman, R., "Managing Product Obsolescence - Now You See It Now You Don't," *Electronic Design*, Vol 52, 2004, pp. 47–52.

Various ways of product obsolescence management of chip manufacturers are discussed. Semiconductor manufacturers are trying to meet the requirements of Europe's Restriction of Hazardous Substances (RoHS) to switch over to lead-free products. International lead-free mandates must contend with changing out virtually entire product inventories, assigning part numbers to the new devices and communicating all of these changes in real time to their distributors, OEMs and contract manufacturers. The British government is partially finding the National Obsolescence Center to support those companies suffering from the commercial consequences of component obsolescence.

Schwartz, R.J., Bowen, A.R., and Knowles, T., "Solving Bezel Reliability and CRT Obsolescence," *Cockpit Displays X*, Orlando, Florida, Vol. 5080, pp. 96–107.

Scientific Research Corporation designed a Smart Multi-Function Color Display with Positive Pilot Feedback under the funding of an U. S. Navy Small Business Innovative Research program. The Smart Multi-Function Color Display can replace the obsolete monochrome Cathode Ray Tube display currently on the T-45C aircraft built by Boeing. The design utilizes a flat panel color Active Matrix Liquid Crystal Display and TexZec's patented Touch Thru Metal bezel technology providing both visual and biomechanical feedback to the pilot in a form, fit, and function replacement to the current T-45C display. Use of an existing color AMLCD, requires the least adaptation to fill the requirements of

this application, thereby minimizing risk associated with developing a new display technology and maximizing the investment in improved user interface technology. The improved user interface uses TexZec's Touch Thru Metal technology to eliminate all of the moving parts that traditionally have limited Mean-Time-Between-Failure. The touch detection circuit consists of Commercial-Off-The-Shelf components, creating touch detection circuitry, which is simple and durable. This technology provides robust switch activation and a high level of environmental immunity, both mechanical and electrical. Replacement of all the T-45C multi-function displays with this design will improve the Mean-Time-Between-Failure and drastically reduce display life cycle costs. The design methodology described in this paper can be adapted to any new or replacement display.

Sherif, Y.S. and Rice, E.L., "The Search for Quality: The Case of Planned Obsolescence," *Microelectronics Reliability,* Vol. 26, No. 1, 1986, pp. 75–85.

Planned obsolescence involves a design plan that is intended to hasten existing products to become undesirable (not necessarily below that of competitive offerings) either functionally or psychologically and consequently to be replaced by new products. Many manufacturing companies since the last decade have adopted the policy of planned obsolescence in their products. Their main objective is to cut costs, increase profits and secure continuous consumption and production. When this policy is abused, however, so that customers are not getting products which can perform adequately and safely for a reasonable amount of time, the end result may prove to be more detrimental than beneficial, not only to producers and consumers, but to the nation as a whole. In this age of scarce resources, energy shortages and new challenges, this paper re-examines planned obsolescence and searches for quality in todays products.

Shirlaw, S.G., "Radio and Communications-Based Train Control: Migration, Interoperation and System Engineering Issues," *IET International Conference on Railway Engineering, ICRE 2008*, Hong Kong, China, 2008, pp. 124–128.

CBTC is now the technology chosen by many Transit operators worldwide. As operators target efficient train operations, they also take the opportunity of the change to CBTC technology to ask for improved performances and for the integration of more constraints. This paper presents these enhanced requirements and constraints and the ways in which advanced engineering solutions help to deal with these as well the varied operating conditions now found in urban environments. The advanced solution from Alstom is the URBALIS networked CBTC. The previous non-CBTC Train Control systems from Alstom have delivered design headways of 90 seconds for operations at around 105 seconds. Examples of such operations include lines in Sao Paulo and Santiago giving real peak throughput of 40,000 to 70,000 pphpd (passengers per hour per direction). Now the target, for example on a project such as Milan Metro Line 1, is to achieve a 15% improvement to allow operation at 90 seconds on a heavy metro rail line. A first CBTC innovation was the implementation in 2003 of a Radio-based CBTC for the 20 km Singapore North-East line. This allowed driverless operation of a heavy metro rail line with a capacity of 42,000 pphpd. Now, the 36 km Shanghai Line 10 project, to be delivered in 2010, will be the world's second heavy metro rail driverless line. This line, as

well as the 110 kph driverless Beijing Airport Express link, are being implemented with URBALIS as an advanced and affordable solution for driverless metros. For CBTC systems, the many trackside and train-borne interfaces are of paramount importance to the safety and performance of the system. The URBALIS networked CBTC has a communication system based on three integrated networks: a trackside network, a train network and a radio network. Standard radios are used, but with a choice of propagation medium: Free Propagation, Leaky Feeder or Wave Guide. This choice of medium allows an optimum match to the radio environmental constraints found in Transit applications. Advanced technologies also facilitate rapid migration to CBTC in difficult Transit projects where there is little time to do the work. Facilitating equipment fitment to existing trains is another key issue. Interoperation can be a key issue and covers many facets. An example is given of a major suburban Metro line that has to allow interoperation of CBTC equipped Metro trains with ETCS equipped Mainline trains. Finally, to meet the needs of such a wide range of performance and operating constraints, the System Engineering approach is now integrated with a product line engineering approach. This also helps to deal with other key customer needs such as achieving on-time delivery and obsolescence management.

Short, P., "Don't Fret Over IC Obsolescence, Prepare For It," *Electronic Design*, Vol. 54, pp. 22.

Several tips for ICs to protect the systems from obsolescence are discussed. Component engineering in the design phase should be included and the problem components and cost drivers should be identified. The probability of an early discontinuation notice should be minimized by choosing the right part for the socket. The parts should be chosen that specifically target the market and application, and a vendor should be selected that has a reputation for supplying devices for the length of time which is required. One should be bewared of compatibility in picking a processor and calculate the entire life-cycle costs of non-recurring costs and logistics costs. Reviewing one's plans and problem parts will also provide great help. A strategy should be developed to predict and respond before the part goes end of life (EOL). Prediction tools can become a part of the system if the suppliers are contacted frequently.

Shuman, L., "Cost-Benefit Analysis Tools for Avionics Parts Obsolescence," Maxwell Air Force Base, Alabama, Air University, Graduation Requirements, 2002.

Obsolescence management, an ever-increasing topic in the Department of Defense, is not new. Since the service life of military systems is much longer than commercial systems, maintaining military systems when parts and components go out of production remains a sustainment challenge. Typically, resolving obsolete parts problems are incorrectly identified as reliability and maintainability issues that provide no improved capability or reduced cost; the primary benefit is continued sustainability of the existing system. Since loss of a capability is not an option, maintaining the capability without a part redesign does require increased cost for the commercial market to support a military-unique application. In addition, constrained defense funding will necessitate prudent use of limited funding to balance current systems maintenance and new systems acquisition. The specific objective of this project is to show the need for automated cost-benefit

analysis tools to assist program/item managers in identifying the cost savings associated with resolving obsolete parts problems. The project provides an analysis of the cost-benefit relationship of the resolution options available to the program/item manager. Additionally, the project identifies and analyzes cost-benefit analysis tools for making decisions associated with sustaining the obsolete item versus acquiring a supportable replacement.

Shuman, L.L.M., "Cost-Benefit Analysis Tools For Avionics Parts Obsolescence." Maxwell Air Force Base, Alabama, Air Command and Staff College Air University, 2002.

Obsolescence management, an ever-increasing topic in the Department of Defense, is not new. Since the service life of military systems is much longer than commercial systems, maintaining military systems when parts and components go out of production remains a sustainment challenge. Typically, resolving obsolete parts problems are incorrectly identified as reliability and maintainability issues that provide no improved capability or reduced cost; the primary benefit is continued sustainability of the existing system. Since loss of a capability is not an option, maintaining the capability without a part redesign does require increased cost for the commercial market to support a military-unique application. In addition, constrained defense funding will necessitate prudent use of limited funding to balance current systems maintenance and new systems acquisition. The specific objective of this project is to show the need for automated cost-benefit analysis tools to assist program/item managers in identifying the cost savings associated with resolving obsolete parts problems. The project provides an analysis of the cost-benefit relationship of the resolution options available to the program/item manager. Additionally, the project identifies and analyzes cost-benefit analysis tools for making decisions associated with sustaining the obsolete item versus acquiring a supportable replacement.

