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Comparing Lifecycle Sustainment Strategies in an Electronic Component Obsolescence Environment

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Rapid advancements in technology and the diminishing lifecycle of electronic systems have complicated the sourcing and sustainment activities of many organizations as suppliers of original components go out of business or refuse to produce obsolete products. This article explores diminishing manufacturing sources and material shortages as well as the obsolescence costs and reliability issues associated with electronic components. Using the current United States Air Force situation as an example, the overall research question asks how obsolescence management can be improved through various sourcing strategies. This article utilizes a simulation model to evaluate equipment demand requirements and sustainment costs for three different approaches: (1) a re-engineering strategy, (2) a lifetime buy strategy, and (3) a programmed redesign strategy. Statistical analysis and long-term forecasted cost comparisons of these three strategies provide a framework to help acquisition, and sustainment managers determine the approach with the lowest total cost of ownership.

Introduction

The question addressed by this research is how to proactively respond to emerging obsolescence and diminishing manufacturing sources and material shortages (DMSMS) before they occur. This study examines one of the "fruit flies" of the obsolescence trend, which are the microprocessors and semi-conductors used extensively in avionic components (Fine, 1998). These so called "fruit flies" are useful because, like their namesake, they progress through an entire lifecycle in a comparably short period of time.

The research uses simulation to drive a comparison of three different obsolescence-focused sourcing strategies in an effort to determine which makes sense in a financially constrained budgetary environment. The three strategies that will be compared are: (1) a re-engineering strategy, (2) a programmed redesign strategy, and (3) a lifetime buy strategy.

Background

DMSMS/Obsolescence

DMSMS, according to the *Diminishing Manufacturing Sources and Material Shortages Guidebook*, is "the loss or impending loss of manufacturing suppliers of items or raw

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/ucap.

materials" (Defense Standardization Program Office, 2009). For the purposes of this work, DMSMS and obsolescence will be used interchangeably and are intended to be representative of the same idea, that a key component of a product family or other system is no longer available. It is this concept that motivates the questions addressed by evaluating different sourcing strategies in this article.

Supply chain disruptions due to DMSMS can result in catastrophic failure as systems become unsustainable. In response to DMSMS issues, organizations often respond by re-engineering existing systems to replace the obsolete component with an available alternative, stockpiling discontinued components, or contracting new companies to manufacture the item (Weiss, 1995; Josias, Terpenny, & McLean, 2004; Frank & Morgan, 2007; Trenchard, 2003). While these initiatives have been successful, they are quite expensive. Many have pushed for more proactive strategies to obsolescence (*Electronics Weekly*, 2002; Meyer, Pretorius, & Pretorius, 2004; Howard, 2002; Condra, 1999; Torresen & Lovland, 2007; Marion, 2001; Sandborn, Mauro, & Know, 2005; Francis, 2006; Leonard, Wolf, & Stolinski, 1988; Flaherty, 2005). Costs associated with obsolescence are unavoidable. However, developing a proactive plan for predicted DMSMS issues is much less expensive than reacting to an unexpected obsolescence event when it occurs (Bumbalough, 1999; Josias et al., 2004; Frank and Morgan, 2007; Trenchard, 2003).

While DMSMS or obsolescence can and does impact most equipment eventually, the majority of obsolescence cases involve electronic parts, primarily integrated microcircuits and conductors. In the past thirty years, these electronics technologies have rapidly advanced, resulting in shorter life spans for nearly all electronic components, with the estimate that 3% of global electronics become obsolete every month (Sandborn, 2007b).

An example of this type of obsolescence is provided by the United States Air Force F-22 aircraft. Within three years of initial development, several key suppliers stopped producing components required for the F-22's avionics systems, most notably Intel's I-960 chips. While Intel and the other suppliers had committed to long-term plans in the 1980s, by the 1990s, new technology had replaced the 25-Megahertz I-960 processor with 200 and 300 Megahertz processors, which were widely used as the new standard. As a result, Intel could not afford to continue production of the obsolete I-960 in the small amounts required by the F-22 program (Bowers, 2001).

Obsolescence can occur at any stage of the logistics lifecycle, as early as design development or late into post-production periods (Pyett, 1997; Howard, 2002; Sandborn, 2007a; Solomon, Sandborn, & Pecht, 2000; Singh, Whitman, & Malzahn, 2004; Hitt, 2000; Livingston, 2000; Josias et al., 2004; Stogdill, 1999). It can greatly impact the projected lifecycle costs of products and systems, by forcing the development of new sources of supply, extensive re-engineering efforts to modify product families or systems, and reverse engineering to develop internal manufacturing capabilities. Each of these options can increase costs as they bear with them the additional burden of a new learning curve (Gillespie and Hamilton, 2011).

While the electronics industry regularly abandons older, low-demand technology in an effort to provide the latest and greatest advances to demanding consumers, many organizations seek to prolong the life of their systems, even as they have become increasingly reliant on electronic technology. As a result, the effort to prolong the life of systems is made more difficult by the acceleration of technology development. Campbell (2009) explores the accelerating trend of obsolescence for electronics in relation to Moore's Law, describing products in the 1970s facing obsolescence within two to three years from the end of production. This is compared to products manufactured since 2000, which often face obsolescence issues in the early manufacturing phase. The result of these issues is a growth in obsolescence problems as suppliers eliminate parts and materials, long before the projected end of a system's lifecycle (Pecht and Das, 2000, Solomon et al., 2000; Singh et al., 2004; Josias et al., 2004; Sandborn, 2007a; Torresen and Lovland, 2007).

Obsolescence Strategies

Since the 1990s, industry has struggled with the accelerating rate of product obsolescence due to the rapid rate of technology advancement (Wilson, 2001; Gomes, 2008). The problems associated with this increased technological complexity have also been compounded by increased acquisition complexity (Alvarado, Barkmeyer, & Burgess, 2010). Many corporations have formed internal diminishing manufacturing sources (DMS) programs to reduce the risk of undetected obsolescence threats. The DMS programs at Texas Instruments, Honeywell Technology, Boeing, and Northrop Grumman share DMSMS updates and alerts (Porter, 1998; Schneiderman, 2010; Sullivan, 2002; Cavill, 2000). Companies like QinetiQ have also emerged specializing in DMS support, offering short-term and long-term assistance (*Electronics Weekly*, 2002). Hard-to-find parts brokers and after-market semiconductor manufacturers, like Lansdale Semiconductor, Rochester Electronics, and Austin Semiconductor, provide critical services when DMSMS issues arise (Wilson, 2002; Johnson, 1999; Singh, Sandborn, Lorensen, & Geiser, 2002; Solomon et al., 2000; Frank and Morgan, 2007; Manor, 2006; Neal, 2004).