Singh, P. and Sandborn, P., "Forecasting Technology Insertion Concurrent With Design Refresh Planning for Cots-Based Electronic Systems," *Annual Reliability and Maintainability Symposium,* Arlington, Virginia, 2005, pp. 349–354.

This paper describes a methodology for forecasting technology insertion concurrent with obsolescence driven design refresh planning. The optimized parameter is the life-cycle cost of the system. The resulting analysis provides a design refresh schedule for the system (i.e., when to design refresh) and predicts the design refresh content for each of the scheduled design refreshes. Optimal design refresh content is determined using a hybrid analysis scheme that utilizes Monte Carlo methods to account for uncertainties (in dates) and Bayesian Belief Networks to enable critical decision making after candidate refresh dates are selected.

Singh, P. and Sandborn, P., "Obsolescence Driven Design Refresh Planning for Sustainment-Dominated Systems," *Engineering Economist,* Vol. 51, No. 2, pp. 115–139.

Many technologies have life cycles that are shorter than the life-cycle of the product they are in. Life-cycle mismatches caused by the obsolescence of technology (and particularly

the obsolescence of electronic parts) results in high sustainment costs for long field life systems, e.g., avionics and military systems. This article presents a methodology for performing optimum design refresh planning for sustainment-dominated electronic systems based on forecasted technology obsolescence and a mix of obsolescence mitigation approaches ranging from lifetime buys to part substitution. The methodology minimizes the life-cycle cost by determining the optimum combination of design refresh schedule for the system (i.e., when to design refresh) and the design refresh content for each of the scheduled design refreshes. The analysis methodology can be used to generate application-specific economic justifications for design refresh approaches to obsolescence management

Sjoberg, E.S. and Harkness, L.L, "Integrated Circuit Obsolescence and its Impact on Technology Insertion Definition for Military Avionics Systems," *Proceedings of the IEEE 1996 National Aerospace and Electronics Conference. Part 1 (of 2),* Dayton, Kentucky, Vol. 2, 1996, pp. 792–799.

> The Georgia Tech Research Institute (GTRI) has developed an approach for efficiently postulating and evaluating methods for addressing IC obsolescence and thereby extending the life of radars and other avionics systems. The GTRI approach identifies specific assemblies for potential replacement and evaluates the system level impact. The initial impetus for this research was the increasing obsolescence of the ICs contained in the AN/APG-63 system. Just recently, the approach has been applied to the AN/ALQ-135 Internal Countermeasures Set of the F-15 aircraft.

Smith, D.R., "Obsolescence Evaluation of Process Control Computer Systems," *IEE Transactions on Power Apparatus and Systems,* Vol. PAS-101, No. 1, January, 1982, 191–194.

> The determination of when a process control computer system is obsolete and requires replacement is a problem that must be approached in a logical and objective manner. An approach has been developed which uses specific trigger points to determine when a detailed investigation of obsolescence is needed and which defines specific criteria against which the performance and continued suitability of the system can be judged. The methodology described can be applied to any type of process control computer system to give a systematic approach to determining and justifying the need to replace an existing system.

Smith, T., "Future Initiatives for Obsolescence Mitigation Strategies," *RTO Systems Concepts and Integration Panel (SCI) Symposium*, Budapest, Hungary, Vol. 30, 2000, pp. 30-31–30-13.

> The accelerating pace of technology change requires new approaches to the design manufacture and through life support of military and long life cycle commercial platforms to minimize the effects of short-term technology obsolescence. The purpose of this paper is to describe medium and long-term strategies for the mitigation of obsolescence currently being considered in the UK. All complex military equipment are at risk from the effects of unmanaged technology obsolescence before and after they enter service. A systems sentineling approach is described for the evolution of strategies

that would involve co-operation between users and manufacturers to produce affordable through life solutions.

Smitherman, K.O. and Smith, J.W., "Military TTL Obsolescence: What Now?," *Southcon/87 Conf Rec.,* Atlanta, Georgia, Vol. 7, No.1, 1986, 4p–1.

Recent announcements by major Integrated Circuit (IC) manufacturers to discontinue various Transistor Transistor Logic (TTL) devices has resulted in a very serious problem for the military community. The number of military systems utilizing these devices as well as the different types and number of devices involved is staggering. Redesign is an alternative, but in most cases, should be the last option exercised due to the costs, time, and other considerations involved. An overview of some alternatives is given that are available to minimize the impact of IC obsolescence, and what is being done to lessen the impact of this problem.

Smiths Industries, "Obsolescence Management Policy," 1999.

No abstract available.

Sohns, C.W. and Ward, C.D., "Electronic Component Obsolescence," *Future of Instrumentation Workshop*, Oak Ridge, Tennessee, 2010.

Electronic component obsolescence occurs when parts are no longer available to support the manufacture and/or repair of equipment still in service. Future instrumentation containing complex components WILL face obsolescence issues as technology advances. This paper describes hardware and software obsolescence as well as factors to consider when designing new instrumentation.

Solomon, R., Sandborn, P.A., and Pecht, M.G., "Electronic Part Life-Cycle Concepts and Obsolescence Forecasting," *IEEE Transactions on Components and Packaging Technologies,* Vol. 23, No. 4, 2000, pp. 707–717.

Obsolescence of electronic parts is a major contributor to the life-cycle cost of long-field life systems such as avionics. A methodology to forecast life cycles of electronic parts is presented, in which both years to obsolescence and life-cycle stages are predicted. The methodology embeds both market and technology factors based on the dynamic assessment of sales data. The predictions enabled from the models developed in this paper allow engineers to effectively manage the introduction and on-going use of long field-life products based on the projected life-cycle of the parts incorporated into the products. Application of the methodology to integrated circuits is discussed and obsolescence predictions for dynamic random access memories (DRAMs) are demonstrated. The goal is to significantly reduce design iterations, inventory expenses, sustainment costs, and overall life-cycle product costs.

Song, J.-S. and Zipkin, P.H., "Managing Inventory With the Prospect of Obsolescence," *Operations Research,* Vol. 44, No. 1, 1996, pp. 215.

How should inventory management respond when there is a possibility of imminent obsolescence (or, more generally, deteriorating demand)? We use an inventory-control model to address this question. The model incorporates a Markovian submodel to describe the uncertain events leading to obsolescence. These events and their uncertainties come in a variety of patterns. We devote considerable attention to specifying the submodel, and we compare a few alternatives numerically. Also, we compare optimal policies to simpler alternatives, and we investigate the response of the model to parameter changes. Generally, we find that obsolescence does (or should) have a substantial impact in the way inventories are managed. The nature of these effects, moreover, is fairly intricate. It appears that obsolescence cannot be captured in a simpler model through parameter adjustments. These conclusions presume that we cannot dispose of excess stock, either directly or through price promotions; we show also that the disposal option can make the problems of obsolescence more manageable.

Song, Y. and Lau, H.C., "A Periodic-Review Inventory Model With Application to the Continuous-Review Obsolescence Problem," *European Journal of Operational Research,* Vol. 159, pp. 110–120.

In this paper we consider a stochastic-demand periodic-review inventory model with sudden obsolescence. We characterize the structure of the optimal policy and propose a dynamic programming algorithm for computing its parameters. We then utilize this algorithm to approximate the solution to the continuous-review sudden obsolescence problem with general obsolescence distribution. We prove convergence of our approximation scheme, and demonstrate it numerically against known closed-form solutions of special cases. 2003 Elsevier B.V. All rights reserved.

Srinivasan, V. and Mason, C.H., "Nonlinear Least Squares Estimation of New Product Diffusion Models," *Marketing Science,* Vol. 5, No. 2, 1986, 169–178.

No abstract available.

Stogdill, R.C., "Dealing With Obsolete Parts," *IEEE Design and Test of Computers,* Vol. 16, No. 2, 1999, pp. 17–25.

The US Air Force has launched an initiative to develop an affordable, systematic approach to dealing with obsolete electronic parts. In addition to management and reengineering tools, the initiative is developing reliability models for commercially manufactured electronics used in defense systems *Abstract Numbers: B1999-07-0140-00101.*

Stolinski, R. and Leonard, J., "Parts Obsolescence: a New Concern for EES," *IEEE Potentials,* Vol. 6, 1987, pp. 39–41.

> The authors discuss how engineers can avoid the problem of obsolescence of their designs. Two types of solutions are examined. Those that deal with the problem after it occurs include discussion with the vendor, which may provide a solution not previously known to the designer, and life-of-type buys, i. e. , buying a large quantity of the component that will carry the product through its expected life. Alternatively, the design can anticipate the parts obsolescence problem and make it a major design criterion. The authors discuss this solution.

Stradley, J. and Karraker, D., "The Electronic Part Supply Chain and Risks of Counterfeit Parts in Defense Applications," *IEEE Transactions on Components and Packaging Technologies [see also IEEE Transactions on Components, Packaging and Manufacturing Technology, Part A: Packaging Technologies],* Vol. 29, No. 3, 2006, pp. 703–705.

> No abstract available.

Szoch Jr, R.L., E.M. Brown, and Wilkinson, C.D., "Strategic Alliance to Address Safety System Obsolescence and Maintainability," *Proceedings of the 1994 Nuclear Science Symposium and Medical Imaging Conference.* Norfolk, Virginia, October 30–November 5, 1994, Vol. 3, pp .1073–1076.

> This paper describes a joint EPRI/Utility/Supplier project for evaluating the Reactor Protection Systems and Plant Protection Systems at Combustion Engineering (C-E) operating plants. The goal of the project is the development of long term maintenance plans that will solve obsolescence problems and extend the systems' useful life. Solutions developed under this project could be applied generically to other plant systems. The paper will describe each of the five phases of the project including: data collection and analysis, development of obsolescence evaluations and solutions, development of maintenance support evaluations and plans, development of long term plans for participating plants, development of a generic methodology for IC obsolescence and maintainability evaluations.

Tacha, N., McCarthy, A., Powell, B., and Veeramani, A., "How to Mitigate Hardware Obsolescence in NextGen Test Systems," *IEEE Aerospace and Electronic Systems Magazine*, Vol. 25, 2010, pp. 30–36.

> Automatic test engineers are faced with replacing obsolete software and hardware in systems that remain in operation longer than individual components are supported. Replacing obsolete hardware can be especially challenging because of the need to modify test software in order to support new instrumentation. Changes to test software to support new instrumentation might affect multiple areas of the application and require time-consuming development or costly revalidation. This explains how you can mitigate hardware obsolescence with the use of well-designed hardware abstraction layers.

TechAmerica, "Standard for Preparing a DMSMS Management Plan," 2011.

> The purpose of this document is to define the requirements for developing a Diminishing Manufacturing Sources and Materials Shortages (DMSMS) Management Plan. It is intended for use by system integrators, original equipment manufacturers (OEM), and logistic support providers of aerospace, defense and high reliability equipment to help develop their own DMSMS Management Plan, hereinafter also called the Plan, to document the processes used to meet the Technical Requirements detailed in clause 5 which will minimize the impact that obsolete parts and materials have on equipment life cycle costs. It is not intended for use by suppliers of parts or materials. This document states objectives to be accomplished; it does not specify how tasks are to be performed, specific data to be collected or reports to be issued. Those who prepare Plans in compliance with this document are encouraged to document processes that are the most effective and efficient for them in accomplishing the requirements stated in this document. In order to allow flexibility in implementing and updating the documented processes, Plan authors are encouraged to refer to their own internal process documents instead of including detailed process documentation within their Plans. Organizations that prepare such Plans may prepare a single Plan, and use it for all relevant products supplied by the organization, or may prepare a separate Plan for each relevant product or customer.

Teng, C.C., Bernard, III, L.J., and Lessing, P.A., "Technology Refresh of NOAA's Tropical Atmosphere Ocean (TAO) Buoy System," *OCEANS 2006,* Boston, Massachusetts, pp. 1–6.

> National Oceanic and Atmospheric Administration's (NOAA) Tropical Atmosphere Ocean (TAO) buoy array has a long history of providing valuable climate data to both the climate and forecast communities. A major concern for a sustained and long-term TAO operation is the impending obsolescence of the technology used in the current version of the TAO array. An increasing number of components are being discontinued or are no longer supported by the manufacturers due to the technology presently used being more than 10 years old. During the transition of the TAO array from NOAA's Pacific Marine Environmental Laboratory (PMEL) to NOAA's National Data Buoy Center (NDBC), it was decided to take this opportunity to "refresh" the TAO buoy system by replacing the obsolescent components in the current TAO system to ensure continuity of the TAO array. This paper first discusses the obsolescent components in the existing TAO array system. Then, the refreshed components of the refreshed TAO buoy system are discussed, including a newly-designed data logger, modified battery system, commercial off-the-shelf underwater sensors, a new compass, Iridium communication, modified and enhanced shore-side data system, and other minor design modifications. The field testing of the TAO refreshed buoys is also presented.

Teunter, R.H. and Fortuin, L., "End-of-Life Service: A Case Study," *European Journal of Operational Research,* Vol. 107, pp. 19–34.

> Philips is a company that produces electronic equipment like kitchen appliances, television sets, videorecorders, medical equipment, and so on. This equipment is sold

world-wide. The central service organization of Philips, situated in Eindhoven (The Netherlands), is responsible for providing spare parts for these products during the entire service period. The length of this service period depends on the type of product. Television sets, for instance, have a service period of eight years. Since the service period is typically much longer than the production period, the service department places a large `final order' for spare parts at the moment the product is taken out of production. This final order is expected to suffice, with a sufficiently large probability, until all service obligations have ended. In this paper we seek close to optimal final order quantities. Actually, this paper is a follow-up on a more theoretical paper, in which a close to optimal final order quantity, given by an explicit formula was derived. This paper presents the results of trying to apply that formula in practice.

Teunter, R.H. and Fortuin, L., "End-of-Life Service," *International Journal of Production Economics,* Vol. 59, 1999, pp. 487–497.

Producers of complex machines offer lasting service contracts to their customers. To be able to provide service, spare parts are held in stock. Since the service period is typically much larger than the production period, the service department places a large `final order' for spare parts at the moment the machine is taken out of production. This final order is expected to last until all service contracts have ended. In this paper we deal with finding (close to) optimal final order quantities. The main result is the derivation of a close to optimal final order quantity, given by an explicit formula. Furthermore, we also determine `remove-down-to' levels for spare parts. These levels are used to reduce cost by removing stock before all service contracts have expired. The effects of introducing remove-down-to levels on the expected cost and the optimal final order quantity are shown.

Teunter, R.H. and Klein Haneveld, W.K., "The 'Final Order' Problem," *European Journal of Operational Research,* Vol. 107, No. 1, 1998, pp. 35–44.

When the service department of a company selling machines stops producing and supplying spare parts for certain machines, customers are offered an opportunity to place a so-called final order for these spare parts. We focus on one customer with one machine. The customer plans to use this machine up to a fixed horizon. Based on this horizon, and on the failure rates of the components, the prices of spare components and the consequences of the machine failing before the critical lifetime is reached, the size of the final order is determined.

Teunter, R.H. and Klein Haneveld, W.K., "Inventory Control of Service Parts in the Final Phase," *European Journal of Operational Research,* Vol. 137, No. 3, 2002, pp. 497-511.