More recently, companies are beginning to offer total lifecycle assurance guarantees for support during the end of the product's lifecycle. The total lifecycle assurance typically includes parts availability and technology transition support. In the United Kingdom, Zarlink Semiconductor has signed an agreement with customers to support end-of life chips, providing Rochester Electronics as a guaranteed source of supply for discontinued chips, with companies offering similar lifecycle support emerging in the US (Cattani and Souza, 2003). Radstone Technology implemented a program called Whole Program Life in 2000, supporting its single-board computers and computer sub-systems (Cavill, 2000). Additionally, many microchip manufacturing firms provide last-time buy alerts one year prior to the end of production (Pourakbar, Frenk, & Dekker, 2012).

While the Department of Defense (DoD) has increased its dependency on electronic equipment across the spectrum of warfare since the 1970s, the exponentially expanding commercial electronics market has dwarfed the military demand for electronics (Lillard, 1993; Solomon et al., 2000; Howard, 2002; Tryling, 2007; Tomczykowski, 2003). Consequently, chip manufacturers producing military-specific microchips have struggled to earn profits from the government contracts and have chosen not to renew contracts for unprofitable production requirements, preferring to focus on more profitable, higher-demand chip production for the commercial sector. As a result, by the 1990s, many military programs were forced to use commercial-off-the-shelf (COTS) chips. The use of COTS chips as an obsolescence strategy motivates the planned upgrade scenario we will simulate.

On the surface, COTS does not appear to be a long-term solution for military equipment because the persistently decreasing microchip lifecycle affects COTS products at the same rate as military-grade microchips. This issue has been exacerbated as, in response to decreasing military budgets and increasing military operations, the lifecycle of older weapon systems are being extended. In some cases like the B-52 and KC-135, the lifecycle can extend beyond 50 years. Additionally, military leaders desire supporting electronic avionics of these systems to have similarly extended lifecycles (Sandborn, 2007a; Solomon et al., 2000; Howard, 2002; Singh et al., 2004; Aley, 2006; Hitt and Schmidt, 1998; Livingston, 2000).

Many studies have been conducted to evaluate COTS solutions in the context of obsolescence (Asher, 1999; McHale, 2001; Wilson, 1999; Redding, 1995; Prophet, 2002;

Condra, 1999; Livingston, 2000; Pope, Elliot, & Turbini, 1998; Dowling, 2000, Baca, 2005). Prophet (2002) explains that COTS remains a postponement mechanism for obsolescence challenges, recommending improved end-of-life forecasting and accurate cost models to determine the optimum point of replacement for electronic systems. Wilson has published several articles examining the inadequacies of using COTS as a sole strategy to prevent obsolescence (Wilson, 1999). His next article explored the development of the COTS-focused DoD DMSMS strategy (Wilson, 2000). He then addressed the importance of developing a cross-functional DMSMS strategy to include product design, engineering, and accurate lifecycle information to reduce the DoD's reliance on COTS as a standard solution (Wilson, 2001).

Asher (1999) argues that the effectiveness of the COTS strategy has been diminished due to the more strenuous requirements for military operations. Asher contends that the unintended result of the COTS strategy has accelerated the withdrawal of major microchip manufacturers from the military market while remaining microchip manufacturers refuse to manufacture microchips that meet the Military Standard (MIL-STD) and Military Specification (MIL-SPEC) requirements. While the DoD routinely turns to expensive redesign and after-market manufacturing, Asher argues that hundreds of millions of finished products using MIL-SPEC manufactured chips remain in inventory at many continuing supply manufacturers in the U.S. Asher recommends acquiring these MIL-SPEC microchips before implementing the more costly reverse engineering process. The reliance on COTS electronics and the current rate of microchip obsolescence requires that engineers, acquisitions specialists, and logisticians to solve a problem where existing products do not meet long-lived platform requirements.

The move towards COTS has nonetheless garnered support within military communities. In response to the diminishing leverage of military organizations in the microchip market, NATO promoted the use of commercial components for avionics and other electronics in its 2001 microchip obsolescence strategy (NATO, 2001). A 1998 report from the Air Force Research Laboratory supports the transition from military-specific avionics components to COTS components. The report cites improved supportability and the opportunity for significant cost savings, reduced risks, and predictable incremental upgrades (Haldeman, Cannon, & Luke, 1998).

In addition to COTS, the DoD developed the generalized emulation of microcircuits (GEM) program in 1988. GEM manufactures electronic circuits, conductors, and other parts that are no longer available from commercial sources. GEM supports a wide variety of weapon systems across the DoD, though in 12 years it has only manufactured 45,000 microcircuits (Bumbalough, 1999; Robinson, 2004). Concerned about the high costs associated with after-market manufacturing, Rhea (1998) and Sandborn (2008) examined the GEM reverse engineering program, explaining that continued use of trailing edge technology increases costs 50% to 500% more than the original part. While redesigning, engineering, and manufacturing obsolete microchips is extremely costly, the GEM program has at least helped ensure sustainability and availability of DoD weapon systems.

Obsolescence Models

As obsolescence problems became more frequent, Nelson and Norman (1977) and Marjit (1992) conducted studies to examine possible correlations between production techniques and obsolescence incidents. By the 1990s, the DoD's struggle against technology obsolescence led to an array of studies to determine obsolescence causes and solutions, often for very specific components. In 1998, Bell argued for improved tracking and forecasting methods to predict obsolescence for the F-15 aircraft radar systems and other avionics components, and the expeditious deployment of these tools Air Force-wide (Bell, 1998). Gravier developed a regression model to predict the obsolescence of integrated circuits, which identified that the primary indicators for obsolescence were age of the design and whether the design was MIL-SPEC or commercial (Gravier, 1999). Finally, in 1999, Maddux prepared a technical report for the U.S. Army Aviation and Missile Command outlining the urgency of the DMSMS problem for semi-conductors and microchips. He recommended the establishment of annual DMSMS conferences between the DoD and defense contractors, designing a simulation tool to predict DMSMS issues, and the need for continued aggressive research to resolve issues of obsolescence (Maddux, 1999).

As early as 1998, Pertowski, Hazeltine, and Denham (1998) recommended the compilation of a Component Information Management System providing a data warehouse for commercial and defense companies to pool data in an effort to resolve DMSMS threats. Sandborn et al. (2005) explains that existing commercial forecasting tools provide exceptional visibility and availability of parts and components, identifying alternate suppliers when available. However, these tools are not able to predict or forecast obsolescence. Sandborn (2007a) expands his argument for the development of a data-mining algorithm to augment commercial obsolescence risks to increase the predictive capabilities of existing systems. Another approach is offered by Reed, Mandelbaum, and Kneece (2008), suggesting the use of value engineering techniques to reduce the risks of DMSMS through processes of creative thinking and design development.

Kasarda et al. (2007) presented an alternative view recommending the implementation of a new concept of "design for adaptability" (DFAD). They suggest that products are retired from the market primarily because they are not adaptable. During the product design and engineering phases, adaptability should be integrated into the design, allowing for product upgrades and modifications to meet changing requirements, thereby extending the lifecycle of the product.