We consider an appliance manufacturer's problem of controlling the inventory of a service part in its final phase. That phase begins when the production of the appliance containing that part is discontinued (time 0), and ends when the last service contract on that appliance expires. Thus, the planning horizon is deterministic and known. There is no setup cost for ordering. However, if a part is not ordered at time 0, its price will be

higher. The objective is to minimize the total expected undiscounted costs of replenishment, inventory holding, backorder, and disposal (of unused parts at the end of the planning horizon). We propose an ordering policy consisting of an initial order-up-to level at time 0, and a subsequent series of decreasing order-up-to levels for various intervals of the planning horizon. We present a method of calculating the optimal policy, along with a numerical example and sensitivity analysis.

Teunter, R.H., Syntetos, A.A., and Babai, M.Z., "Intermittent Demand: Linking Forecasting to Inventory Obsolescence," *European Journal of Operational Research,* Vol. 214, No. 3, November 2011, pp. 606–615.(3).

The standard method to forecast intermittent demand is that by Croston. This method is available in ERP-type solutions such as SAP and specialised forecasting software packages (e.g., Forecast Pro), and often applied in practice. It uses exponential smoothing to separately update the estimated demand size and demand interval whenever a positive demand occurs, and their ratio provides the forecast of demand per period. The Croston method has two important disadvantages. First and foremost, not updating after (many) periods with zero demand renders the method unsuitable for dealing with obsolescence issues. Second, the method is positively biased and this is true for all points in time (i.e., considering the forecasts made at an arbitrary time period) and issue points only (i.e., considering the forecasts following a positive demand occurrence only). The second issue has been addressed in the literature by the proposal of an estimator (Syntetos-Boylan Approximation, SBA) that is approximately unbiased. In this paper, we propose a new method that overcomes both these shortcomings while not adding complexity. Different from the Croston method, the new method is unbiased (for all points in time) and it updates the demand probability instead of the demand interval, doing so in every period. The comparative merits of the new estimator are assessed by means of an extensive simulation experiment. The results indicate its superior performance and enable insights to be gained into the linkage between demand forecasting and obsolescence. 2011 Elsevier B.V. All rights reserved.

Thompson, H.A., Ramos-Hernandez, D.N., Fu, J., et al., "A Flexible Environment for Rapid Prototyping and Analysis of Distributed Real-Time Safety-Critical Systems," *Control Engineering Practice,* Vol. 15, January 2007, pp. 77–94.

Currently, there is a plethora of low-cost commercial off-the-shelf (COTS) hardware available for implementing control systems. These range from devices with fairly low intelligence, e.g., smart sensors and actuators, to dedicated controllers such as PowerPC, programmable logic controllers (PLCs) and PC-based boards to dedicated systems-on-a-chip (SoC) ASICS and FPGAs. When considering the construction of complex distributed systems, e.g., for a ship, aircraft, car, train, process plant, the ability to rapidly integrate a variety of devices from different manufacturers is essential. A problem, however, is that manufacturers prefer to supply proprietary tools for programming their products. As a consequence of this lack of 'openness', rapid prototyping and development of distributed systems is extremely difficult and costly for a systems integrator. Great opportunities thus exist to produce high-performance, dependable distributed systems.

However, the key element that is missing is software tool support for systems integration. The objective of the Flexible Control Systems Development and Integration Environment for Control Systems (FLEXICON) project IST-2001-37269 is to solve these problems for industry and reduce development and implementation costs for distributed control systems by providing an integrated suite of tools to support all the development life-cycle of the system. Work within the Rolls-Royce supported University Technology Centre (UTC) is investigating rapid prototyping of controllers for aero-engines, unmanned aerial vehicles and ships. This paper describes the use of the developed co-simulation environment for a high-speed merchant vessel propulsion system application. 2006 Elsevier Ltd. All rights reserved.

Tikku, S. and Raiskums, G., "Combating Obsolescence - ACR Digital Control Systems Design," *27th Annual Conference of the Canadian Nuclear Society and 30th Canadian Nuclear Society - Nuclear Energy A World of Service to Humanity*, Toronto, Canada, 2006.

The ever increasing use of digital technologies and products to meet the control, automation and monitoring needs of the nuclear power plant- even though justified by the benefits it provides - comes with an increased risk of technological obsolescence happening through the course of the plant life. Some well considered strategies are being employed in the ACR design process to minimise this risk and alleviate the consequence if it happens. These include application of a modular overall architecture, adoption of international widely accepted standards to harmonise equipment qualification and software practices, production of control functional specifications that are not influenced by target platform, and careful selection of technologies and products.

Tomczykowski, W., "DMSMS Acquisition Guidelines - Implementing Parts Obsolescence Management Contractual Requirements Rev 3.0, Defense Micro Electronics Activity (DMEA)," 2001.

These Diminishing Manufacturing Sources and Material Shortages (DMSMS) acquisition guidelines compile the ideas and comments expressed by experienced program managers over the past few years at a variety of forums, meetings, and conferences. This Acquisition Guidelines document for DMSMS provides the program manager and the integrated product team (IPT) with suggested contractual language that could be used to prepare a request for proposal (RFP) or to modify an existing contract to include cost effective DMSMS practices. This document is an adjunct to and its use is complementary with the Resolution Cost Metrics for DMSMS, Program Managers Handbook-Common Practices to Mitigate the Risk of Obsolescence-and the resolution guides referenced therein.

Tomczykowski, W., Fritz, A., and Scalia, R., "Program Managers Handbook - Common Practices to Mitigate the Risk of Obsolescence," DMEA, 2000.

The Program Managers Handbook—Common Practices to Mitigate the Risk of Obsolescence— provides practices and a list of resources that other program managers have used to minimize the impacts and cost of obsolescence. The primary audience for

this handbook is a program manager who has been recently introduced to DMSMS. This handbook provides the program manager a shopping list of common practices and resources. The handbook complements the commonly used resolution guides—the Naval Sea Systems Command Case Resolution Procedures Guide, the Air Force Materiel Command DMSMS Program Case Resolution Guide, and the Army Materiel Command DMSMS Case Resolution Guide. Common practices in this handbook can be implemented to minimize the impact of DMSMS.

Tomczykowski, W.J., "A Study on Component Obsolescence Mitigation Strategies and Their Impact on R&M," *Reliability and Maintainability Symposium,* 2003, pp. 332–338.

> This paper discusses the insights obtained from managing obsolescence mitigation strategies within the Department of Defense (DoD) during the last two decades. The numerous solutions investigated, from alternative or substitute components to complete system redesign can affect reliability and maintainability (R&M) as well as cost. However, with careful implementation of design practices many of the effects can be mitigated. In addition to presenting the common practices that mitigate the effect and risk of DMSMS, this paper also addresses the nonrecurring engineering (NRE) costs impacts associated with ensuring that solutions meet the original product's system performance and R&M requirements.

Tomek, M., "Parts Obsolescence Mitigation in the Harpoon Modulator," *Proceedings of the 1998 23rd International Power Modulator Symposium,* Rancho Mirage, California, June 21–25, 1998, pp. 150–155.

> Parts obsolescence has initiated an investigation by the Harpoon Program into a new modulator design for the output RF oscillator electron tube (Magnetron). The new modulator design would require full program development including reliability and environmental screening and life cycle determination. Proto-typing and production schedule are factors which would also contribute to a lengthy and costly development program. Following the current trend to out-source the new modulator results in the loss of jobs, reduces company revenue, and eliminates the opportunity for RTIS to make a value added contribution. This paper outlines the proposal to keep the current modulator which has proven to be right for the application, and introduces only minor design changes to overcome the problem of parts obsolescence. During the time interval since this paper was written, a hardware version has been constructed to produce empirical data which initiated the idea to present this paper at the conference to assist in resolving any problems related to incorporation of the proposed concepts.

Torok, R.C. and May, R.S., "Strategies for Instrumentation and Control Obsolescence Management," *6th American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies*, Knoxville, Tennessee, Vol. 2, pp. 1044–1051.