Sandborn (2007a) proposed a forecasting model analyzing sales data for electronic parts (using the mean sales and standard deviation) plotted against the predicted lifecycle curve for the item. The analysis was able to predict the remaining lifecycle for the specific part and its future versions. This approach uses a fixed window of obsolescence, determined as a fixed number of standard deviations from the peak sales year. Sandborn's model did not find a strong correlation between sales and obsolescence for flash memory chips, though the model did find a correlation between sales data and obsolescence for memory modules. This model heavily relies on a continuous stream of accurate data, with forecast data becoming more accurate as obsolescence approaches. Several authors have offered modified forecasting models, each with their own limitations and parameters (Henke & Lai, 1997; Feldman & Sandborn, 2007; Sandborn et al., 2005; Sjoberg & Harkness, 1996; Blackman & Rogowski, 2008).

An early model presented by Brown, Lu, and Wolfson (1964) explores inventory level decisions and forecasting for products threatened by obsolescence. Pertowski et al.'s (1998) obsolescence management model focused on the integration of information management systems, leading to the development of the Government-Industry Data Exchange Program. Amspaker (1999) emphasized the need to look beyond electronics, thereby including raw materials, durables, and software into the DMSMS program. Overstreet (2002) incorporated process mapping strategies utilizing the bill of materials (BOM) and supply chain maps.

Geyer, Van Wassenhove, and Atasu (2007) examined the economics of remanufacturing obsolete components. They concluded that remanufacturing is a viable option if the remanufacturing location can meet demand, remanufacturing is less expensive than manufacturing new items and remanufacturing costs are such that the final operations and maintenance (O&M) costs are below the total cost of replacement level. More recent models include product design to prevent component lifecycle mismatch, lifetime purchase decisions for items with multiple obsolete parts (Cattani & Souza, 2003; Ellram, 1995; Pecht, Solomon, Sandborn, Wilkinson, & Das, 2002; Meyer et al., 2004; Torresen and Lovland, 2007), and technology refreshment strategies (Singh, Sandborn, Geiser, & Lorensen, 2003). The research presented here will attempt to compare these strategies using empirically generated data. The comparison shall examine mean time between failures rates as an indicator of directional influences on sustainment costs.

Building on Gravier (1999), we develop a model that provides a cost-based replacement forecast for avionics components and other electronic sub-systems. The model reduces the risks of obsolescence events while also providing more accurate forecasts of the expenditures required to sustain systems. Finally, the analysis shows what strategies are most effective at reducing the total cost of ownership.

Methodology

This study will analyze differences in total cost for avionics components in a fleet of 96 aircraft by utilizing an Excel-based normal interval model used to simulate component demand over a 30-year lifecycle. Component failure rate was chosen as the focus of this research as the models used here are based on empirical failure rate data and from the repair and acquisition costs for the F-16 AN/APG-68 radar memory cards (Steadman, Olsen, Matusiak, & Shivley, 2000). Analysis of these models will provide the framework to compare sustainment strategies for electronic avionic components.

Three component failure rate models will be used to compare current United States Air Force (USAF) sustainment practices in relation to a revised sustainment strategy. The first model used in this study, named the Re-engineering Model, simulates current USAF sustainment processes for electronic avionic components. The Re-engineering Model calculates component failure in relation to flight hours used and the overall age of the component technology. The probability of failure increases in the Re-engineering Model as hours used and overall age increase. This model accounts for repairs at the base and depot levels for the entire 30-year lifecycle of the supported weapon system. Once a component fails and is replaced by a spare, the flight hours of the replaced component is reset to zero. The overall age of the technology continues to accumulate, in effect increasing the probability of failure as the technology ages. The model calculates the repair costs for each component, dependent on age of technology, to determine annual costs for the fleet, total lifecycle costs for each aircraft, and total lifecycle costs for the fleet.

The second model, the Programmed Upgrade Model, simulates a revised sustainment strategy introducing technology upgrades at scheduled time intervals within the 30-year lifecycle of the supported weapon system. This model calculates component failure just as the previous model, resetting flight hours to zero when a replacement component is installed while continuing to accumulate age. However, in this model when a component is identified for the programmed upgrade, both the flight hours used and overall age of technology are reset to zero. The model calculates repair and upgrade costs to determine annual and total lifecycle cost for each aircraft and the total fleet.

Both of the models use the following rules to calculate demand requirements and repair or replacement costs following principles generally agreed upon in obsolescence literature. The probability of part failure increases as the number of operating hours increases and the probability of failure increases as the total age of the technology increases. The repair costs also increase as the total age of the technology increases (Marion, 2001; Luke, Bittorie, Cannon, & Haldeman, 1999; Pope, Elliot, & Turbini, 1998; Howard, 2002).

The third model is the Lifetime Buy Model. The Lifetime Buy Model makes a one-time purchase of all of the components that will be needed at the start of the program. The model uses the number of failures predicted by the re-engineering model to size the one time purchase. The model does not increase the cost of repairs over time as it treats components as throwaway replacements, drawing one from inventory to replace each failed part.

The characteristics of component failure rates will not be the focus of the Lifetime Buy Model, only the aggregate cost to replace the components. The total cost required to facilitate the lifetime buy strategy will be compared with the cost predicted by the other two models. Finally, the pros and cons of the lifetime buy strategy will be discussed in the context of the other two strategies.

Labor costs will not be considered in the analysis, as there is no assumption of reduced manpower requirements as a result of a prediction of reduced part failures. The research assumes the manpower available through a predicted reduction in part failures will be consumed by other maintenance tasks. As a result, the analysis carries a potentially conservative bias.

The basic research questions derived from these simulations are:

Question 1: Is there a statistically significant difference between the Re-engineering Model mean failure rate and the Programmed Upgrade Model mean failure rate?

H_{01}: The Programmed Upgrade Model predicted mean failure rate is not statistically different from the Re-engineering Model.

H_{a1}: The Programmed Upgrade Model predicted mean failure rate and the Re-engineering Model predicted mean failure rate are statistically different.

Question 2: Does the Programmed Upgrade Model suggest the opportunity for a significant lifecycle sustainment cost savings?

H_{02}: The Re-engineering Model lifecycle sustainment costs are less than or equal to the Programmed Upgrade Model lifecycle sustainment costs.

H_{a2}: The Programmed Upgrade Model lifecycle sustainment costs are significantly less than the Re-engineering Model lifecycle sustainment costs.

Question 3: Based on the resulting aggregate component cost suggested by each of the three strategies, which is suggested as the most cost effective approach?

The models used in this study are based on the empirical data observed for three components. Each of these components is composed of a network of microchips, semiconductors, and integrated circuits. The three components are all used on one aircraft type, though the analysis can be expanded to include multiple aircraft types with unique or shared avionics components for future studies.