> Utility design engineers, strategic planners, and executives need a comprehensive approach for managing the obsolescence of aging instrumentation and control (IC) as

nuclear plants look forward to license extension and decades of future operation. Digital technology has almost entirely displaced the analog technology on which the IC designs were based, but cost-effective modernization strategies that maximize benefits of implementing new technology have proven elusive. A well considered strategy for IC modernization can introduce capabilities that both increase benefits and reduce implementation costs. Automation of error-prone tasks and improved data collection/processing to enable condition-based maintenance are examples. These improvements can potentially result in staff reductions, even while increasing equipment reliability. However, these benefits are largely being left on the table under the prevalent practice of system-level tactical upgrades, because they cannot be realized simply by inserting islands of newer technology into an existing environment. A plant-wide or fleet-wide integrated approach can help utilities to realize these benefits. This paper discusses the risks, benefits and issues associated with IC modernization, and describes an approach for developing a plant-specific obsolescence management strategy. Specific issues considered include: key decisions and who should make them; plant-wide or company-wide issues, such as existing organization and culture; changes in planning or execution that can achieve better and cheaper results; techniques for understanding costs, benefits and risks so that project prioritization and phasing can be done in a more effective manner; and the importance of developing an end-point vision to guide the modernization strategy.

Torresen, J. and Lovland, T.A., "Parts Obsolescence Challenges for the Electronics Industry," *IEEE Workshop on Design and Diagnostics of Electronic Circuits and Systems, DDECS*, Krakow, Poland, 2007, pp. 131–134.

The lifetime of electronic parts has decreased over the years. The result is that companies designing embedded systems with long life-time would have problems. Thus, there are problems with manufacturing the products for as many years as they would like to as well as being able to provide spare parts for customers. To be able to analyze the extent of the problem as well as learning about how the industry copes with the problem, we have conducted a survey among the foremost Norwegian original equipment manufacturer (OEM) companies and contract manufacturers. This paper presents the main observations from this survey. The main conclusion from the survey is that obsolescence is a problem, but the extent of it depends on how much proactive focus a company has. The companies taking precautions would benefit from that by extending the time span before they have to redesign their systems. 2007 IEEE.

Transition Analysis Component Technology, I, "Unclassified-Computer Aided Prediction Tool for Parts Obsolescence Management," SSIR Topic No. N193-1BO, 1995.

Obsolescence is an increasing problem facing every weapon system in the Department of Defense. Cutbacks in defense spending have resulted in the need to keep currently fielded systems operational for longer periods of time than originally planned. Obsolescence of the components used to maintain these aging systems is resulting in reduced mission readiness. This research project explores where and how obsolescence is effecting weapons systems, what factors drive obsolescence, and how those factors can be used to

predict obsolescence problems so that preemptive measures can be taken. An evaluation of currently available automated tools is included as well-as a preliminary design of a computer-aided obsolescence prediction system.

Trenchard, M., "The Obsolescence Minefield," *IEE Review,* Vol. 49, pp. 29.

The article discusses the nature and risks of obsolescence in UK's electronics-oriented industries. Despite the fact that software, mechanical and other areas are also now under threat, there is still reluctance in some areas to tackle the problem in a truly effective way. It reported that until it is realized that prevention is usually far cheaper than a cure, problems will continue to be resolved in an inefficient and uneconomic way.

U.K. Ministry of Defence, "A Guide To Managing Obsolescence," 1998.

No abstract available.

U.K. Ministry of Defence, "Obsolescence Management," 2001 (cancelled 10/23/01).

No abstract available.

U.S. Air Force Materiel Command (DMSMS Program) and United Technology Corporation, "Case Resolution Guide," Dayton, Ohio, 1998.

No abstract available.

U.S. Army Materiel Command (DMSMS Program), "Case Resolution Guide," 2001.

No abstract available.

U.S. Defense MicroElectronics Activity, "Resolution Cost Factors for Diminishing Manufacturing Sources and Material Shortages," McClellan AFB, California, 1999.

The cost of resolving Diminishing Manufacturing Sources and Material Shortages (DMSMS) problems is of primary concern to Department of Defense (DoD) program managers. The DoD Executive Agent for microelectronics DMSMS, the Defense Microelectronics Activity (DMEA), is developing cost factors for various DMSMS resolutions so that DoD programs can uniformly report cost avoidance and determine the cost impact of implementing a DMSMS program. Under Contract GS-35F-4825G, task order DMEA90-98-F-0018, ARINC identified the resolutions most commonly used by DoD and developed nonrecurring engineering cost factors for each. This final report describes the approach used and presents the identified cost factors.

U.S. Defense Microelectronics Activity, "Diminishing Manufacturing Sources and Material Shortages: A Guidebook of Best Practices and Tools for Implementing a DMSMS Management Program," McClellan, California, 2009, pp. 61.

> This guidebook on Diminishing Manufacturing Sources and Material Shortages (DMSMS) is a compilation of the best practices from across the Department of Defense for managing the risk of obsolescence for electronic, electrical, and mechanical parts. In addition, it identifies various tools that may be useful for analyzing and tracking the effectiveness of DMSMS programs. We recommend that the program manager use this guidebook as a desktop reference to quickly pinpoint key actions required to manage DMSMS issues and address concerns.

U.S. Department of Defense, "Test Method Standard Microcircuits," 2004.

> No abstract available.

U.S. Department of Defense, "Diminishing Manufacturing Sources and Material Shortages (DMSMS) Guidebook," 2010.

> No abstract available.

U.S. Department of Defense and Kunesh, N., "Diminishing Manufacturing Sources and Material Shortages Management Guidance," 2005.

> No abstract available.

U.S. Naval Sea Systems Command, "Case Resolution Procedures Guide," 1999.

> This Diminishing Manufacturing Sources and Material Shortages (DMSMS) Case Resolution Procedures Guide is intended to provide assistance in both reactive and proactive DMSMS problem identification, analysis, and resolution. It will provide a uniform and systematic approach to assist Naval Sea Systems Command (NAVSEA) activities in analyzing and resolving DMSMS situations throughout weapon system acquisition and life cycle support. It will also provide a baseline for performance of proactive cost-benefit analyses to address emergent DMSMS situations.

Underwood, K.D., "Minimizing the Risks of Diminishing Manufacturing Sources and Material Shortages: Evaluating Electronic Avionics Lifecycle Sustainment Strategies," *Graduate School of Logistics and Acquisition Management*, Wright-Patterson Air Force Base, Ohio, 2011.

> The Air Force faces increasingly difficult challenges to maintain and sustain its highly technical weapon systems, struggling against rapid technology advancement and diminishing lifecycle for electronic systems. The reduced lifecycle times have not only complicated sustainment, the lifecycles have diminished to the point that new military aircraft designs face challenges of obsolescence within the manufacturing cycle, and in some cases before manufacturing even begins. This research project explores

Diminishing Manufacturing Sources and Material Shortages (DMSMS) and obsolescence cost associated with electronic avionic components. The overall research question asks how obsolescence management can be improved in the Air Force.

This project utilizes two integrated models, the first, to determine electronic avionics demand requirements for a fleet of 96 aircraft over a 30-year period, and the second to evaluate sustainment cost over time for a) re-engineering strategy, b) lifetime buy strategy, and c) programmed redesign strategy. Statistical analysis and long-term cost comparison of these three strategies will provide a framework to evaluate specific weapon systems for future studies and to develop an attainable low-cost sustainment strategy.

Vadde, S., Kamarthi, S.V., and Gupta, S.M., "Pricing of End-of-Life Items with Obsolescence," *Proceedings of the 2006 IEEE International Symposium on Electronics and the Environment*, Scottsdale, Arizona, May 8–11, 2006, pp. 156–160.