The models simulate the 30-year system lifecycle analyzing sub-system lifecycle times in relation to total cost of sustainment analysis. The models make three basic assumptions: (1) immediate re-supply when a part is required; (2) every aircraft will fly its assigned missions; and (3) the Programmed Upgrade Model assumes that the design, engineering and manufacturing of upgrade packages will incorporate the technical details and requirements to ensure full mission capabilities of both the avionic component and the supported system.

The models use a series of random number calculations based on a probability of failure for the electronic component in a pre-flight test and a post-flight test for each aircraft. The simulated aircraft have been given predetermined ages, representing a newly acquired weapon system delivered between April 2009 and January 2013, delivered in lots of six aircraft in the months of January, April, July, and October. Each aircraft is scheduled to fly one three-hour training mission every three days. The mission length is determined by another normal interval calculator with a mean of three hours and a standard deviation of thirty minutes. The avionics use times for each mission are twice the mission flight time, capturing additional time the systems are operating during pre-flight inspections, routine maintenance, and post-flight checks. The models calculate the standard deviation for the probability of failure based on hours of operation (Ross, 2008) and the remaining lifecycle period of each of the avionic components. If the component fails, the models provide a replacement and record the demand requirement for each (see FIGURE 1).

Within each model are a total of 2,108,160 replications. Each aircraft flies 122 missions per year and, as was previously stated, each flight prompts two checks. Each check evaluates the fitness of three discrete components, labeled as A, B, and C, and each aircraft flies for 30 years. Finally, there are 96 aircraft in the fleet.

FIGURE 2 lists and defines many of the equations utilized in the simulation. The equations were derived by the authors to replicate the F-16 AN/APG-68 radar memory card

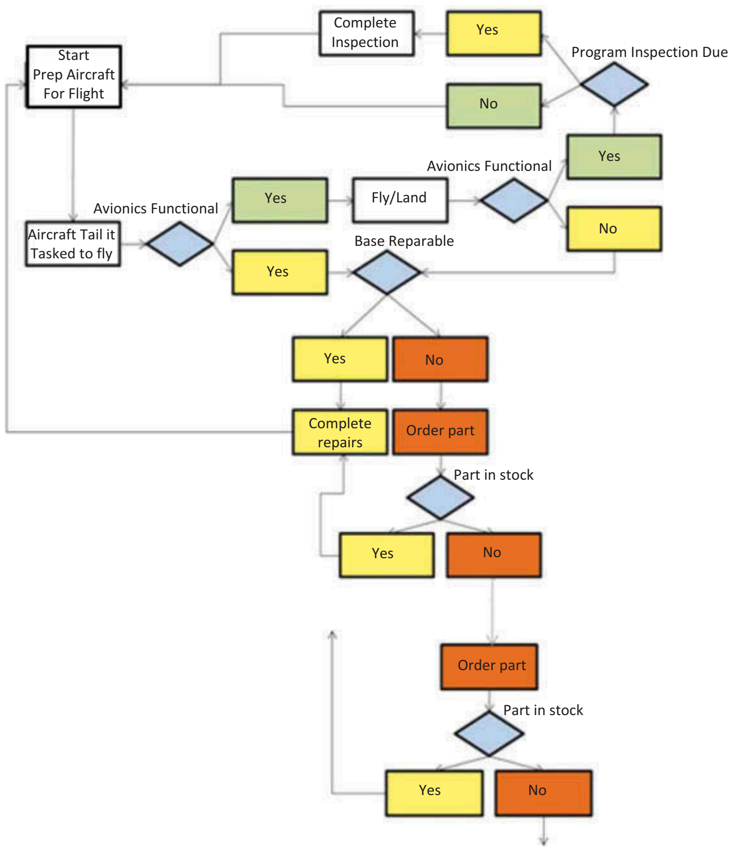

FIGURE 1 Avionics failure test process.

R = Average failure time for the avionic component
A = Avionic hours operated (**A = 2F**)
F = Flight hours
O = Optimal life of the avionic component (**O = 1.5*R**)
M = Maximum life of the avionic component (**M = 2R**)
L = Percentage of lifecycle time remaining ($\mathbf{L = M - \Sigma_{1-n} A_i/M}$) for each period, i = 1, 2
H = Hours of optimal use remaining ($\mathbf{H_i = O - \Sigma_{1-n} A_i}$)* for each period, i = 1, 2
β = Optimal hours remaining coefficient ($\mathbf{\beta = (1 - 1/L_{i-1}}$)
ρ = preflight failure test ((($\mathbf{\rho = L * H_i^{1/3}}$)/2)^2)
*Note: When a new component is issued from supply, the Reengineering Model calculates the new component lifecycle hours of optimal use remaining as $\mathbf{\beta H_{i-1}}$; the Programmed Upgrade Model component lifecycle hours of optimal use remaining is **O**.

FIGURE 2 Demand model definitions.

performance reported by Steadman et al. (2000). The mean failure rate of the avionic component (R) is the leading variable for the demand rate models. The value of R is empirically determined and represents the average life span for the avionic component (Steadman et al., 2000).

The avionics systems for each aircraft are inspected before and after each flight to determine serviceability. The preflight failure test is conducted by generating a normal interval random number with the mean and standard deviation determined by the age of the component at the time of the test. The value for the random number is generated with the formula below and represents the simulated age of the component ρ:

$$\rho = \left(\frac{L * \sqrt[3]{H_i}}{2}\right)^2 .$$

Here, L is the percentage of lifecycle time remaining for each period and H_i is the hours of optimal use remaining for each period. The standard deviation was calculated with the formula:

$$\sqrt{(1 - L)} .$$

The simulated age of the component (ρ) is evaluated against the mean failure rate of the component (R). If $\rho < R$ then the avionic component worked, if $\rho > R$ then the component failed. If the component failed, the system would be rebooted by the maintenance personnel, represented in another random number calculation (.0001 - .9999) evaluated against L_i, if the reboot value is $>L_i$, then the system rebooted with normal operations, if the value is $<L_i$, then the system requires replacement and a new component is issued from supply and installed on the aircraft. A complete list of variable definitions is included below.

Once the test was completed, the aircraft flies the mission. The total avionics operation time is calculated as $A = 2F$, capturing the preflight and post-flight tests and maintenance procedures. When the aircraft returns from its mission, the avionics systems are checked again in a post-flight check using the same calculations, using the new additional flight hours from the most recent mission to calculate the new values for L and H.

The time interval for the simulation is set for 30 years, evaluated in one day increments from January 1, 2013 to December 31, 2043. The aircraft and avionics systems history for the test population have been calculated using the acquisition date as the initial start date for each aircraft numbered 1 through 96. Once the aircraft history results are calculated, the model results for the 30-year test period (January 2013–December 2043) are isolated and analyzed.

The cost comparison models for the Re-engineering Strategy and the Programmed Upgrade Strategy are empirically based on repair and acquisition costs for the F-16 AN/APG-68 radar memory cards (Steadman et al., 2000). Both models use an annual repair cost increase of 3% and evaluated components with initial acquisition costs of $8,000 for component A, $10,000 for component B, and $12,000 for component C. Initial repair costs were evaluated at $1,000 for component A, $2,000 for component B, and $3,000 for component C with programmed upgrade costs estimated at $2,000, $2,200, and $2,400. The annual and lifecycle parts costs were calculated as:

$$S = \sum_{i=1}^{n} A_i + C_i,$$

where S equals the equivalent annual sustainment cost occurring over n periods; A equals the acquisition cost of the replacement item; C equals the O&M repair costs during each period, $i = 1, 2 \ldots, n$. The Re-engineering Model assumes no new system acquisition costs relying on repair processes to sustain the avionic components, whereas the Programmed Upgrade Model calculates a 5-year upgrade cost in the repair process and a 15-year programmed replacement cost. While the repair costs for the Re-engineering Model continue to increase by 3% annually, the Programmed Upgrade Model assumes that the introduction of new technology during the upgrade and replacement model will reset the repair costs at the original amount due to Moore's Law and decreasing cost of new technology.

Analysis and Results

The Average Component Time to Failure results collected from the Re-engineering Model have a wide range spanning from 100 hours to 4,800 hours with a mean value of 3,300 hours. While the overall distribution of the model results has normal characteristics, the distribution pattern is easier to recognize when examined over three discrete time intervals. The three intervals were chosen as they highlight the impact of the Programmed Upgrade Model and therefore facilitate its comparison with the Re-engineering Model. The first interval spans the years 2013 to 2022, the second spans 2023 to 2032, and the third spans 2033 to 2042.

Analysis of the time intervals indicates a reduction in the mean Time to Failure for component A, from 3,200 hours in the first interval to 2,150 hours in the second and third intervals. The component B average Time to Failure in interval one was 3,200 hours. During interval two, the average fell to 1,950 hours, and in interval three, the average increased slightly to 2,150 hours. Component C experienced similar changes with the Time to Failure in interval one at 3,150 hours, interval two at 1950 hours, and interval three at 2,150 hours.

The Programmed Upgrade Model results for the Average Component Time to Failure spans 3,000 hours to 4,500 hours with a mean of 3,629 hours. The narrower range of the Programmed Upgrade Model results indicates that the variability remained consistent throughout the simulated test period negating the requirement to evaluate smaller time intervals.

As seen in TABLE 1 below, the Programmed Upgrade Model Time to Failure average is higher than that of the Re-engineering Model, indicating higher utilization, reduced repair requirements, and potentially less cost over the lifecycle of the supported weapon system. While the full lifecycle time Re-engineering Model was found to be 12% lower than the Planned Upgrade Model, comparing the time interval model results shows this difference increases over time to nearly 50%.

TABLE 1 Component average time to failure comparison

	A	B	C
Programmed upgrade model	3648.29	3604.10	3633.19
Reengineering model full lifecycle	3133.54 ↓14.11%	3057.81 ↓15.16%	3110.85 ↓14.38%
Reengineering model interval 1 2011–2020	3196.62 ↓12.38%	3193.67 ↓11.39%	3158.74 ↓13.06%
Reengineering model interval 2 2021–2030	2162.87 ↓40.72%	1955.95 ↓45.73%	1885.53 ↓48.10%
Reengineering model interval 3 2031–2041	2141.38 ↓41.30%	2177.40 ↓39.59%	2169.42 ↓40.29%

Initial comparison of the data indicates a reduction in variance for the Programmed Upgrade Model resulting in a more narrow distribution for average Time to Failure throughout the 30-year lifecycle of the supported weapon system. Next, the results from both models were compared using a two-tailed T-test to determine the statistical significance for the difference. The T-test results indicate a significant statistical difference between the Re-engineering Model and the Programmed Upgrade Model with p-values of <0.01, for all three components (see TABLE 2).

Hypothesis 2 was tested using a Lifecycle Cost Model to compare the sustainment costs of the Re-engineering Model and Programmed Upgrade Model. The annual sustainment cost for both models were compared using a two-tailed T-test resulting in p-values <0.1 for all three components (see TABLE 3). The Sustainment Cost Model analysis and T-test comparisons indicate a lower total cost for all three components using the Programmed Upgrade Model.

During the 30-year simulation, annual sustainment costs for the Re-engineering Model steadily increased over time, while annual sustainment costs for the Programmed Upgrade Model experienced significantly lower growth over time. The cost behavior of the two models can be seen in the graphs below.

TABLE 2 Average time to failure T-test comparison

	T-Test
Component A	0.000001529867571
Component B	0.000002457917378
Component C	0.000014258598852

TABLE 3 Annual sustainment costs T-test comparison

	T-Test
Component A	0.0012254
Component B	0.0852913
Component C	0.0933468

While the Programmed Upgrade Model identifies the predictable cost spikes during the scheduled upgrade point (see FIGURE 3), the total lifecycle costs were 46% lower for component A, 26% lower for component B, and 26% lower for component C than the Re-engineering Model costs (see TABLES 4 and 5 below).

An examination of the models during 10-year intervals revealed the Re-engineering Model component sustainment costs increased at nearly double the rate of the Programmed Upgrade Model.

Finally, the cost of the Lifetime Buy Strategy is considered. TABLE 4 shows the total cost required to acquire all of the three different components needed to support the complete lifecycle of the platform. As TABLE 6 demonstrates, the Lifetime Buy Strategy is significantly more costly than the other models considered.

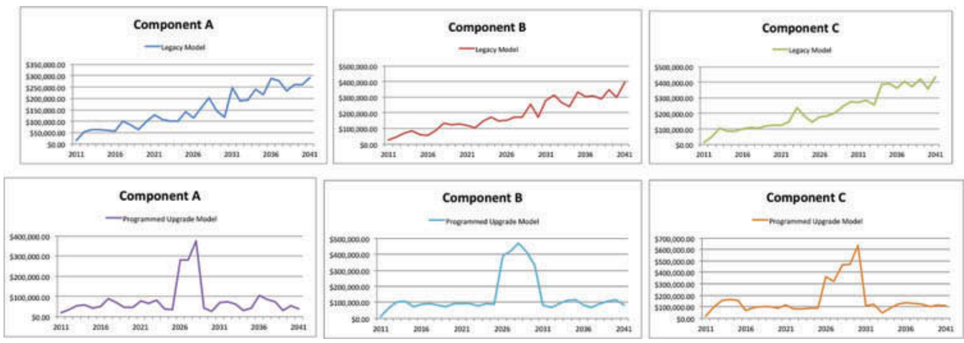

FIGURE 3 Annual sustainment costs.