Variability in the inflow of end-of-life (EOL) products and fluctuating inventory levels often make the processing of EOL products an economically risky operation for product recovery facilities (PRFs). Choosing an appropriate pricing policy can enhance the performance of PRFs by methodically clearing their inventory and increasing profits. This work presents two pricing models to counter the prospect of product obsolescence that can happen either gradually or suddenly. Product obsolescence can cause demand drop and inventory pile up, both of which could dent the revenues of PRFs. In the first model, gradual obsolescence and environmental regulations that limit the disposal quantity in landfills are considered. In the second model, the case of sudden obsolescence is addressed. Examples are presented to illustrate the pricing strategies for each model.

van Delft, C. and Vial, J.P., "Discounted Costs, Obsolescence and Planned Stockouts With the EOQ Formula," *International Journal of Production Economics,* Vol. 44, No. 3, 1996, pp. 255–265.

In this paper, we propose a simple economic order quantity for a class of inventory management problems concerning items with a short and stochastic lifetime. The analysis is relevant to the management of items in industries subject to fast technological progress, where the obsolescence rate is large. The approach is performed in the framework of the total discounted cost criterion. A new economic order quantity is computed; it may turn out to be significantly smaller than the one given by Wilson formula. Finally, we show that a policy maker who faces the risk of obsolescence, can plan stockouts if sufficiently many customers accept late delivery.

van Jaarsveld, W. and Dekker, R., "Estimating Obsolescence Risk from Demand Data to Enhance Inventory Control - A Case Study," *International Journal of Production Economics,* Vol. 133, No. 1, 2011, pp. 423–431.

In this paper obsolescence of service parts is analyzed in a practical environment. Based on the analysis, we propose a method that can be used to estimate the risk of

obsolescence of service parts, which is subsequently used to enhance inventory control for those parts. The method distinguishes groups of service parts. For these groups, the risk of obsolescence is estimated using the behavior of similar groups of service parts in the past. The method uses demand data as main information source, and can therefore be applied without the use of an expert's opinion. We will give numerical values for the risk of obsolescence obtained with the method, and the effects of these values on inventory control will be examined.

Van Jaarsveld, W. and Dekker, R., "Estimating Obsolescence Risk From Demand Data to Enhance Inventory Control - A Case Study," Econometric Institute, Erasmus University Rotterdam, Amsterdam, Vol. 133, 2011, pp. 423–431.

In this paper obsolescence of service parts is analyzed in a practical environment. Based on the analysis, we propose a method that can be used to estimate the risk of obsolescence of service parts, which is subsequently used to enhance inventory control for those parts. The method distinguishes groups of service parts. For these groups, the risk of obsolescence is estimated using the behavior of similar groups of service parts in the past. The method uses demand data as main information source, and can therefore be applied without the use of an expert's opinion. We will give numerical values for the risk of obsolescence obtained with the method, and the effects of these values on inventory control will be examined. 2010 Elsevier B.V. All rights reserved.

van Kooten, J.P.J. and Tan, T., "The Final Order Problem for Repairable Spare Parts Under Condemnation," *Journal of the Operational Research Society,* Vol. 60, No. 10, 2009, pp. 1449–1461.

We consider a manufacturer of complex machines that offers service contracts to her customers, committing herself to repair failed spare parts throughout a fixed service period. The suppliers of spare parts often discontinue the production of some parts as technology advances and ask the manufacturer to place a final order. We address the problem of determining final orders for such spare parts. The parts that we consider are repairable, but they are subject to the risk of condemnation. We build a transient Markovian model to represent the problem for a repairable spare part with a certain repair probability and repair lead time and we present some approximations that allow for further real-life characteristics to be included. Furthermore, an approximate model that can be computed more efficiently is presented, and the sensitivity of the results obtained with respect to the problem parameters is discussed, helping us develop several managerial insights.

Velazco, R., Anghel, L., and Saleh, S., "A Methodology for Test Replacement Solutions of Obsolete Processors," *9th IEEE On-Line Testing Symposium*, July 7–9, 2003, pp. 209–213.

Obsolescence of electronic components is a big concern affecting most electronic equipments involved in safety critical applications (automotive, avionics, airframe, nuclear plants, military applications...). Indeed, such applications are active years longer than was originally anticipated. This paper addresses a methodology to validate emulated

replacement solutions and propose solutions to be experienced on a Motorola 6800 processor to illustrate the proposed approach.

Walden, D., Blanshan, K.M., and Kranz, G.M., "Technology Roll Lessons Learned on Embedded Avionics Platforms," *IEEE Aerospace and Electronic Systems Magazine*, May 2000, pp. 10–23.

Open system architectures based on commercial off-the-shelf (COTS) building block components offer the ability to leverage the latest technology into fielded products while minimizing the impact to the operational flight software, typically the most costly component of an avionics development or upgrade. Our team has developed a layered hardware and software approach based on industry standard hardware and software interfaces to abstract the application (operational) software developers from the underlying technology rolls to the hardware and operating system software that naturally occur as part of the commercial marketplace, A technology roll is defined as the replacement of a current product with a subsequent generation of a product from the same product family. In this article, we describe the components and the layered architecture of our open system architecture approach. We discuss specific system, hardware, and software technology insertions that incorporate the latest available technology and how these changes have been abstracted from the application software. The article concludes by discussing lessons Learned from the use of these common components and corresponding technology rolls across various platforms (3 refs.)

Waldman, M., "Planned Obsolescence and the R&D Decision," *Rand Journal of Economics,* Vol. 27, No. 3, 1996, pp. 583–595.

By investing in R&D, a durable-goods monopolist can improve the quality of what it will sell in the future, and in this way reduce the future value of current and past units of output. This article shows that if the firm sells its output, then it faces a time inconsistency problem; i.e., the R&D choice that maximizes current profitability does not maximize overall profitability. The result is that if output is sold rather than rented, then in its R&D decision the monopolist has an incentive to practice a type of planned obsolescence that lowers its own profitability.

Walk, S.R., "Projecting Technology Change to Improve Legacy System Support Strategies," *Naval Engineers Journal,* Vol. 122, 2010, pp. 113–120.

Planning for the maintenance and sustainability of legacy systems often involves attempting to time the obsolescence of a component or a system of components. Serious questions arise, such as: When will critical parts no longer be available? Will the next-generation technology replacing the current technology have a serious impact on system maintenance, repair, operation, or performance? When will software systems no longer be supported? These questions, if not outright overlooked, are often answered using qualitative information, such as expert opinions, market forecasts, or supplier assurances. However, reliable quantitative methods have been developed that project the growth and diffusion of technology in time, including projecting technology substitutions, saturation

levels, and performance improvements. These quantitative technology forecasts can be applied at the early, mid-life, and even end-life stages of Navy technology platforms to better plan legacy system maintenance and sustainability strategies. In practice, a quantitative technology forecast is completed to ascertain the time in the future when a technology trajectory would have a significant impact on the sustainability of a legacy technology, system, or platform. Such future projections provide reliable time-referenced information when considering cost and resource requirement trade-off strategies to maintain or replace a component or system. This paper introduces various quantitative technology forecasting techniques and illustrates their practical applications toward considering legacy system support strategies. 2011, American Society of Naval Engineers.

Wang, K.-H. and Tung, C.-T., "Construction of a Model Towards EOQ and Pricing Strategy for Gradually Obsolescent Products," *Applied Mathematics and Computation,* Vol. 217, 2011, pp. 6926–6933.

Due to the rapid advance of technology, manufacturers marketing models and quickly changing consumer tastes, products such as apparel, clothing accessories and consumer electronics are likely to face the problem of short product life cycles. This study deals with the problem of determining order quantity and multi-discount selling prices for these types of gradually obsolescent products, in which two novel proposals are presented as follows: (1) without considering any exogenous factors that could affect demand, we develop a time-dependent demand model that appropriately portrays an integrated demand behavior associated with the characteristic of obsolescence; (2) we then treat the selling price as an exogenous factor influencing demand and, referring to the linear demand $D = - p$, the effect that "the increase of demand due to price change is linearly correlated with the difference between two consecutive selling prices" is incorporated, so as to make the demand model be a function of both time and selling price. Afterwards, optimization models are hereby formulated to predetermine pricing strategy with a limited number of price changes by maximizing retailers profit. As a result, numerical examples illustrate that the multi-discount model indeed provides higher total profit than a single discount one. This is presented along with the result analysis conducted to gain some managerial insights. 2011 Elsevier Inc. All rights reserved.