TABLE 4 Legacy model 10-year interval sustainment costs

Legacy Model	A	B	C
2013 annual cost	$15,000	$25,000	$14,000
2022 annual cost	$99,000	$131,000	$126,000
2032 annual cost	$119,000	$175,000	$272,000
2043 annual cost	$291,000	$175,000	$272,000
Full lifecycle cost	$4,670,000	$5,829,000	$6,759,000
Compared to programmed upgrade model	↑87.39%	↑36.31%	↑35.58%

TABLE 5 Programmed upgrade model 10-year interval sustainment costs

Programmed Upgrade Model	A	B	C
2013 annual cost	$20,000	$11,000	$19,000
2022 annual cost	$46,000	$93,000	$89,000
2030 (upgrade) annual cost	$376,000	$470,000	$636,000
2032 annual cost	$28,000	$66,000	$50,000
2043 annual cost	$39,000	$84,000	$117,000
Full lifecycle cost	$2,492,000	$4,276,000	$4,985,000
Compared to legacy model	↓46.63%	↓26.64%	↓26.24%

TABLE 6 Lifetime buy cost

Component	A	B	C
Total Required	1235	1251	1222
ACQ Cost	$8,000	$10,000	$12,000
	$9,880,000	$12,510,000	$14,664,000
Lifetime Buy Strategy Cost =>			$37,054,000

In addition to the highest cost of the three strategies, the Lifetime Buy Strategy bears additional risk as the component performance requirements evolve over time or as the platform exceeds its originally designed lifecycle.

Conclusions and Recommendations

Three component obsolescence-sourcing strategies were compared in this analysis. The first was the Re-engineering Strategy, which simulated a typical component repair strategy. The second was the Programmed Upgrade Strategy that simulated a planned technology upgrade as part of the repair process. Finally, the cost of the Lifetime Buy Strategy was determined based on the simulation results of the re-engineering strategy.

The statistical test and cost analysis support the hypothesis that a strategy designed to upgrade and replace electronic components can improve reliability and result in significant total cost of ownership savings over the other two approaches. In addition to a lower total cost of ownership, the reduction in overall risk presented by the planned upgrade strategy provides a compelling benefit as well. Taking into account the combined benefits of improved performance, cost and risk show the planned upgrade strategy to be the most robust approach.

There are limitations to the analysis performed, however that should be noted. First, with regard to the Lifetime Buy Strategy, the quantity of parts purchased was provided by the requirements generated by the Re-engineering Strategy. As such, the total purchased quantity is a point estimate and not an interval. A point estimate was deemed sufficient for this analysis, as the intent was to evaluate the performance of the three strategies against one another vis-à-vis variances in electronic equipment availability. Further, the cost data was taken from Steadman and colleagues (2000), which was the source of the empirical availability data as well.

The second significant limitation of this work is that the outcome of the analysis is heavily influenced by the reliability characteristics of the simulated data. In this case, as with the cost data, the electronic component availability performance was measured for a specific set of equipment in a context. In that context, the reliability related benefits of the technology upgrade were significant. In another context with a less pronounced benefit, the outcome may be different.

The implications of this analysis suggest an extensive total cost of ownership savings opportunity. While the simulation in this analysis used three components, the Hicks, Riggs, McDonald, and Sanner (2003) study showed that USAF aircraft avionics systems utilize 53 to 475 electronic components. Applying the planned upgrade strategy to an entire product family or system would multiply the potential available benefit to the total cost of ownership, without considering the capability and performance benefits offered by the continual improvements in technology.

While this analysis demonstrates that a planned upgrade strategy is beneficial, obsolescence strategies must begin before equipment is purchased and delivered. Sourcing strategies, to include the desired time-phased upgrades and replacement plans, must be coordinated with design engineers during the earliest phases of the design process. A cross-functional approach will allow for a system architecture that is flexible enough to allow for a time-phased upgrade of components and software. Without this early, cross-functional collaboration, time-phased upgrades may not be technically or economically feasible.

In addition to design concerns, contracts must be crafted in a manner to clearly define owner and supplier requirements to support time-phased upgrades for electronic components. These contracts must also provide for economic incentives for suppliers who provide systems that perform better than the contract objectives and penalties for systems that do not meet contract requirements.

Opportunities for Further Research

There are many opportunities for additional research to test the model proposed in this study. First, a comprehensive case study analysis of the planned upgrade strategy would be beneficial to validate the results of the simulation. Additionally, the case study analysis could also help to further the understanding of the risks associated with the different approaches. Further effort should also be invested in the analysis of the design and implementation costs associated with the planned upgrade strategy versus the repair strategy as this analysis only considered the cost of the components themselves.

An important extension of this research would be to quantify the impact of changes in equipment reliability in the outcome. Specifically, how sensitive is this analysis to a change in the reliability of the electronic components? Not only would this shed light on the appropriate contexts in which a given model would be preferred but it could also highlight the value of investment into the robustness of the component design as a sourcing consideration. Further analysis should also investigate the sensitivity of the analysis to variances in component cost. Other areas of research suggested by this work would include evaluating the optimal redesign interval for components based on technology evolution factors or the characteristics of a particular product or system, be they expected lifecycle, relative total cost of ownership or criticality.

Acronyms

BOM	Bill of Materials
COG	Component Obsolescence Group
COTS	Commercial-Off-the-Shelf
DFAD	Design for Adaptability
DMS	Diminishing Manufacturing Sources
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DoD	Department of Defense
GEM	Generalized Emulation of Microcircuits
MIL-SPEC	Military Specifications
MIL-STD	Military-Standard
NATO	North Atlantic Treaty Organization
O&M	Operations & Maintenance
USAF	United States Air Force

Disclaimer

The views expressed in this academic research paper are those of the authors and do not reflect the official policy or position of the U.S. Air Force, Department of Defense, or the U.S. Government.

References

Aley, J. (2006). The V-22 Program: Paving the Way for Navy Obsolescence Management and Mitigation. *Defense AT&L*, March, 18–20.

Alvarado, W., Barkmeyer, D., & Burgess, E. (2010). Commercial-Like Acquisitions: Practices and Costs. *Journal of Cost Analysis and Parametrics*, 3(1), 41–58.

Amspaker, M. (1999). Expanding Current Obsolescence Tools to Non-Electronic Areas. In *DMSMS Conference*. Retrieved from http://smaplab.ri.uah.edu/dmsms98/papers/amspaker.pdf

Asher, J. (1999). The COTS Contradiction. *Military and Aerospace Electronics*, 10(4), 31–36.

Baca, M. (2005). The Third Dimension in Obsolescence Management. *Military and Aerospace Electronics*, 16(9), 15–18.

Bell, J. E. (1998). *Tracking and correcting for diminishing manufacturing sources and obsolescence in a mature fighter aircraft: A study of the F-15/APG-63/70 radar systems* (Master's thesis). Air Force Institute of Technology, Wright-Patterson AFB, OH.

Blackman, I., & Rogowski, R. (2008). *The Obsolescence Tools Minefield: A Guide to Availability Monitoring*. UK: COG Intl. Ltd.

Bowers, P. (2001). The Air Force Develops an Initiative to Manage Change in Avionics Systems. *The Journal of Defense Software Engineering*, September, 4–7.

Brown, F., Lu, J., & Wolfson, R. (1964). Dynamic Modeling of Inventories Subject to Obsolescence. *Management Science*, 11, 51–63.

Bumbalough, A. (1999). USAF Manufacturing Technology's Initiative on Electronics Parts Obsolescence Management. In *Proceedings of 44th International SAMPE Symposium* (pp. 2044–2051), Long Beach, CA.

Campbell, S. (2009). On the Absence of Obsolescence. *IEEE Annals of the History of Computing*, 31(4), 120–122.

Cattani, K.D., & Souza, G.C. (2003). Good Buy? Delaying End-of-Life Purchases. *European Journal of Operational Research*, 146, 216–228.

Cavill, P. (2000). Whole Program Lifew COTS: Warding Off the Curse of Component Obsolescence. *Military and Aerospace Electronics*, 11(12), 13.

Condra, L. (1999). *Combating Electronic Component Obsolescence by Using Common Processes for Defense and Commercial Aerospace Electronics*. NDIA Paper. Defense Standardization Program. Retrieved from http://www.dsp.dla.mil/app_uil/content/documents/ndia_article.pdf

Defense Standardization Program Office. (2009). *SD-22, Diminishing Manufacturing Sources and Material Shortages: A Guidebook of Best Practices and Tools for Implementing a DMSMS Management Plan*. Fort Belvoir, VA: Defense Standardization Program Office.

Dowling, T. (2000). Planning for Change with a Holistic View of the System. In *Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components*, Vol. 22, October 23–25, Budapest, Hungary.

Electronics Weekly. (2002). Proactive Approach Cuts Costs of Obsolescence. 2064, 22.

Ellram, L. (1995). The Use of Total Cost of Ownership Concepts to Model the Outsourcing Decision. *The International Journal of Logistics*, 6(2), 55–66.

Feldman, K., & Sandborn, P. (2007). Integrating Technology Obsolescence Considerations into Product Design Planning. In *Proceedings of ASME 2007, International Design Engineering Conference*, Las Vegas, NV.

Fine, C. H. (1998). *Clockspeed*. Reading, MA: Perseus Books.

Flaherty, N. (2005). New Parts for Old. *IEE Review*. 51(1), 34–37.

Francis, L. (2006). Tackling Obsolescence. *Electronics Weekly*, 2235, 20–21.

Frank, B., & Morgan, R. (2007). Obsolescence Mitigation and Management of Electronics Test Equipment. *Autotestcon, IEEE*, 5, 527–536.

Geyer, R., Van Wassenhove, L.N., & Atasu, A. (2007). The Economics of Remanufacturing Under Limited Component Durability and Finite Product Lifecycles. *Management Science* 53(1), 88–100.

Gillespie, B., & Hamilton, D. (2011). A Closed-Form Solution for the Production-Break Retrograde Method. *Journal of Cost Analysis and Parametrics*, 4(2), 119–126.

Gomes, L. (2008). Companies Struggle to Keep Up as Technologies Grow Obsolete. *Wall Street Journal*, 251(100), B7.

Gravier, M. (1999). *Logistics Regression Modeling of Diminishing Manufacturing Sources for Integrated Circuits* (Master's thesis). Air Force Institute of Technology, Wright-Patterson AFB, OH.

Henke, A., & Lai, S. (1997). Automated Parts Obsolescence Prediction. *Proceedings of the DMSMS Conference*, San Antonio, TX. Retrieved from http://smaplab.ri.uah.edu/dmsms/laip.pdf

Hicks, B., Riggs, L., McDonald, L., & Sanner, J. (2003). Managing Change through Roadmapping. *IEEE Transactions on Components and Packaging Technologies*, 26(1), 11.D.4-1–11.D.4-8.

Hitt, E. (2000). Rebuilding the Requirements Process for Aging Avionics. *IEEE Transactions on Components and Packaging Technologies*, 4.A, 3-1–3-6.

Hitt, E., & Schmidt, J. (1998). Technology Obsolescence Impact on Future Needs. In *Digital Avionics Systems Conference (17th DASC). AIAA/IEEE/SAE* 1(A33), 1–7.

Howard, M. A. (2002). Component Obsolescence—It's Not Just Electronics Anymore. In *Proceedings FAA/DoD/NASA Aging Aircraft Conference*, San Francisco, CA.

Johnson, G. (1999). Second Hand Semiconductors: Recycling Manes Cents (and $Millions). *Electronic News*, 45(2253), 10.

Josias, C., Terpenny, J., & McLean, K. (2004). Component Obsolescence Risk Assessment. In *Proceedings of the 2004 Industrial Engineering Research Conference (IERC)*, Houston, TX.

Kasarda, M., Terpenny, J., Inman, D., Precoda, K., Jelesko, J., Sahin, A., & Park, J. (2007). Design for Adaptability (DFAD)—A New Concept for Achieving Sustainable Design. *Robotics and Computer-Integrated Manufacturing*, 23(6), 727–734.

Leonard, J., Wolf, J., & Stolinski, R. (1988). Microcircuit Parts Obsolescence. In *IEEE Region 5 Conference: "Spanning the Peaks of Electrotechnology"* (pp. 229–231).

Lillard, D. (1993). Older Parts Resuscitate Programs. *Electronic Engineering Times*, 771, 58–60.

Livingston, H. (2000). *GEB1: Diminishing Manufacturing Sources and Material Shortages (DMSMS) Management Practices*. Retrieved from http://www.dmea.osd.mil/docs/geb1_paper.pdf

Luke, J., Bittorie, J. W., Cannon, W. J., & Halderman, D. G. (1998). A Commercial-Off-the-Shelf Based Replacement Strategy for Aging Avionics Computers. In *Aerospace and Electronics Conference* (pp. 177–181), Dayton, OH.

Luke, J., Bittorie, J., Cannon, W., & Haldeman, D. (1999). Replacement Strategy for Aging Avionics Computers. *IEEE AESS Systems Magazine*, March, 7–11.

Maddux, G. (1999). Investigate DMSMS Impact on Selected Spare Parts. Technical Reports 5-20237, 5–20238.

Manor, D. (2006). Addressing the Instrument Obsolescence Problem—Options and Solutions. *Autotestcon: IEEE System Readiness Test Conference* (pp. 426–430), Anaheim, CA.

Marion, R. (2001). Mitigating COTS Obsolescence in Military Test. *Autotestcon: IEEE Systems Readiness Technology Conference*, 746–756.

Marjit, S. (1992). Technology and Obsolescence: A Reinterpretation of the Specific-Factor Model of Production. *Journal of Economics*, 55(2), 193–207.

McHale, J. (2001). Radstone Fights Obsolescence through Redesign on US Army Firefinder. *Military and Aerospace Electronics*, 12(3), 3–4.

Meyer, A., Pretorius, L., & Pretorius, J. (2004). A Model to Manage Electronic Component Obsolescence for Complex or Long Life Systems. *Engineering Management Conference, Proceedings*, *IEEE Intl*., 3, 1303–1309.