Weber, R., "An Integrated Hardware and Software Reuse Environment for System Development," *Proceedings of the IEEE 1991 National Aerospace and Electronics Conference, NAECON,* 1991, pp. 990–996.

To reduce the risk of cost and schedule overruns during system development, an integrated hardware and software reuse environment is proposed in which the system development process is integrated with a hardware and software reuse methodology. A reuse technology is proposed that defines system artifacts in terms of domain model artifacts, organizes system artifacts according to their requirements and, the system development life cycle stage in which they were developed, and supports a user role-driven reuse catalog. The corresponding reuse environment requirements are analyzed, and an engineering information system is proposed as the underlying engineering

environment to support the tight integration of this reuse methodology and the system development process.

Weiss, K.A., Ong, E.C., and Leveson, N.G., "Supporting the Development of New Air Traffic Management Software," *Proceedings of the 21st Digital Avionics Systems Conference,* 2002, Vol. 1, pp. 2E3-1– 2E3-9.

One factor inhibiting adoption of new air traffic management systems is the inability to provide sufficient assurance for the safety-critical software components. This paper describes an approach to specifying and validating safety-critical systems called SpecTRM (specification tools and requirements methodology). An experimental demonstration of SpecTRM applied to the conflict alert/mode-C intruder (CA/MCI) function of the standard terminal automation replacement systems (STARS) is used as an example. Using SpecTRM to build a model of blackbox software functionality, such as CA/MCI, helps in validating system design early in the development process and in building safety into the design from the beginning. The use of SpecTRM informal and formal specifications/models to specify the system and software functions assists in eliminating inconsistencies and discrepancies common in plain-English documents. In addition, the specifications and models are executable and analyzable. Finally, the resulting specification provides documentation for reference during the maintenance phase of the software life cycle, including the design rationale and the design features related to safety.

Weltzin, C. and Schlonsky, S., "Reducing Obsolescence of Linux-Based ATEs With Virtualization," *IEEE Instrumentation & Measurement Magazine,* Vol. 14, No. 4, 2011, pp. 8– 10..

In automatic test applications ranging from U.S. Department of Defense (DoD) projects to semiconductor manufacturing, automated test equipment (ATE) and test program sets (TPS) represent a significant investment. While much of the investment in test takes the form of capital expenditures, another significant portion that cannot be ignored is the time spent integrating, validating, and upgrading software and developing driver support to accommodate new ATE hardware. Without ongoing hardware upgrades and associated software maintenance, ATE systems can quickly face obsolescence - resulting in large replacement costs.

White, M.,"Measuring the Cost of Obsolescence," *Fourteenth International Conference on Nuclear Engineering, ICONE 14*, Miami, Florida, 2006.

The Advanced Test Reactor (ATR) at the Idaho National Laboratory (INL) has provided the capability for irradiation testing of nuclear fuels and materials since 1967, and is expected to operate for several more years. Within the scope of extending the life of a nuclear plant is dealing with aging and obsolescence issues. A component can be considered obsolete if the manufacturer no longer supports the component, or if the manufacturer does not even exist anymore. Though these components can be considered obsolete, the cost of obsolescence may or may not be significant; it may be more cost-

effective to leave and/or repair the component rather than to replace it. The project at hand is to develop a tool that will not only identify these components, series of components, or entire systems that are obsolete, but to quantify the cost of obsolescence. This engineering tool will be based on empirical formulas created from data collected from factors that deal with obsolescence. These factors are primarily, the cost of item replacement, current cost of maintenance, cost of maintenance of the replacement, cost of failure, risk of failure, safety, increase in performance/efficiency, length of manufacturer's support, and so forth. The objective is to be able to look at the outcome of this engineering tool and clearly see what needs to be replaced, be it a component, series of components, or an entire system. If there are several such replacements needed, which one(s) have the greatest priority for replacement. Therefore the engineering tool will identify, quantify, and prioritize the cost of obsolescence in the plant. An engineering tool of this type should find application in a number of nuclear and non-nuclear facilities. While the engineering tool is being developed, the first stage of development will be on system components. Once the foundation is set it will be used to evaluate other systems and eventually expand and develop the engineering tool for the entire plant.

Wilkinson, C. and Wasson, J., "Component Obsolescence Management for Military Electronics," *5th Annual Commercialization of Military and Space Electronics Conference*, Los Angeles, California, 2001.

> The electronic components obsolescence problem, also called diminished manufacturing sources, components unavailability, or parts obsolescence*,* is approaching crisis proportions for low volume complex electronics systems manufacturers, which include the military, aerospace and medical industries. Today's electronic component manufacturers are concentrating on volume-driven electronic products, such as computer, consumer, and telecommunications products, which are primarily designed for office and other benign applications, which generally have shorter design, production, and service lifetimes. The impacts of this phenomenon on the military electronics industry, and the civil aerospace industry as well, are particularly profound and require an immediate and vigorous response. This paper will define the various facets of the problem and will provide some recommended solutions on how to deal with component obsolescence problems in military electronics equipment.

Wilkinson, C., Wasson, J., et al., "Component Obsolescence Management for Aerospace Electronic Equipment," *Proceedings 1999 Avionics Conference - Civil and Military Convergence?,* London (Heathrow), United Kingdom, 1999.

> The electronic components obsolescence problem, also called diminished manufacturing sources, components unavailability, or parts obsolescence, is approaching crisis proportions for low volume complex electronics systems manufacturers, which include the military, aerospace and medical industries. Today's electronic component manufacturers are concentrating on volume-driven electronic products, such as computer, consumer, and telecommunications products, which are primarily designed for office and other benign applications, which generally have shorter design, production, and service

lifetimes. The impacts of this phenomenon on the civil and military aerospace industry are particularly profound, and require an immediate and vigorous response.

Woodward, D.G., "Life-Cycle Costing - Theory, Information Acquisition and Application," *International Journal of Project Management,* Vol. 15, 1997,pp. 335–344.

Especially in the last two decades of an increasingly-competitive business environment, dwindling resources and an ever-increasing need to obtain value for money in all areas of corporate activity, it has become essential that all available resources be used optimally. Physical assets form the basic infrastructure of all businesses and their effective management is essential to overall success. It has thus become essential to plan and monitor assets throughout their entire life-cycle, from the development/procurement stage through to eventual disposal. Life-cycle costing is concerned with optimizing value for money in the ownership of physical assets by taking into consideration all the cost factors relating to the asset during its operational life. Optimizing the trade-off between those cost factors will give the minimum life-cycle cost of the asset. This process involves estimation of costs on a whole life basis before making a choice to purchase an asset from the various alternatives available. Life-cycle cost of an asset can, very often, be many times the initial purchase or investment cost. It is important that management should realize the source and magnitude of lifetime costs so that effective action can subsequently be taken to control them. This approach to decision making encourages a long-term outlook to the investment decision-making process rather than attempting to save money in the short term by buying assets simply with lower initial acquisition cost. It is suggested project managers should familiarize themselves with what the approach involves, to better appreciate how they might then contribute to the enhanced quality decision making which it makes possible.

Wu, C.Y., Chen, J. Hwang, J.Y., et al, "New Control System for the 50 MeV Linear Accelerator of TLS," *IEEE Particle Accelerator Conference, PAC 2007,* Albuquerque, NM, June 25–29, 2007, pp. 404–406.

The pre-injector of the Taiwan Light Source (TLS) is consists of a 140 kV thermionic gun and a 50 MeV travelling wave type linear accelerator (linac) system. A linac control system has been renewed to avoid obsolescence. It is also utilized to improve performance, decouple the vacuum interlock logic from the linac control system, and provide a better control functionality for top-up operation. One VME crate system is dedicated for the linac control, the new hardware equipped with high resolution of analogue interface to provide better control. Vacuum interlock logic will be done via a dedicated programmable logic controller (PLC). The remained linac devices, which are necessary for sequential control such as door access interlock, klystron warm up, gun warm up, trigger interlock, gun high voltage interlock, klystron modulator high voltage interlock, water flow interlock, will be done by another PLC. Both interlock and sequential control of PLC will be controlled by the VME crate. All of the other functions without interlock or sequence requirement will be controlled by the VME crate directly as well. New control system is expected to provide better control functionality, better performance, easy for maintenance, and useful easy to add new hardware equipments.

Xiaozhou, M., Thornberg, B., and Lawal, N., "Embedded System Design With Maintenance Consideration," *Proceedings of the 34th International Convention MIPRO*, Opatija, Croatia, May 23–27, 2011, pp. 124–129.

This paper deals with the problems of maintaining a long lifetime embedded system, including obsolescence, function change requirement or technology migration etc. The aim of the presented work is to analyze the maintainability of long lifetime embedded systems for different design technologies. FPGA platform solutions are proposed in order to ease the system maintenance. Different platform cases are evaluated by analyzing the essence of each case and the consequences of different risk scenarios during system maintenance. Finally, the conclusion is drawn that the FPGA platform with vendor and device independent soft IP is the best choice.

Xiaozhou, M., Thornberg, B., and Lawal, N., "Portability Analysis of an M-JPEG Decoder IP From OpenCores," *6th IEEE International Symposium on Industrial Embedded Systems (SIES),* Vasteras, Sweden, June 15–17, 2011, pp. 79–82.

The reuse of predefined Intellectual Property (IP) can shorten development times and help the designer to meet time-to-market requirements for embedded systems. Using FPGA IP in a proper way can also mitigate the component obsolescence problem. System migration between devices is unavoidable, especially for long lifetime embedded systems, so IP portability becomes an important issue for system maintenance. This paper presents a case study analyzing the portability of an FPGA-based M-JPEG decoder IP. The lack of any clear separation between computation and communication is shown to limit the decoder's portability with respect to different communication interfaces. Technology and tool dependent firmware IP components are often supplied by FPGA vendors. It is possible for these firm IP components to reduce development time. However, the use of these technology and tool dependent firmware specifications within the M-JPEG decoder is shown to limit the decoder's portability with respect to development tools and FPGA vendors.

Xie, X.L.,"On Optimal Inventory Model for Obsolescence Perishable Products Under Unpermitted-Stockout," *2nd International Conference on Manufacturing Science and Engineering, ICMSE 2011*, Guilin, China, Vol. 201–203, 2011, pp. 1292–1295.

With the advancement of science and technology and the fast change of buyer requirements, the short-life products have been shortened at large, some formerly long-life products gradually turn to value deterioration products. The ratio of value deterioration products to modern products is getting higher and higher. This paper develops a deterministic economic order quantity EOQ inventory model, where the demand rate depends on the on-hand inventory when inventory level exceeds certain quantity, otherwise the demand rate is constant. The effects of obsolescence are taken into account, for it is related to the demand rate. The results are discussed through two numerical examples. A sensitivity analysis of the optimal solution with respect to parameters of the system is carried out. (2011) Trans Tech Publications.

Yang, S.-J.S., Yang, F.-C., Wang, K.-J, and Chandra, Y., "Optimising Resource Portfolio Planning for Capital-Intensive Industries Under Process-Technology Progress," *International Journal of Production Research,* Vol. 47, No. 10, 2009, pp. 2625–2648.

> This paper addresses the problem of resource portfolio planning of firms in high-tech, capital-intensive manufacturing industries. In light of the strategic importance of resource portfolio planning in these industries, we offer an alternative approach to modelling capacity planning and allocation problems that improves the deficiencies of prior models in dealing with three salient features of these industries, i.e., fast technological obsolescence, volatile market demand, and high capital expenditure. This paper first discusses the characteristics of resource portfolio planning problems including capacity adjustment and allocation. Next, we propose a new mathematical programming formulation that simultaneously optimises capacity planning and task assignment. For solution efficiency, a constraint-satisfied genetic algorithm (CSGA) is developed to solve the proposed mathematical programming problem on a real-time basis. The proposed modelling scheme is employed in the context of a semiconductor testing facility. Experimental results show that our approach can solve the resource portfolio planning problem more efficiently than a conventional optimisation solver. The overall contribution is an analytical tool that can be employed by decision makers responding to the dynamic technological progress and new product introduction at the strategic resource planning level.

Young, F.C.D. and Houston, J.A., "Formal Verification and Legacy Redesign," *IEEE Aerospace and Electronic Systems Magazine,* Vol. 14, No. 3, 1999, pp. 31–36.

> Sustaining weapons system hardware and software represents a significant and ever-increasing portion of total system cost. Hardware components are becoming obsolete much sooner while weapons system lifetimes are increasing, We must identify more cost-effective solutions to engineering and reengineering these subsystems. Verifying and validating weapons systems are two of the most costly parts of either engineering process. Traditionally, hardware validation and verification is done by simulation and testing, In the past few years, math- and logic-based formal methods tools have begun to scale up to and be applied successfully to real-world problems. Incorporating formal verification methods into engineering and reengineering processes will cost-effectively and significantly improve the level of trust and the quality of our weapons systems. Formal methods are especially well suited for redesigning current weapon systems which have become unsupportable due to component obsolescence because they help minimize the astronomical costs of rigorously reverifying the reengineered components. We believe that formal methods are an important tool for effective engineering of future weapon systems.

Yu-Lin, H. and Chia-Chi, P., "Competition, Dedicated Assets, and Technological Obsolescence in Multistage Infrastructure Investments: A Sequential Compound Option Valuation," *IEEE Transactions on Engineering Management,* Vol. 58, No. 1, 2011, pp. 141–153.

> Multistage investments are common in area-wide developments of privatized telecommunication networks and other complex infrastructure systems. They represent an incremental strategy that maintains flexibility in managing market risks, funding needs, and resource constraints in geographical expansions. Though compound options can be used to valuate multistage investments, their valuation is complex when the project in question requires upfront and interim investments in dedicated assets for future expansions. The problem becomes more complex when infrastructure markets are competitive and the investment in question is prone to rapid technological progress, which quickly makes the currently best in-use technology obsolete. This paper develops a European sequential compound call option pricing model to valuate multistage investments and analyze how competition, dedicated assets, and technological obsolescence influence the value of flexibility in this incremental strategy.

Zheng, L., "Knowledge Representation and Decision Support for Managing Product Obsolescence," Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 2011.

> Three primary aspects of this research are investigated. First, ontologies for obsolescence knowledge representation are developed in a systematic way with the use of UML diagrams. The generality of the developed ontology is demonstrated with distinct examples. Diminishing Manufacturing Sources and Material Shortages (DMSMS) obsolescence provides the basis for this study. Second, an ontology-based hybrid approach for integrating heterogeneous data resources in existing obsolescence management tools is proposed. Third, decision support models are developed and formalized, and include the obsolescence forecasting method for proactively managing obsolescence, and the mathematical models to determine the optimal design refresh plan to minimize the product life cycle cost for strategic obsolescence management. Finally, the design of the obsolescence management information system is provided along with a system evaluation methodology.

Zheng, L., Terpenny, J., and Sandborn, P., "Design Refresh Planning Models for Managing Obsolescence," *Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, Chicago, Illinois, 2012.

> Fast moving technologies have caused high-tech components to have shortened life cycles, rendering them obsolete quickly. Obsolescence is a significant problem for systems with operational and support life that are much longer than the procurement lifetimes of their constituent components. Design refresh planning is a strategic way of managing obsolescence. Mathematical models are presented herein to determine the design refresh plan that minimizes total cost. The plan includes guidance on when to execute design refreshes (dates) and what obsolete/non-obsolete system components should be replaced at a specific design refresh. When data uncertainty is considered and obsolescence dates of the components are assumed to follow specific probability

distributions, different solutions for executing design refreshes and the probabilities of adopting these solutions can be obtained. The final optimal cost becomes an expected value. An example of an electronic engine control unit (ECU) is included for demonstration of the developed models.