Neal, T. (2004). Obsolescence Replacement—Applied Technology. *Autotestcon Proceedings*, 58–61.

Nelson, R., & Norman, V. (1977). Technological Change and Factor Mix Over the Product Cycle. *Journal of Development Economics*, 4(1), 3–25.

North Atlantic Treaty Organization (NATO). (2001). *Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components*. Brussels, Belgium: North Atlantic Treaty Organization (NATO).

Overstreet, R. E. (2002). *Process Mapping a Diminishing Manufacturing Sources and Material Shortages Reactive Management Strategy: A Case Study* (Master's thesis). Air Force Institute of Technology, Wright-Patterson AFB, OH.

Pecht, M., & Das, D. (2000). Electronic Part Lifecycle. *IEEE Transactions on Components and Packaging Technologies*, 23(1), 190–192.

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

Pertowski, T., Hazeltine, M., & Denham, C. (1998). Approaches to Reduce Impact of Electronic Component Obsolescence. In *IEEE International Frequency Control Symposium* (pp. 430–438), Pasadena, CA.

Pope, S., Elliot, T., & Turbini, L. (1998). Designing for Technological Obsolescence and Discontinuous Change: An Evaluation of Three Successful Electronic Products. In *Proceedings IEEE International Symposium on Electronics and the Environment* (pp. 280–286), Oak Brook, IL.

Porter, Z. (1998). *An Economic Method for Evaluating Component Obsolescence Solutions*. Seattle, WA: Boeing Corporation.

Pourakbar, M., Frenk, J. B. G., & Dekker, R. (2012). End-of-Life Inventory Decisions for Consumer Electronics Service Parts. *Production and Operations Management*, 21(5), 889–906.

Prophet, G. (2002). Guarding Against Component Obsolescence. *Electronic Design, Strategy, News*, 47(25), 63–70.

Pyett, B. (1997). *Diminishing Manufacturing Sources and Material Shortages: Solutions to Obsolescence in Microcircuits*. National Defense University, Executive Research Project.

Redding, J. (1995). DMS: Keeping Your Eagles, Tomcats, and Mustangs Up and Running. *Defense and Security Electronics*, 27(12), 13–14.

Reed, D. L., Mandelbaum, J., & Kneece, J. R. (2008). A Partnership between Value Engineering and the Diminishing Manufacturing Sources and Material Shortages Community to Reduce Ownership Costs. Report D-3598. Alexandria, VA: Institute for Defense Analyses.

Rhea, J. (1998). Reverse Engineering: Keeping Obsolete Parts Alive. *Military and Aerospace Electronics*, 9(9), 4–5.

Robinson, D. (2004). GEM Program Meets DoD Requirements, Does not Compete with Industry. *Military and Aerospace Electronics*, 15(2), 30.

Ross, M. A. (2008). Next Generation Software Estimating Framework: 25 Years and Thousands of Projects Later. *Journal of Cost Analysis and Parametrics*, 1(2), 7–30.

Sandborn, P., Mauro, F., & Knox, R. (2005). A Data Mining Based Approach to Electronic Part Obsolescence Forecasting. *IEEE Transactions on Components and Packaging Technologies*, 30(3), 397–401.

Sandborn, P. (2007a). Designing for Technology Obsolescence Management. In *Proceedings Industrial Engineering Research Conference*, Nashville, TN.

Sandborn, P. (2007b). Software Obsolescence—Complicating the Part Technology Obsolescence Management Problem. *IEEE Trans on Components and Packaging Technologies*, 30(4), 886–888.

Sandborn, P. (2008). Trapped on Technology's Trailing Edge. *IEEE Spectrum*, 45, 42–58.

Schneiderman, R. (2010). What's Old is New Again in Product Obsolescence Programs. *Electronic Design*, 58(10), 1–8.

Singh, P., Sandborn, P., Geiser, T., & Lorensen, D. (2003). Electronic Part Obsolescence Driven Design Refresh Planning. *International Journal of Agile Manufacturing*, 7(1), 23–32.

Singh, P., Sandborn, P., Lorensen, D., & Geiser, T. (2002). Determining Optimum Redesign Plans for Avionics Based on Electronic Part Obsolescence Forecasts. In *Proceedings of the World Aviation Congress, SAE Intl*.

Singh, P. R., Whitman, L. E., & Malzahn, D. (2004). Methodology to Mitigate Supplier Risk in an Aerospace Supply Chain. *Supply Chain Management*, 9(2), 154.

Sjoberg, E. S., & Harkness, L. (1996). Integrated Circuit Obsolescence and Its Impact on Technology Insertion Definition for Military Avionics Systems. In *Aerospace and Electronics Conference, NAECON 1996*, Vol. 2 (pp. 792–799), Dayton, OH.

Soloman, R., Sandborn, P., & Pecht, M. (2000). Electronic Part Lifeycle Concepts and Obsolescence Forecasting. *IEEE Transactions on Packaging and Manufacturing Technology, Part A: Packaging Technologies*, 23(4), 707–717.

Steadman, B, Olsen, E., Matusiak, R., & Shivley, J. (2000). Falcon Flex: A New F-16 Business Practice. *IEEE Transactions on Components and Packaging Technologies*, 23(3), 147–153.

Stogdill, R. (1999). Dealing with Obsolete Parts. *IEEE Design & Test of Computers*, 16(2), 17–25.

Sullivan, L. (2002). Obsolete-Parts Programs Thriving. *Electronic Buyers' News*, 1296, 26–28.

Tomczykowski, W. (2003). A Study on Component Obsolescence Mitigation Strategies and their Impact on R&M. In *Proceedings Reliability and Maintainability Conference, IEEE* (pp. 332–338), Tampa, FL.

Torresen, J., & Lovland, T. A. (2007). Parts Obsolescence Challenges for the Electronics Industry. In *Proceedings of Design and Diagnostics of Electronic Circuits and Systems 2007, DDECS '07,* April 11–13 (pp. 1–4), Kraków, Poland.

Trenchard, M. (2003). The Obsolescence Minefield. *IEE Review*, 49(9), 29.

Tryling, D. (2007). Planning for Obsolescence. *Electrical Apparatus*, 60(4), 23–24.

Weiss, P. (1995). DMS Conference Underscores the Need for Support of Older Systems. *Defense and Security Electronics*, 27(12), 8–9.

Wilson, J. R. (1999). Obsolete Parts Still Bedevil COTS Initiative. *Military and Aerospace Electronics*, 10(12), 1–4.

Wilson, J. R. (2000). Obsolescence: The New Enemy. *American Institute of Aeronautics and Astronautics*, 38, 38–41.

Wilson, J. R. (2001). Industry Begins Coming to Grips with Diminishing Manufacturing Sources. *Military and Aerospace Electronics*, 12(2), 14–18.

Wilson, J. R. (2002). Global War on Terrorism Intensifies the Problem of Obsolete Parts. *Military and Aerospace Electronics*, 13(11), 18–21.

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